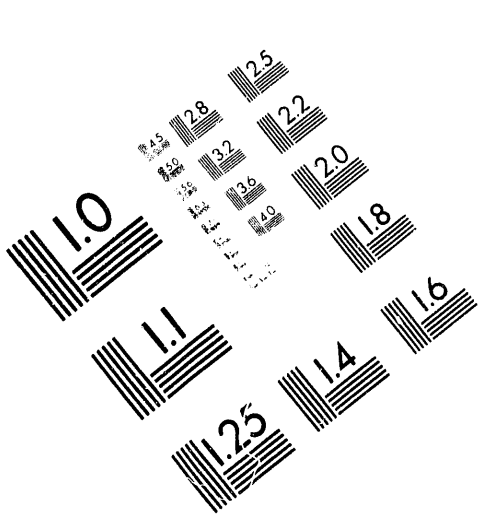
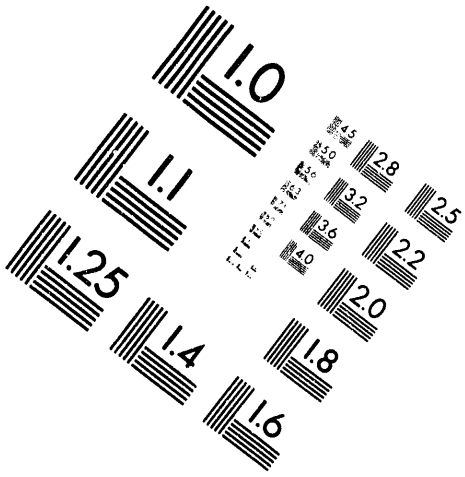
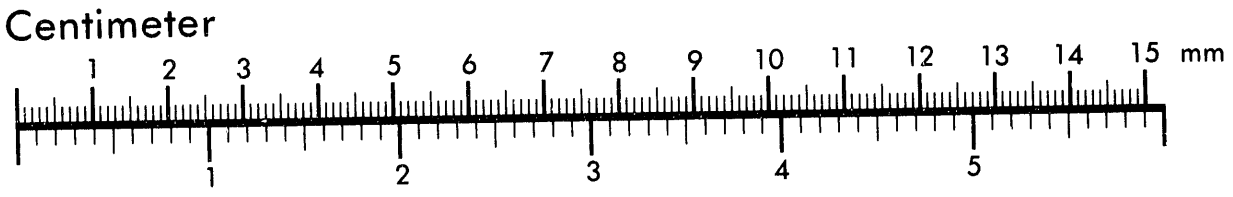
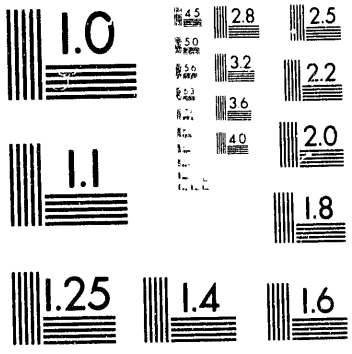


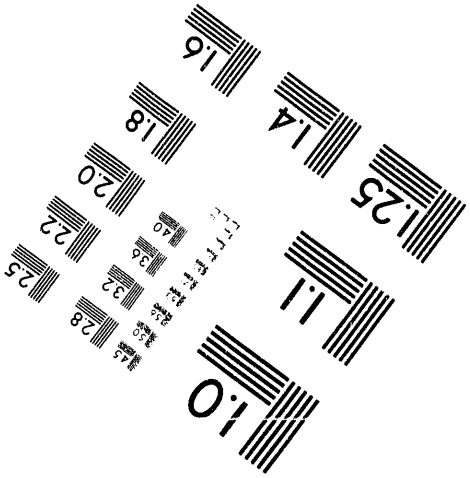


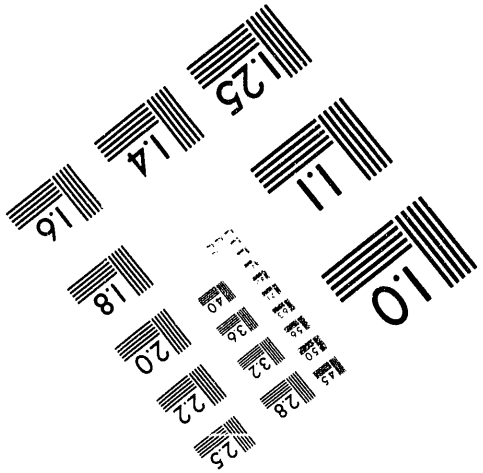
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Environmental Remediation '91

"Cleaning Up the Environment for the 21st Century"

Proceedings of the
ER'91 Conference
at Pasco, Washington
September 8-11, 1991

Sponsored by:

Pat Whitfield
U.S. Department of Energy
Office of Environmental Restoration

Hosted by:

Willis W. Bixby
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Field Office, Richland

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PREFACE

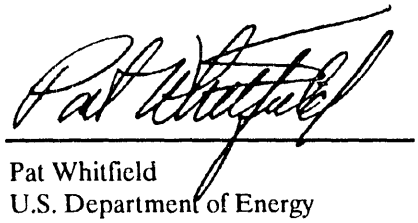
Environmental Remediation '91 was sponsored by the Department of Energy's (DOE's) Office of Environmental Restoration and hosted by the Field Office, Richland, and was the presentation of program activities underway and completed between May 1990 and September 1991. The meeting is held every two years.

The purpose of the conference was to provide an opportunity for people working on all aspects of the DOE's Environmental Restoration Program to present their most recent accomplishments--successes and failures--so others working on similar activities could learn.

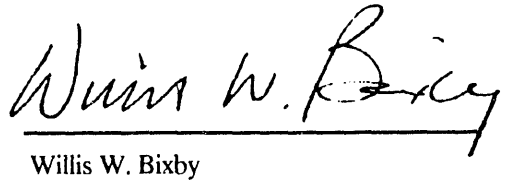
Presentations by DOE-Headquarters Senior Management and staff ensured that the personnel and organizations who would be affected by new policies had an opportunity to hear about them from the policy makers themselves. Presentations by the DOE Field Offices provided an opportunity for both DOE-HQ and the contractors to learn about, and discuss, how these policies are implemented. Presentations by DOE contractor personnel discussed the specifics of ER projects, encouraging technical information exchanges. Presentations by Federal and State regulators allowed DOE and contractor personnel to understand more fully the constraints under which the regulators operate. Presentations by universities and industry encouraged DOE and contractors to consider technologies and ideas which were developed outside the DOE complex--to ensure that DOE does not become internally focussed and exclude innovative approaches. And the discussions engendered by these presentations allowed those cleaning up the contamination to talk directly both with those managing, and those regulating, the cleanup.

The conference provided attendees an opportunity to make contacts with people from other offices, sites, or organizations, to discuss programs, projects, and technologies, and to take a step back from their own activities and look at the big picture of ER activities within the entire DOE complex. These proceedings provide conference attendees with a record of the presentations. For those unable to attend the conference, these proceedings document the presentations.

We hope that, attendee or not, these proceedings will be a starting point for the ER future. We look forward to identifying and pursuing new technologies and innovative solutions to DOE's environmental contamination; to new ways of doing business--from new contracting approaches to recycling D&D materials; and we look forward to your input into these new ideas and their implementation.



Pat Whitfield
U.S. Department of Energy
Office of Environmental Restoration



Willis W. Bixby
U.S. Department of Energy
Field Office, Richland

September 1991

TABLE OF CONTENTS

INTRODUCTIONS BY CO-GENERAL CHAIRMEN 1
Willis Bixby, DOE-RL; Pat Whitfield, DOE-HQ, Co-Chairs

PLENARY--Willis Bixby, DOE-RL; Pat Whitfield, DOE-HQ, Co-Chairs

Leo Duffy, Director, Office of Environmental Restoration and Waste Management, DOE-HQ 3

Richard Guimond, Deputy Assistant Administrator for Solid Waste and Emergency Response, EPA-HQ 5

Dana Rasmussen, Regional Administrator, EPA Region 10 9

Christine Gregoire, Director, Washington Department of Ecology, State of Washington 11

John Wagoner, Manager, DOE-RL 15

LUNCHEON SPEAKER--Honorable Sid Morrison, Representative, 4th Congressional District, U.S. Congress 19

EARNING PUBLIC CONFIDENCE AND SUPPORT--Bill Dixon, WHC; Jack Baublitz, DOE-HQ, Co-Chairs

Unified Theory of Sciences for Implementation of Environmental Restoration at Department of Energy Sites 21
Timothy J. Carlson

Case Studies on Designing Meetings for Effective Institutional Interactions 27
Rebecca M. Imholz

Creating a Context for Public Confidence in Environmental Remediation Programs 31
Patricia J. Serie

Effective Outreach is Good Public Policy 37
William Sanderson

How Public Issues Shape Environmental Restoration Plans-Experiences with Colorado UMTRA Projects 39
Bill Hunt

Future Site Use and Cleanup Strategy Alternatives: The Hanford Approach 43
Max Power

Efforts to Earn Public Support and Confidence in Hanford Site Cleanup Work 47
M.C. Brown

Rocky Flats Community Relations-"Coming Out of the Dark" 51
Frazier R. Lockhart

ER PROGRAMMATIC ISSUES AND SITE SUMMARIES--Liz Bracken, DOE-RL; Julie D'Ambrosia, ETA, Co-Chairs

Programmatic Environmental Impact Statement for the Office of Environmental Restoration and Waste Management 55
Glen L. Sjoblom

Department of Energy Policy for Acceptance of Facilities for Environmental Restoration 59
William E. Murphie

An Overview of the Major Progress in the Environmental Restoration Program at the Savannah River Site 61
J.M. Pope

Achieving Technical Consistency and Meeting Technology Development Needs in the Oak Ridge Environmental Restoration Program 69
D.W. Swindle

RCRA Closures at Rocky Flats Plant-A Programmatic Perspective and Case Study 75
Randy T. Ogg

Accelerated Cleanup of Past Practice Waste Sites on the Hanford Site, Richland Washington 81
W.L. Johnson

Strategic Planning of an Integrated Program for State Oversight Agreements 85
Ann E. Walzer

Approach and Strategy for Setting Remedial Action Goals for Multiple Sites with Multiple Contaminants 91
Robin K. White

IN SITU REMEDIATION--Randy Harris, HAZWRAP; Sally Mann, DOE-HQ, Co-Chairs

A Co-Metabolic Approach to Groundwater Remediation 95
A.V. Palumbo

Bioremediation of Hanford Groundwater 101
T.M. Brouns

In Situ Grouting of Low-Level Burial Trenches with a Cement-Based Grout 107
C.W. Francis

A Thermodynamic Analysis of Melt Immiscibility and Its Implications During Vitrification 115
Donald J. Carpenter

Engineering-Scale Tests of In Situ Vitrification to PCB and Radioactive Contaminated Soils 119
Stephen C. Liikala

Potential for Using a Six-Phase Alternating Current Power Supply for In Situ Vitrification 123
R.L. Richardson

Geosafe Experience During the ISV Operational Acceptance Tests . . . . . NA
V.F. Fitzpatrick

POSTER-REMEDIATION PROJECTS AND QUALITY ASSURANCE--Janet L. Bryant, PNL, Chair

Facilitation Techniques for Environmental Restoration Planning and Implementation 129
Jean Bench

Life Cycle Planning to Forecast Budget Requirements and Maintain Effective Cost Controls 135
L.C. Durante

Treatment of Y-12 Plant Mixed Waste Contaminated Soils Utilizing the Westinghouse Soil Washing Process 139
D.C. Grant

Soil Vapor Extraction Test in a Radiologically Contaminated Site, Hanford Site 143
L.C. Swanson

Expeditious Remediation of a Leaking Underground Tank 147
D.E. Bernhardt

Electrokinetic Remediation of Contaminated Soils 151
E.R. Lindgren

Groundwater Remediation Via Four Case Studies 159
Steven Sontag

NEPA/CERCLA Integration at Rocky Flats 163
R.J. Schassburger

Public Involvement in Remedial Work Programs at Historic Low-Level Radioactive Waste Sites, Recent Canadian Experience 165
Brad Franklin

Working with States on a Joint DOE/State Funded Cleanup Project 169
Loretta B. Fahy

Development of an Administrative Record System and Information Repository System on the Hanford Site, Benton County, Richland, Washington 173
Brian S. Sprouse

Decommissioning of the 105-F and 105-H Fuel Storage Basins in the 100 Area at the Hanford Site 179
P.W. Griffin

Determination of the Probability for Radioactive Materials on Properties in Monticello, Utah 185
Mary J. Wilson

Accelerated Cleanup of the 316-5 Process Trenches at the Hanford Site 191
G.C. Henckel

Determining the Number of Samples Required for Decisions Concerning Remedial Actions at Hazardous Waste Sites 195
Joni L. Skiles

Program Management Strategies for Following EPA Guidance for Remedial Design/Remedial Action at DOE Sites 199
J.P. Hopper

HANFORD TANK OPRATIONS AND SAFETY ISSUES--Harry Harmon, WHC-Chairman

Hanford Waste Tank Safety Issues: A Program Overview 215
Harry Babad

The Path to Gaining a Defensible Understanding of "Watch List" Tank Risk and Interim Stabilization Needs 221
Ben Johnson

Evaluation of Tanks that Release Flammable Gases 227
H. Babad

Ferrocyanide-Containing Waste Tanks: Ferrocyanide Chemistry and Reactivity 233
R.D. Scheele

High Organic Containing Tanks-Assessing the Hazard Potential 243
R.C. Hill

Operating Watch List Tanks: A Study in Control 247
Phil Ohl

Extended Tank Use Analysis 251
C. De-Figh-Price

Development of Tank Instrumentation--The Search for Appropriate Monitoring 257
S.J. Mech

RISK ASSESSMENT/PATHWAY ANALYSIS--J.S. Devgun, ANL; Vern Rogers, RAE, Co-Chairs

A Risk Computation Model for Environmental Restoration Activities 261
J.G. Droppo, Jr.

Release Criteria and Pathway Analysis for Radiological Remediation 265
G. Subbaraman

A Framework for Evaluating Innovative Statistical and Risk Assessment Tools to Solve Environmental Restoration Problems 271
N.L. Hassig

Balancing CERCLA Risk and DOE Radiological Performance Assessment Methodologies and Practices 277
R. Shuman

Methodology for Conducting a Performance Assessment of an Engineered Disposal Facility 283
Randy C. Janke

Airborne Source-Term Modeling of Past and Future Interim Storage Practices of Hanford Site Waste Treatment Facilities Using Airsource Model 291
S.P. Roblyer

Baseline Risk Assessment Methodology for Mixed Waste 295
F. Harvey Dove

An Effective Methodology for Establishing Cleanup Standards for Mercury Contaminated Soils 301
Samar Chatterjee

CLEANUP PROJECT FIELD EXPERIENCE--Lew Goidell, DOE-SR; Pat Hopper, WMCO, Co-Chairs

Design and Construction of an Interceptor System for Radioactively Contaminated Solvent 307
Thomas G. Weiss, Jr.

Accelerated Cleanup of Carbon Tetrachloride in a Radiologically Contaminated Site at the Hanford Site 313
M.C. Hagood

Land Surface Cleanup of Plutonium at the Nevada Test Site 321
L.L. Ebeling

M-Area Basin Closure-Savannah River Site (U) 327
S.R. McMullin

Decommissioning of a Resource Conservation and Recovery Act Treatment Storage, and Disposal Facility: A Case Study of the Interim Stabilization of the 216-A-29 Ditch at the Hanford Site 333
David L. Smith

A Successful Environmental Remediation Program Closure and Post-Closure Activities (CAPCA) Y-12 Plant, Oak Ridge, Tennessee 339
Marvin H. Bowers

D & D PROJECT ACTIVITIES--Mike Hughes, WHC, Chairman

An Evaluation of Alternative Reactor Vessel Cutting Technologies for the Decommissioning of the Experimental Boiling Water Reactor at Argonne National Laboratory 345
L.E. Boing

SRS Waste Removal and D & D Program for Underground Waste Tanks (U) 351
G.H. Street

Decommissioning of a Grout- and Waste-Filled Storage Tank in the 200 East Area of the Hanford Site 357
S. G. Marske

Safe Storage of Deactivated Radiological Chemical Processing Plants in the 200 West Area of the Hanford Site 361
R.G. Egge

Decommissioning a Nuclear Reactor 367
Gilbert M. Montoya

Remedial Action for the Baker and Williams Warehouses Site New York, New York 377
Mark M. Benge

A Case Study: Underpinning of Structures as an Alternative to Demolition/Reconstruction for Removal of Underlying Contaminated Soils at the St. Louis Downtown Site (SLDS) 383
Antonio Paez-Restrepo

ACHIEVING RISK-BASED STANDARDS--Curtis Travis, ORNL; John Lehr, DOE-HQ, Co-Chairs

Health-Based Cleanup Goals at Hazardous Waste Sites: Implications for Risk Management 389
Curtis C. Travis

Meeting Health-Based Standards at Hazardous and Mixed Waste Sites: Are We Deluding Ourselves? 393
William A. Wallace

Contaminant Sorption/Desorption Rates: Implications for Groundwater Restoration 401
Paul V. Roberts

The Effectiveness of the Pump and Treat Method for Aquifer Restoration 403
Carolyn B. Doty

Groundwater Clean-Up: The Savannah River Site Experience (U) 407
Joseph G. Horvath

SITE CHARACTERIZATION AND MONITORING--Rogert Freeberg, DOE-RL; Stephen Stowe, ORNL, Co-Chairs

Innovative Investigation Methodologies and Techniques for Site Characterization 413
Mark D. Nickelson

Siting and Constructing Very Deep Monitoring Wells on the U.S. Department of Energy's Nevada Test Site 415
James J. Cullen

Initial Site Characterization Approach and Preliminary Results; 200 West Area Carbon Tetrachloride Expedited Response Action, Hanford Site, Washington 421
V.J. Rohay

Accelerated Cleanup of the 618-9 Burial Ground 427
J.M. Frain

Remediation Strategies for Perched Water Bodies Underlying the Idaho Chemical Processing Plant at the Idaho National Engineering Laboratory 433
J.V. Wozniewicz

Site Characterization for Remedial Design at National Priority List and FUSRAP Sites 439
James Neiheisel

ER APPROACHES AND LESSONS LEARNED--Les Price, DOE-OR, Chairman

Putting Ecology in Environmental Remediation: The Strategic Planning Process 443
L.A. Kapustka

Natural Resources Damage Assessments at Department of Energy Facilities-Using the CERCLA Process to Minimize Natural Resources Injuries 447
J.J. Bascietto

Managing a Site Cleanup Under an Accelerated Schedule the Lowman Story 455
Paul Mann

In-Situ Storage: An Approach to Interim Remedial Action-Recent Case Studies in Canada 459
Robert L. Zelmer

Surface Water Management at a Mixed Waste Remediation Site 465
David S. Schlotzhauer

Air Stripping of Volatile Organic Chlorocarbons: System Development, Performance, and Lessons Learned (U)* 469
S.T. McKillip

Removal Action Under CERCLA Section 104 for PCB-Contaminated Soil at DOE Mound Plant 475
John B. Price

POSTER-CLEANUP TECHNOLOGIES--J.M. Pope, WSRC, Chairman

Remediation Technology Needs and Applied R&D Initiatives 479
S.C.T. Lien

Proposed Plan for Vitrification Demonstration of Low-Level Radioactive Wastes at the Fernald Environmental Management Project 485
Rod F. Gimpel

Selection of Innovative Technologies for the Remediation of Soils Contaminated with Radioactive and Mixed Wastes 491
John Steude

Soil Washing Results for Mixed Waste Pond Soils at Hanford 511
M.A. Gerber

Facility Design to Apply Cover Material Over Radioactive Residue in Storage Silos 517
Leslie J. Fekete

Removal of Heavy Metals and Radionuclides by Seeded Magnetic Filtration 527
J.P. Bibler

Sorters for Soil Cleanup 531
E.T. Bramlitt

Three-Dimensional Computer Simulations of Bioremediation and Vapor Extraction 533
Bryan Travis

Application of Sphagnum Peat, Calcium Carbonate, and Hydrated Lime for Immobilizing Radioactive and Hazardous Contaminants in the Subsurface 543
P.A. Longmire

Development of a Polishing System for FEMP Wastewater Discharges 551
David Brettschneider

Destruction of Complexants Used in Groundwater Decontamination 555
K.M. Hodgson

"Smart" Pump and Treat 559
William Isherwood

Visual System for Waste Tank Cleanup 567
W.J. Millsap

Remediation Technology Development from the UMTRA Program 573
G.R. Thiers

Application of a Structured Light Source to Waste Surface Mapping in Waste Storage Silos at Fernald, Ohio 579
D.L. Jacobski

Utilization of the Magnetic Induced Polarization Technique in Environmental Remediation Problems 583
D.J. Jin

Evaluation of Proposed Designs for Streamflow Monitoring Structures at Waste Disposal Sites 589
R.B. Clapp

Integrated Demonstrations for the Removal of Uranium Substances from Soils 597
Kimberly R. Nuhfer

The Buried Waste Integrated Demonstration 603
Kevin M. Kostelnik

COPING WITH REGULATORY ISSUES IMPACTING THE ER PROGRAM-- Leo Little, DOE-RL; Gary Dintsch, HAZWRAP, Co-Chairs

CERCLA Integration with Site Operations: The Fernald Experience 605
S.W. Coyle

Successful Integration of the CERCLA and NEPA Compliance Processes in the Weldon Spring Site Remedial Action Project: A Case Study 615
George R. Bierman

CERCLA Document Flow: Compressing the Schedule, Saving Costs, and Expediting Review at the Savannah River Site 621
W. Dean Hoffman

Taking Interim Actions: Integrating CERCLA and NEPA to Move Ahead with Site Cleanup 623
M.M. MacDonell

An Overview of Public Health Service Health-Related Activities As They Relate to the Department of Energy's Environmental Restoration Program 627
Paula L. Kocher

An Approach to Regulatory Compliance with Radioactive Mixed Waste Regulations 633
Gary G. Baker

Implementation of 29 CFR 1910.120 At a Multiple-Contractor Operated Facility 643
Oba L. Vincent

EDUCATION AND ER METHODS AND PROGRAMS--Donna Campbell, CBC; Texas Chee, DOE-HQ, Co-chairs

Environmental Restoration and Waste Management . . . . . NA
Texas Chee

Historical Genesis of Hanford Site Wastes 649
Michele S. Gerber

Discovering Where the Problem is Hiding: Techniques from the Formerly Utilized Sites Remedial Action Program (FUSRAP) 655
Daniel S. Stout

Environmental Restoration Technology Programs at Mesa State College: A Strategic Look at Manpower Needs 661
Robert J. Harrison

A DOE University-National Laboratory Waste-Management Education and Research Consortium (WERC) 665
Ron K. Bhada

Leveraging Educational, Human Resources, and Organizational Infrastructure to Provide Solutions to Environmental Remediation Work Force Problems 671
Gregory B. Hayward

The Role of Columbia Basin College in Training Technicians for Environmental Remediation at the DOE Hanford Site 677
Kenneth F. Ferrigno

Improving Conduct of Operations in Nuclear Waste Cleanup Projects 681
J.A. Yeazel

CLEANUP TECHNOLOGIES--Erich Evered, EG&G-RF; Elizabeth Sellers, DOE-AL, Co-Chairs

Technology Development for a Disposal Cell at the Weldon Spring Site Remedial Action Project 685
Charles C. Reith

Robotics Technology for the Retrieval of Waste from Underground Storage Tanks . . . . . NA
R. MacDonald

Use of Novel Extraction Chromatographic Resins to Decontaminate Uranium Groundwater . . . . . NA
D.M. Einolf

Threshold Limited Kinetics of Aromatic Hydrocarbons in Shallow Soil Systems 691
Paul D. Kuhlmeier

Soil Washing: A Promising Technology for the Cleanup of Hanford 697
R.L. Treat

Results of Vitrifying Fernald K-65 Residue 703
D.S. Janke

Ground Water Extraction, Treatment, and Upgradient Injection Systems Provide a Mechanism to Control Tritium Plumes at DOE Facilities 707
Philip Nixon

RESSAC: Rehabilitation of Soils and Surfaces after an Accident: A European Research Program for Remediation of Radioactive Contamination 713
H. Maubert

ENVIRONMENTAL QUALITY ASSURANCE AND DATA MANAGEMENT--
Bob Newell, KEH; Frazier Lockhart, DOE-RF, Co-Chairs

A Project Manager's Primer on Data Validation 717
Sharon J. Ramos

Environmental Restoration Project Configuration Control 723
L.L. Hutterman

Environmental Restoration Remedial Action Quality Assurance Requirements Document 727
R.F. Cote

Compliance with ASME NQA-1 and QAMS-005/80 Quality Requirements Under the Environmental Restoration Program at the Idaho National Engineering Laboratory 729
L.R. Dausin

Application of Classic Engineering Techniques (Value Engineering and Observational Method) at the Weldon Spring Quarry 733
Richard D. Ferguson

UMTRA PROJECT CASE STUDIES AND LESSONS LEARNED--
Ralph Lightner, DOE-HQ; Steven Hill, JEG, Co-Chairs

Laboratory-Scale Tests of a Chemical Barrier for Use at Uranium Mill Tailings Disposal Sites 739
Robert R. Spangler

The Grand Junction, Colorado, UMTRA Program: Engineering Design and Management of More than 4,000 Remedial Action Designs 745
Mark Marino

Architecture and Environmental Restoration: Remediating Uranium Mill Tailings From Buildings 751
James D. Teply

Implementation Planning for Remedial Design and Remedial Action at The Department of Energy's Monticello Mill Tailings NPL Site 755
Debbie L. Richardson

Completed Remedial Cleanup at the Durango, Colorado Uranium Mill Tailings Remedial Action Site: A Case Study 761
Steven Hamp

Uranium Mill Tailings Remedial Action Project Vicinity Property Program 765
Paul T. Mann

Determining the "R" in ALARA: A Parametric Study to Establish Cleanup Criteria 769
R. Bonilla

REMEDY SELECTION--N.J. Beskid, ANL; Jim Buelt, PNL, Co-chairs

Hanford Site Past Practice Investigation Strategy 773
K. Michael Thompson

Chaos and Remedial Investigations 777
Robert M. Galbraith

Remedial Action Assessment System (RAAS)-A Computer-Based Methodology for Conducting Feasibility Studies 783
James L. Buelt

Selection of a Preferred Remedial Well Configuration Using Groundwater Modeling Techniques 789
Harvey Dove

Issuance of the CERCLA Rod for an Operable Unit Remedial Action at The Weldon Spring Site-Lessons Learned 793
S.H. McCracken

Changes in "Selected Remedy" After Record of Decision 795
Robert D. Rowlands

ER PROGRAM COMPLIANCE ISSUES--Charlie Sherman, WSRC; Gary Bodenstein, DOE-OR, Co-Chairs

Comparative Overview of Federal Facility Compliance Agreements and Consent Orders 801
Denton Lankford

Tiger Team Findings Related to DOE Environmental Restoration Activities 807
William M. Levitan

Risk Assessment Issues for Cleanup at DOE Facility . . . . . NA
Paul Franco

Integration of Removal Actions Into the Operations at a DOE Facility 811
Oba L. Vincent

Management of Petroleum Underground Storage Tanks at the Hanford Site 817
L.M. Douglas

Overview of the Closure Approach for the Hanford Site Single-Shell Tank Farm 823
E.H. Smith

UMTRA Project Management of Residual Radioactive Material Commingled with Hazardous Waste at Vicinity Properties 829
Charlene Esparza-Baca

POSTER-CHARACTERIZATION AND RISK ASSESSMENT--Martin Siegel, PNL, Chairman

Effect of Radon Dose on Cleanup Criteria and Using RESRAD for Chemical Risk Assessment 833
C. Yu

Long-Term Public Health Impacts of Decommissioning the Hanford Surplus Production Reactors: Implications for CERCLA Remedial Actions at Hanford 839
J.D. Goodenough

Evaluation of a Contaminant Pathway and Mobility at a U.S. DOE Site Using Groundwater Chemical Data 841
Robert W. Sobocinski

Status of Existing Federal Environmental Risk-Based Standards Applicable to Department of Energy Operations 847
Gordon R. Bilyard

Strategy for Integrated CERCLA/NEPA Risk Assessments 853
M.M. MacDonell

An Assessment of Baseline Ecological Risks at the Fernald Environmental Management Project, Fernald, Ohio 861
C.S. Duke

Assessing Exposures and Risks in Heterogeneously Contaminated Areas: A Simulation Approach 871
Donald J. Fingleton

Remedial Investigation/Feasibility Study Risk Assessments at a Superfund Mixed Waste Site 877
Samantha Richter Pack

Development of an Adjoint Sensitivity Method for Site Characterization, Uncertainty Analysis, and Code Calibration/Validation 883
Allen H. Lu

Solid: A Computer Model for Calculating the Effective Dose Equivalent from External Exposure to Distributed Gamma Sources in Soil 889
S.Y. Chen

Remedial Investigation for the 200-BP-1 Operable Unit Hanford Site Richland, Washington 891
Mark A. Buckmaster

High Resolution Seismic Reflection Applications for Hydrogeologic Characterizations . . . . . NA
B.R. Lewis

An Integrated Approach for Characterizing Free Product and Related Dissolved Contaminant Plumes . . . . . NA
Mark Shupe

Environmental Soil Sampling Under Storage Tanks Utilizing Angled Auger Borings 895
W.A. Hertel

Methods for Drilling and Well Installation in Radiologically Contaminated Soils 901
David L. Aloysius

Electrical Resistance Tomography to Monitor Vadose Water Movement 907
Abelardo Ramirez

Graphical Presentation of Ferrocyanide Tank Compositions 911
S.A. Colby

Efficiency-Based Groundwater Monitoring Design Using the Monitoring Efficiency Model (MEMO) 915
Charles R. Wilson

Use of Lysimeters for Determining Characteristics of Pore Water . . . . . NA
Jose Cercone

Evaluation of a Rapid Headspace Analysis Method for Analysis of Volatile Constituents in Soils and Sediments 919
W.R. Sims

AUTHOR INDEX 927

ATTENDEE LIST 931

The following plenary session and luncheon presentations are transcriptions of the actual presentations that were given at the ER'91 Conference. These presentations have been edited for this proceedings, however they are generally a direct transcription of the presentations.

INTRODUCTIONS BY CO-GENERAL CHAIRMEN

Willis Bixby
Deputy Manager for Environmental Restoration and Projects
DOE-RL

Leaders in environmental restoration know, "Time is of the essence." The challenge facing us is how we clean up this legacy in the most cost effective, regulatorily compliant, and timely manner, while recognizing the pressures and the desires of the public, the regulators, the tribes, and the political pressures. With the new course set by Admiral Watkins when he came in two years ago, towards an openness in environmental restoration, that openness is going to permeate all the things that we do here and we need that openness to be able to share our successes, our failures, and our problems openly in order to set a course for the future. The key to meeting the challenge of cleaning up the environment of the 21st Century is going to be teamwork; teamwork between DOE, EPA, the regulatory authorities, between the DOE sites, and with one another. This conference is an excellent place for that to start. Before we move into the major part of the program now, a function like this does not happen without a lot of hard work behind the scenes. Those people include Julie D'Ambrosia from headquarters, Liz Bracken and Ted Pietrok from DOE-RL, Hank McGuire and Steve Slate, Billie Neth, Don Wood, Diane Hulin, Katherine Bray, Mike Berriochoa, Lucy Love, Mary Goldie, Inga Leigh, Jim Cochran and Marv Weiss.

Pat Whitfield
Assoc. Director, Office of Environmental Restoration
DOE-HQ

Many of you may not know that this conference is part of a series that was started many years ago, in the old Nuclear Energy Environmental Remediation Program. So we have Jack Baublitz and the crew to thank for the seed that started this. When I attended the last of those conferences, it was in Albuquerque about a year and a half ago, and there were 400 people there. Actually, 400 people is a nice sized conference because you can talk to most of them at some point during the 3 or 4 days. It's disappointing that it'll be difficult to talk with each and every one of you over the next several days, but we're going to give it a try. At least we're glad you're here to listen to what's being said, and to understand what's going on in DOE's program. The number of you that are here indicate the importance of this program, I believe, both to DOE and to the country as a whole.

Especially recognizing that there are many of you here from non-DOE perspectives, we really appreciate the fact that our regulators are here to participate in this conference with us. I think it's important that not only are they here to talk in the plenary session, but they're also here to give papers in the individual technical sessions, and to put their perspective in place. I'm especially pleased by that. We have been trying, both DOE and the regulators, to work together more effectively that we have in the past and I believe we're making progress, and I believe the conference shows that. The environmental restoration mission is to clean up the DOE complex from past operations, protect the public health, worker health, and the environment. We're also required to spend the taxpayers dollars effectively. In order to do that we have to work closely among ourselves so that our successes or our failures get recognized from site to site, and we don't make the same mistakes over and over and over. We also need to go forward in an open manner. I believe you will recognize by the time this several days is over that we've talked about all our warts, in the various technical sessions, I hope there'll be some successes that we've had an opportunity to talk about and enjoy, but the main thing is that we've talked about the program as it is, so that everyone who's here knows and understands it as it is. Some of us will learn more about the programs from the presentations and more about the technical problems. Out of that we hope to be able to identify places where we can bring our own particular skills to the program and therefore improve the program and the program effectiveness. There are going to be about 200 papers presented on a broad range of topics. Many of these topics will include programmatic issues, problems, and the progress we're making. I hope we'll hear about some new technologies. I encourage you to ask questions in the sessions, I encourage you to have discussions in the hallways, interact among yourselves, and transfer as much information as we can. This is the only way the program can be a success in the future.

As we strive to reach Leo's vision of safer, cleaner, and cheaper, we will have some important but tough choices to make the choice of priorities of activities in any given budget year. The choice of how clean is clean for a particular site and that site's intended use. The choice of when to accept today's technology and move into the cleanup, and when to wait for better technologies to do a better job. I believe we can do this in a cost-effective way only by working closely with our regulators and our neighbors. Thank you very much for coming, I hope you'll enjoy the conference as much as I'm going to.

Leo Duffy
Director, Office of Environmental Restoration and Waste Management
DOE-HQ

It's rewarding to see the effort that Pat and Willis have put into generating this conference, I think it's long overdue. Hanford is one of the major challenges in the U.S. Department of Energy, and starting the conference at Hanford is a step to the future of the clean up for the 21st century. It's nice to see the regulators here, as Willis said, and as Pat indicated, Secretary Watkins' whole approach is open response to the requirements of the regulators and to the public. The theme of today's talk is commitment-commitment to the environment. We will protect the public and worker health, and the safety of the environment around our sites. It is also commitment to the future-the future depends on what we do now.

This conference is a prologue to the future of the 21st Century. It's a commitment to the regulators and to our compliance agreements. And it's commitment to the American people, that we will not waste their tax dollar. How are we going to do that? Well basically, it's a commitment to reduce costs through efficiency. We're not there. It's a commitment to economical solutions, to cost controls through good management and planning. We're not there. It's a commitment to new technologies; and we're not there. So we have a lot of work to do. Our guiding operation is the Five Year Plan. The most recent accomplishment, if you call it an accomplishment, was last week when we issued the 3rd Five Year Plan, and this is a recording, "it's a plan, not a budget"! Those of you who recognize the importance of that, this Five Year Plan took about a thousand people in our organization to put together. When Pat had the responsibility in 1989 to put together the first Five Year Plan, he started out with 59 people, and worked throughout the organization to get volunteers to come in and work with him on the Five Year Plan, and we put out about a 500-page document; I think we're now into a 1000-page document. It was a very difficult assignment. We're committed to a 30-year clean up program. A lot of people don't understand that. You know, the 30 years came from a request from Governor Booth Gardner, that we should have a time table for the clean up, and we agreed to the 30-year clean up as a timetable which the Secretary felt was reasonable, with respect to what he knew. But, to get there, we needed a plan; it's surprising that in 1989 we only had 1.3 billion dollars identified to the clean up to the U.S. Department of Energy's 40-year legacy. Well, the Five Year Plan is the bible.

Well, we don't have a great plan, we have a good plan. A great plan would have confirmed realistic guidelines and schedules. We don't have that. A great plan would have validated all our work scopes. We don't have that. A great plan would've validated cost estimates for the 2300 ADS sheets, and we don't have that. A great plan would've demonstrated that we are meeting every commitment in our compliance agreement, and we don't have that. A great plan would've shown technology development schedules in consonance with our technology needs for clean up, and we don't have that. A great plan would've shown that detoxification treatment technologies are available instead of, as Willis said, "suck, muck, and truck," and "hog and haul," and we don't have that. A great plan would've scheduled issues for consistent health and risk penalties throughout the Unites States; we don't have that. A great plan would address the sites specific requirements of how clean is clean and we don't have that. A great plan would've tried to resolve the issue of mixed-waste treatment; the 700 mixed-waste streams; and we don't have that.

Unfortunately, we only have a good plan. We've been at it for two years. Many of the issues are going to be resolved; there're going to be resolved over the next 10 years, the decade of the '90s. The decade of the '90s is a threshold for the clean up of the 21st Century. But with a good plan, we have a 4.5 billion dollar budget for 1992. Would we have 4.5 billion dollars if we didn't have a good plan? The answer is no. Would we have 4.5 billion dollars if we didn't have 2300 ADS sheets that we present to Congress as part of our justification for the need for 4.5 billion dollars? The answer is no. Would we have the state in-travel working group if there wasn't an open commitment by the U.S. Department of Energy to discuss the planning process through this operation? The answer is no. Would we have the environmental working group that we have working with us in conjunction with the Five Year Plan? The answer is no. We would not have any of these items without a good plan.

We're committed to ERMAC, the Environmental Restoration and Management Contract for efficient, economical clean up, and we're almost there. We got 200 comments from our public register notice, Commerce Business Daily notice, and I believe about 40 of those are from companies that are interested in the ERMAC. We have a commitment to the future: meeting the regulatory requirements on our current and new facilities and we're getting there. We have a commitment to the taxpayer; everybody wants to know where the money's coming from. It's coming from the taxpayer; it's coming from you, it's coming from me, it's coming from everybody on this panel. And we're going to do it efficiently, and we're going to do it effectively.

With this theme of commitment, where are we? We're entering Fiscal '92. Congress has fired a warning shot across our bow. When we put in our presidential budget, "the Bush Budget," as it's known, the Congress short-costed it 118 million dollars; if it wasn't for Senator John Glenn, we would've been 118 million dollars short on a 4.5 billion dollar budget. Unless you're in the field implementing it, that sounds like the noise level. But Senator Glenn went to the mat, and got us 50 million dollars back. We're still short 68 million dollars on the Bush budget. The new Five Year Plan was issued last week, and again, its a plan, not a budget. Without that plan, you and I don't know what we need and the Congress doesn't know what we need. We need a good plan that can justify the needs. We'll reach our second anniversary here in November 91, we will have gone from 50 people at Headquarters to 315, we will have gone from about 200 people in the field to over 1000.

At Savannah River we will have cleaned up the N basin, and we have demonstrated the TCE integrated demonstration, a positive accomplishment. At Y-12 we replaced the organic solvents with biodegradable solvents, a major accomplishment for Y-12. And that is a significant operation note. We have completion of all technical requirements to open up WIPP, we're ready to open up WIPP. We're down to the short fuse by each one of the operating safety groups and the office of nuclear safety. I'm looking at the outstanding issues. We're ready to open the first repository. That's an accomplishment. The first bin is now in a TRUPACT in Idaho. It's ready to roll. At Hanford we sampled 101-SY and we know what's in the tank. We know, at least we're on the steps of knowing, how to control it, how to neutralize the hydrogen generation. The first step in eliminating a major problem, in my opinion, the most significant problem in the Department of Energy.

In Session 13 and Session 16 we cover clean up technology of the future. EM commitment in the 90's is the prologue to the 21st century. The theme of the conference is cleaning up the environment for the 21st century. Our theme is commitment to the '90s, commitment to the environment, commitment to efficiency, commitment to the taxpayer, and you've heard me say it before, we're committed to better, faster, safer, and cheaper. If the prologue is "commitment," the epilogue should be "success." Cleaning up the environment of the 21st Century is initiated here, this is the threshold, this is the first step. It's not as significant as the man on the moon, but for the people at Hanford it's more significant. So our commitment is dedication to excellence, dedication to efficiency, dedication to good management, and dedication to commitment.

We're here to tell you that the U.S. Department of Energy is committed to the Five Year Plan, we're committed to the regulators and we're committed to our compliance agreements. It's a darn difficult job as both Willis and Pat indicated, and the only way we're going to do it is through cooperation and teamwork. If we don't do it, its going to be a failure and the prologue will not be arguing commitment, the prologue will be arguing, and the epilogue will not be clean up, the epilogue will be we'll still have the problem. So with the teamwork we have, with the technologies that we're developing, with the commitment with industry and education, we'll get there, but its going to be a hard long job.

Thank you.

Richard Guimond
Deputy Assistant Administrator for Solid Waste and Emergency Response
EPA-HQ

When I was invited to talk here I was in charge of radiation, I subsequently am now in for Solid Waste and Emergency Response, and so it's given me another little perspective on things. By integrating the two, I hope to talk to you today a little bit about both of those aspects and how I think the integration of those really fit together well for dealing with clean ups. I think Leo, obviously, must have had a good English teacher that was very interested in alliteration along the way because he's into, "suck, muck, and truck", and, "hog and haul." I have a new one for you Leo, you can now try, "pump, clump, and dump."

What I wanted to talk about was using, not only for DOE related clean ups, but for a number of the old type of clean ups that we have to deal with in this country, whether run by the States or run by EPA, is using the "Superfund model" for dealing with, or as a model for, site remediation. This setup was envisioned by the Congress and how we've been trying to implement it at EPA does give us a straight forward approach with dealing with a complex problem. Now, unfortunately, it doesn't solve all the problems and doesn't provide all the details of what we need to do, but I think it gives us a good introductory kind of framework for trying to take us through the complex set of requirements that are going to need to be met. Also, one of the key things that is available for the U.S. Department of Energy by looking at the Superfund model is to learn from our mistakes. And God knows, we've made our share over the past several years. But in the spirit of Leo's efforts to try to do things safer, cleaner, and cheaper, I think those same goals really are applicable to the Superfund program and how we deal with it. So those are the kind of aspects I want to cover.

Radiation clean up activities out there are very enormous, very large. You're dealing with all the DOE sites with an array of other ones at DOD, with NRC in agreement states you've got over 20,000 licensees, many of them are going to have to deal with clean up and decontamination, down the road. Even with our own Superfund sites, about 1,200 sites are now on the Superfund national priorities list, with about 46 of those that are on there because of radioactive contamination. Now, to get to the 1,200 sites that are currently on the Superfund list, we've looked at about 30,000 sites nationwide and screened those, and we look at an additional 2,000 to 3,000 sites every year. About five percent of the sites that we look at now end up on the national priorities list, but as we noted, a fraction of those are radioactively contaminated. However, I do believe, the number that are radioactive contaminated are likely to increase significantly down the road. The reason is because now radioactive criteria are one of the key criteria in our hazard ranking system, which is a relatively recent addition.

Now, why is Superfund a useful remediation approach? The CERCLA amendments created a number of goals and criteria for the agency to try to implement in looking at cleaning up chemical wastes or various other hazardous waste sites. The two principal ones that I think are first and foremost are applicable here, and I'm sure you are going to hear about them later today, or later in the week, and a number of you are already trying to deal with them. The first goal is to protect the human health and the environment, and the second one is to comply with all applicable or relevant and appropriate requirements and other environmental laws. We usually call these ARARs and if you haven't heard that term, you're going to hear it very much in the future. Now those are, I think, the governing criteria, which I'll get to a little bit later. How do we carry out our program in the Superfund area? Well, the first way is to carry out the national Five Year Plan, that Leo was talking about, and the national pollution contingency plan. This lays out the steps and scheme that we are to follow for dealing with the hazardous waste sites.

This starts by discovery of the site, preliminary assessment of the site, site inspections, hazard ranking (does it have a sufficient score to be ranked on the national priorities list -- how much of a contaminant problem is there), and then we go into a more detailed phase of remedial investigation, feasibility study, detailed risk assessment, how to try to characterize how significant the problem is, and coming up with alternatives for a solution. Then we come up with our record of decision, our remedial design, and our remedial action, construction of final remedies, and then completion and closure. All that, right now, is taking us between 7 to 10 years for a typical site, quite a long time. And this, I think, is part of the place where I think you all can, hopefully, learn a fair amount from some of the things that have taken us along those lines. Where we initially got into looking at sites and characterizing, we found that people would always want more of something else, more characterization, more public input. To try to deal with a number of criticisms we have had out there we would basically expand the process, more comment periods, and expand our characterization. It's gotten us to the point now where we're taking 7 to 10 years to get through a typical site. Needless to say, we've got a fair number of critics that are telling us that's way too long. That it should be done a lot sooner.

I'll give you a story, an anecdote, that just happened very recently. We had a site that just completed construction in our region 4, down in our land area. This site was found in 1983. The site, after being found, went through preliminary assessment, was ranked, I think, in 1984 or 1985, and was put on the National Priorities List. We then went through remedial investigations, feasibility studies, and all that. And in 1990 the site had finally gotten to the stage where we were able to get a consent decree with the responsible parties, and construction finally began. Construction took nine months of the remediation period. We found the site in 1983 and about a month and a half ago completed the construction phase which only took nine months. You have to say to yourself, there must be a better way. And those are some of the challenges that we see and where we're going to be trying to go in improving some of our program.

Obviously we don't want to short circuit and short cut the public from the standpoint of input, we don't want to take any shortcuts relative to the amount of characterization that is done to insure that you've got the right type of selection that you're going to do and you make the right choices relative to the remedial action. But we've got to find a way that we can do all that in a more expeditious manner, find a way where no one's rights get shortchanged, where no technical work is shortchanged, but we do it all in a way that we still do come to the solutions a lot faster. Our administrator at EPA asked us to look at ways of expediting the process and some of the changes that we're trying to take a look at are to see if we can bring about just that--streamlining our overall process. Streamlining the process so that one, we take a look, for example, at standardizing some of our remedies. We're finding, as we've taken a look and gone through several hundred of the sites and that we've analyzed, that after all is said and done and a tremendous amount of characterization is done and you come up with what may be a unique solution for a particular site, that we come up with maybe five or six solutions that come up each time. And, if in fact, that's the direction you go, maybe you can set the parameters for those things a little bit earlier so that you can get to the selection of those particular remedies and get them implemented without getting that last "i" dotted and that last "t" crossed.

Similarly, we're looking at ways of streamlining the process by trying to see if we can streamline the risk assessments themselves. There's a lot of room, in there, I think for us to take a look at what kinds of aspects might be done, we're doing that at the agency and have been trying to revise some of our risk assessment guidelines, taking a look to ensure that we've got a better handle on consistency across the agency, and that the type of solutions that we have when we make risk management decisions are giving an adequate amount of flexibility for regions to deal with. However, we're also trying to factor in as much of the reasonable and appropriate characteristics that are out there from a standpoint of what the real life exposure and real life land use are to be down the road.

I want to identify from the standpoint of risk characterization that one of the key criteria that we have been using is trying to have a benchmark goal of a risk of 1×10^{-4}, that is a lifetime cancer risk. And if the risks are less than that we tend to be able to say that it is an area that we're not likely to go into to take additional action. If the risks are larger than that then we'll go out and see what kind of practical actions might be able to be taken and how much we can reduce the risk. We're trying to get away from too much magic characterization that you have to get down below 10^{-4}, you have to get down lower than that because we're trying to take a look at a lot of those practical solutions that are out there, in some cases, it just can't be done. I think that needs to be taken into consideration.

From the standpoint of dealing with the radiation risks, in particular, one of the problems I think we are facing right now is a lack of really good "how clean is clean" criteria. Both from a standpoint of implementing our own clean ups and dealing with the ones out here that the Department of Energy has to contend with, we really have a lot to be desired and that's one of the key areas that we wanted to work in closely with the Department of Energy over the next several years to try to identify criteria that will work. Right now we are looking at applicable and relevant alternatives and various types of requirements which include uranium mill tailing standards, which include clean air act standards, various individual State standards wherever they might be, MCLs for groundwater protection, NRC standards, 10 CFR 20, and trying to determine how the NCRP goals and recommendations should be considered. We certainly don't have a cookie cutter by any stretch of the imagination and we certainly need to have greater consistency in what we are going to do. If we don't get that consistency, if we don't have those, we are all going to find ourselves arguing a lot down the road. We are going to find ourselves in a situation where we are probably going to be spending a lot more money for a lot less desirable results than we would otherwise do. Right now I think we are dealing with our own Superfund requirements, I also think often we'll find that the State ARARs are some of the more difficult ones for us to try to achieve for various Superfund sites. It's highly variable from State to State but that's another area where we're increasing our efforts to work closely with the States to try to come up with the requirements that both are acceptable to them and we think are achievable with the program that we're trying to implement.

In conclusion, I think, I just want to leave with a few of the aspects of where we need to go. It was said that expectations from everyone are higher than we're able to achieve. --- I was just up on the hill last week talking about our, hopefully it's going to be, 1992 budget and people were telling me "you spent five billion dollars and what have you got to show for it." Right now, in the first few years of the Superfund program, the great push was "get more sites on the national priorities list, you're not getting enough sites, you don't have enough ones you've characterized through." So now we have about 1,200 sites on the national priority list. That's not the push anymore. Peoples' and critics push to us now is "get sites off the national priorities list, you're not getting them off the national priorities list fast enough." We've now got about 63 sites where we have completed the construction. I say "completed the construction" because trying to determine and get credit for what is "success" has been a very difficult problem. Quite candidly if you don't get your bean for success until the job is done, it's going to be our grandchildren who's going to get that bean, it's not going to be us because in a lot of cases it's going to take a long time for the clean ups to go. We're looking at measures that do adequately address risks but, I think, give people a better benchmark as to when they should judge the federal clean up activities, whether they be Superfund or this, as opposed to just when all the clean up is completed.

As an analogy, take a look in the years past where we highlighted a lot of the municipal treatment facilities because we wanted to clean up the nations rivers. Once we constructed the municipal treatment facilities, we basically took credit for the accomplishment, not when the river was clean, cause that might have been 10, 20, or 30 years later. Somewhere I think we need to take a look at measures that people are going to be able to deal with. If you look at federal facilities, I was asked that "we set some goals at EPA for trying to increase the amount of completion that we have on our Superfund list." And as I said, right now we are have completed about 63 out of 1200. We want to more than double that by the end of next year and more than triple that by the end of the following year. Not one of those sites will be a federal facility. Not one. The first federal facility likely to be complete, have construction complete, is probably not going to happen until 1994 and it's

not going to be a DOE facility, it's going to be an Air Force facility that has a fairly modest problem.

I think, in dealing with the DOE facilities, to a great degree, you have a lot of them that are going to be here a long time, these are the ones that we now have on the NPL for this stage of the game, not necessarily the ones that are not on NPL. Now that means that a lot of money is going to be spent and people are going to want to know what have they gotten for it. I urge all of you now, I have talked to Leo and Pat about it, to try to come up with "what are reasonable benchmarks" for trying to determine. A lot of good work is going on, a lot of good work has been going on at EPA. I look around the country and I see all our people in our regional offices that are really killing themselves trying to go out and deal with the urgent actions as well as long term clean up actions. They pick up the paper and someone's just chewing at them for not doing anything I think you need a lot of enthusiasm to be able to begin a process, but look a little farther down the road too to ensure that whatever are appropriate measures of success, you get those defined, and defined early. Now, as you take a look at what your longer term processes are going to be, please feel free to take a look at EPA and how we can do it, and we'd like to have as many suggestions as you all have on how we can improve our own process for dealing with DOE facilities as well as dealing with our own facilities. I think we would welcome these, because, again, we've got a common goal: a safe, clean environment, and to try to do it as effectively and inexpensively as possible. Thank you very much.

Dana Rasmussen
Regional Administrator
EPA Region 10

I'm here today to bring a little bit of field perspective to the process. I'm very delighted to be able to speak here. It is an unprecedented opportunity to face some of the challenges that we have before us. All of you and all of us are going to have to work together to get some of our goals met. In EPA Region 10 we've been involved with DOE clean up sites for several years. We've been working at the INEL Site since 1986 under an EPA corrective order. That INEL action is now in the Superfund process with the recent agreement signed by the State of Idaho, EPA, and DOE. Here at Hanford, the Tri-Party Agreement between our office, DOE, and the State of Washington, was signed in 1989. We've been working here now for 2-1/2 years. We've had some significant progress, we've also had some rocky roads that we've traveled. Over the past year we've been working through a test of our Tri-party agreement as we've negotiated a set of major changes. That process has presented us with many challenges. We've had to face the federal budget process, we've had to face our different management styles, we've had to face the continuing high level of concern by the Public about what we are, or are not, accomplishing here in the field. We've learned a lot through this process through long days and heated discussions on the many important issues. I think it's important to reflect first on some real successes in the process. We've introduced the clean ups and the process so that we can see some real work now. We've dealt with new challenges, such as the comprehensive program to deal with liquid effluent concerns.

Today I want to discuss three challenges that I feel are facing clean up at all U.S. Department of Energy Sites. I'll focus particularly on Hanford because that's where we're located, and that's one of the areas in which EPA Region 10 is most intimately involved. These challenges are first, we must speed up the clean up of the groundwaters and the soils. Second, we have to substantially reduce the cost of clean up. And third, we have to plan for future site uses so that our clean up work is targeted and planned wisely.

The first challenge is to speed up the clean up process. The clean up of soils and groundwater is the core of DOE's environmental program. Because it is our essential mission, we have the right to ask each other "is what we are doing contributing directly to the benefit of the environmental mission, are we organized most efficiently, do all of our procedures support rapid clean up?" EPA, Ecology and DOE have just agreed to a project that will search for ways to reduce the time for the RIFS process to 36 from 30 months. We must eliminate procedures that delay our clean up, and we can shorten these site projects significantly. EPA is prepared to do it's part as, I know, is Ecology. The new past practice investigation strategy at Hanford has shown the flexibility of Ecology and EPA in trying to work this out. I am looking forward to working with DOE and all of you to make this happen.

I'm happier still about the situation at INEL. In that case, DOE, the State of Idaho, and EPA have agreed to some processes that will get us to the ROD stage within three months. We should all be striving to assure that we get to that stage quickly or that we go to clean up. I think, as Rich Guimond told us a little bit earlier, it's ironic that we have to deal with so long an investigation when we can get the clean up done in nine months. We here all have a responsibility to try to move that forward.

Another way to speed up the clean up process is to look for earlier opportunities for clean up projects. Projects that get going before the clean up of past projects is complete. We have three expedited response actions here at Hanford. We have one dealing with the excavation with buried drums and solvents, we have another that deals with the clean up of highly contaminated trenches from liquid disposal, and the third is dealing with the pumping and treating of carbon tetrachloride. In all these cases, the problem is well enough understood now so that we can begin without final decisions on the clean up standards and clean up scope. All of these three projects are slow to get going. We cannot accept this slowness. We must push the clean up process forward. We must look for other opportunities to get early expedited clean up. We at EPA are committed to do what we can to make this work and we urge the U.S. Department of Energy to budget funds to make that work also. If we don't do this, the public and the Congress are going to look at us, and it's going to effect our ability to get our clean up done later.

That brings me to the second challenge. We must reduce costs. We must find ways to get this work done more efficiently. We have to become mindful of what the public expects of us. As Leo said, this comes from our fellow taxpayers and each of us. And it's those fellow taxpayers to whom we owe our great public trust. At Hanford, EPA and the State have conducted a cost study. The U.S. Department of Energy did their own independent cost study. Both of these found ways that we could do work more cost effectively and more efficiently. Some of the recommendations from these cost studies have been put into effect and are implemented, but there is much more to do. We all must push the expenditures and screen more procedures that aren't focused on better and faster clean up. We don't have unlimited time. As I mentioned, the public is impatient about the pace of clean up, and I believe that impatience will increase as the bill increases and as time passes. In our experience at EPA, when the public becomes impatient, Congress gets involved, and if Congress gets involved, we're going to find ourselves dealing with mandated timetables, more oversight, and perhaps a reluctance on Congress' part to fund the clean up. This is in none of our best interest. Reducing costs now is the key to getting this clean up done quickly and efficiently and maintaining our public trust.

The third challenge we face is to plan for Hanford's future. Working with the public today to plan for the public of

tomorrow. As Hanford phases out of it's historic mission, new proposals will emerge on the use of the property. A broad range of outside stakeholders from farmers, environmental community, natural resource agency, tribes, and the business community must all be involved in our discussions on the future of Hanford. The Tri-Party Agreement serves as a blueprint for clean up activities but it is not enough. Hanford needs a plan for it's future. It needs a plan that can guide and shape our clean up strategies.

Last fall DOE, EPA, and the State met with local government officials, and they asked us to put together a process that would work with a facilitator to bring together a discussion of all these interested stakeholders. In the next few weeks, this facilitator will begin working with all interested parties to consider future uses of Hanford. We hope that this information will also help guide our clean up strategies today. I am particularly pleased about this unique public process; it's an opportunity to bring government and private process together and for all of us to work out in the open to meet our public trust. As you know, the residents of the Tri-City are very concerned about it. When looking at it from a regional perspective, what happens here at Hanford is a concern for all the Northwest Region. I hear from the State of Oregon, the State of Idaho, you've got the Umatilla and Yakima Tribes here, and there are many people who are interested in what we see happening here and we hope we can get a prototype out of this. I'm certain that we are all committed to a successful clean up of Hanford and other DOE Sites.

Any project of this size has to be dominated by certain values. I think one of the ways Leo did it was to call it "Commitments." And if our values and our commitments are concerned with the public, if we have concern for the public health, for the public funds, if the interest voice is for the public, I know we will be successful. We at EPA are here to support it. We are committed also, like DOE, to making this work. But we need all of your help, so I am thrilled and enthusiastic to see the crowd size here today. You all are going to make a difference and make it happen. We need your help as regulators, we know DOE needs your help as site managers, and if we do it together we can make this an example. So I thank you and hope you learn a lot this week so that you can make that happen.

Christine Gregoire
Director, Washington Department of Ecology
State of Washington

I am pleased to be here today, I am happy to join the distinguished panel of presenters that you have before you this evening and also to be with all of you because you have such a tremendous responsibility in the years and the decade to come. I'd like to give you, if I can, a futuristic prediction from the point of view of a State official. It's going to be a little bit different from what you have heard or you will hear because quite frankly I think I have a bit of a parochial view in that I do represent the Washington State Department of Ecology and it's interests have to be factored into the other kind of interest you've heard this morning. But first let me, before doing so, tell you a little bit about the agency itself and let you know how it fits into the environmental picture here at Hanford. Some of you may know us well, others may not, others wish you didn't know us at all.

The Department of Ecology's mission is to protect, preserve, and enhance Washington State's environment and to promote the wise management of our air, land, and water for the benefit of our current and future generations. We are mainly a regulatory agency, air and water quality, solid and hazardous waste management, shore lands, water resources, toxic clean up, oil spills, and the Hanford clean up effort. This means we are responsible for the enforcement of both Federal and State antipollution laws and we issue a variety of permit's in that capacity having to do primarily with waste handling and/or the discharges to the waters of the State. The legislature has also given us a major role in persuading our public here in Washington State and our private industry to voluntarily practice good environmental ethics. That we exercise command and control is a traditional way for EPA and an environmental agency to do business that we can expect, and we must also insist that there be voluntary commitment to an environmental ethic. The Department of Ecology's role here at Hanford is to enforce our State and Federal laws regulating the treatment, storage, and disposal of hazardous wastes. In the case of Hanford, this means in all practicality, regulating our mixed, hazardous, and radioactive wastes here. So you can see we have an oversight role at Hanford, but also a role in promoting environmental ethics here at the Hanford Site.

Now let's turn, if we can, to the question that I have been asked. "What will environmental clean up be like in the 21st Century?" For inspiration, I decided to first turn to the past, namely, what would my equivalent have predicted for environmental clean up for the year 1891? Our state was only two years old at that time, our population was only 360,000 people. A general feeling was that the state had vast natural resources, just waiting to be tapped. We had no sewage treatment, indeed, we had very little in the way of indoor plumbing. We had a natural recycling ethic present because people reused things, basically, because money was scarce and materials had to be shipped long distances. Therefore, I have concluded in my mind that the state official in 1891 would have been optimistic about the state's future economic development, but it's unlikely that he or she could have predicted our prosperity, our population density, the hazardous substances we have to deal with, and certainly not the question of nuclear waste and it's clean up. So I am humble as I launch into looking out into the future for the 21st Century. Perhaps we know as little about what's really going to happen in our 21st Century as that 1891 official could have predicted about our time.

Looking at the future, I look at two factors. One, what are the past trends, and secondly, what's the current public attitude about where they want the environment to be in the future? The past trends are obvious, more and more strict environmental controls are being put into place to prevent or curtail further pollution. For example, communities used to brag if they had primary sewage treatment, today, most, if not all, have secondary treatment and many are moving to tertiary treatment. There's more and more emphasis on correcting our past mistakes, cleaning up our toxic waste sites and our polluted water bodies, and reclaiming landscapes that we have diminished. What was an opportunity some 20 years ago, of untapped resources is a reality today that we've abused and misused and need to take another look.

Now I turn to the other factor, "what does the public want for the environmental future?" The state of Washington recently undertook and completed a process called Washington Environment 2010 which has been described as the model for the nation. Washington Environment 2010 was done in cooperation with the Environmental Protection Agency. It was created by Governor Gardner in December of 1988 to involve our citizens and governments, Federal and State and local, as well as Tribal, to design a long term environmental strategy for Washington State. It began with an Environment Report, first ever, a diagnosis, if you will, of our current natural health and a prognosis about the quality of our lands, water, and air by the year 2010 if we kept the status quo. We then went out to some 7,000 citizens, a public advisory committee, the Environmental Protection Agency and several other federal agencies, and directors and technical staff of some 19 state agencies for a vision: What they would like to see Washington State's environment to be like 20 years from now. That environment 2010 vision covers our state, but listen closely: We think it also applies to our nation. All of those citizens in governmental agencies said the following, "Our air in the year 2010, even in our major cities, must be healthy for all living things." It has to have resulted from auto emission reduction, and more mass transit. More energy comes from renewable resources and buildings are designed to minimize indoor air quality problems. Our marine surface and ground waters by the year 2010 generally are in excellent condition due to better informed and more responsible citizenry, as well as innovative technology. In 2010, individuals and institutions seek continuous improvement in methods and technologies to achieve a sustainable future. Our political leaders have the wisdom to seek out the best available information, on a variety of viewpoints, and the courage to make and support difficult choices

that balance diverse values and viewpoints, and that favor long-term common goals over short-term parochial concerns. Most of all, 20 years from now, we are driven by a powerful desire to preserve the diversity and the long-term sustainability of natural resources, and thereby our quality of life, and the quality of life for generations to come.

We also asked our citizens to set an action agenda to reach that vision. We didn't want that vision to be something that simply sat on a desk or on a shelf and gathered dust. We put into place 75 recommendations which were adopted by the governor 1 year ago, and I am proud today to say that every one of those 75 recommendations are at some stage of implementation. Air pollution prevention, the first priority problem, identified by those who participated in 2010, is being addressed by the Clean Air Washington Act passed by our legislature this past legislative session. They heard those citizens as we had, and they stepped up to the mark to take the action. Our government managers are finding ways to increase state agency recycling and use of employee mass transit, purchase of recycled products, and reusable alternative fuels. There's a major emphasis on individual citizens and the private industry, making voluntary choices to protect the environment. An outstanding example has been the overwhelming success across the state of Washington, on curbside recycling. Washington State, through its citizen participation, is number one in the country in terms of recycling.

So what are some overlying themes from the 2010 process that we can take to apply to nuclear weapons complex clean up? The environmental movement is here to stay and pollution prevention requirements are going to continue to be more strict. There is an increasing emphasis, and it will continue, on waste reduction; finding ways to prevent production in the first instance of waste, and then, looking to recycling whatever waste we can. In many instances the closer you can come to zero discharge of waste into the environment, the better, and it can be done. The public wants no discharge. This may not be possible at this complex or others around the country, but the public expects us to give an all-out try to accomplish it. Where waste must be generated, every effort must be made to treat before disposal and to avoid land disposal. An example is the liquid waste discharges to the soil at the Hanford reservation. There is a public outcry about the continued use of that methodology. The public is concerned about the health effects from trace amounts of hazardous waste. There's a lack of trust about the level of discharges. They reject the concept that dilution is the solution to the problem.

There's another theme, and that is the public wants a reversal of our past degradation of our land and our water. For example, the public here in the State of Washington voted to place a tax on hazardous substances to provide the money to clean up toxic waste sites here in the State of Washington. They want a future where almost all lands and waters can be reused. The idea of a national sacrifice zone is rejected soundly. All are part of an idea of a sustainable economy; that our actions today don't foreclose the future for succeeding generations, that we can have environmental protection, and we can have economic development at the same time. That's why there's one reason for a great interest here at the Hanford reservation, as Dana mentioned, on land use. In our plans for the Hanford reservation: how will our children and our grandchildren be able to use the Hanford reservation once we've completed our clean up effort? It's also a reason why I believe it's very unlikely the public will allow a solution which involves setting aside polluted land from any other use. For example, leaving the highly radioactive wastes in the single-shell tanks is unacceptable to the public in this State.

There is a great opportunity here at Hanford. I am convinced that, as the cold war ends, environmental protection and environmental restoration will begin to receive the same priority that we once gave to national defense. I applaud the culture and agenda of the Secretary of the U.S. Department of Energy and his direction for the Agency over the coming years. We have the will, and we have the resources, to do a model restoration at Hanford and the other nuclear weapons facilities around our country. We have a chance to create innovative technological solutions to our waste management problems, and we have the mechanism to do it in the Tri-Party Agreement, and other State or Federal agreements to clean up nuclear weapons facilities. There is very strong support for the agreement that we've hammered out here in the State of Washington that will be signed again today to continue that effort and that commitment, as Leo puts it, to the Tri-Party Agreement. But, as Dana indicated, people want us to get on with clean up; they want to be able to see that we have success; they want to be able to see that land and waters have been made cleaner and better; they want the most dangerous materials dealt with; that's why we must immobilize the double-shell tank contents as soon as possible. Of course, they want, and we want, safety to be our primary consideration, and they want us to find innovative ways to do the job with the least possible cost to the taxpayer.

I recommend that we, at Hanford, consider doing a vision much like we've done for Washington State. Where we want Hanford and the Tri-Cities to be in the next 20 years that could serve as a model for other nuclear weapons facilities. If I was to develop my vision for Hanford in the 21st Century, it would be as follows: first, the waste vitrification plant has been operating for 10 years, and Hanford's double-shell tank wastes are now immobilized in glass logs and being shipped to the national repository. Secondly, innovative waste retrieval technologies are being implemented at the single-shell tanks; the tank farms are well on their way to clean up completion. Third, investigation of Hanford's historic hazardous wastes has been completed. Clean up of the sites and the groundwater is in progress throughout the reservation. Next, Hanford is recognized throughout the world as the leader in nuclear and hazardous wastes clean up innovation and technology development. It's Molecular Science Center is up and running and producing a series of discoveries. Next, the clean up success at Hanford has earned the public's trust, that Hanford management is doing the right thing in managing this great resource. And finally, the workers here at the Hanford reservation, with DOE and it's contractors, are given their long overdue credit and public recognition for their expertise and their hard work. Next, Hanford also is famous for the way it rewards persons who come forward with safety, health, and environmental concerns and issues, and employees are encouraged to find innovative progressive ways to solve those problems. Secretary Watkins' policy of openness is not new in that period, it's just part of doing business. Next, Hanford is well-known for a "team approach" to environmental restoration. That means DOE, it's contractors, the Tribes, EPA, the Department of Ecology, the community at large here in the Tri-Cities, and the citizens of the State of Washington, as

well as those who are concerned about the clean up in Idaho and Oregon. And lastly, clean up is two-thirds completed. With just 10 years to go, people are saying, "What a wise investment we have made of our taxpayer dollar at Hanford."

But that's my vision. You may wish to consider as a community, and as Hanford workers, DOE, Westinghouse, and other contractors, putting together a progress report, a way to develop your collective vision at this facility or other facilities around the country, of where you want the site and the region to be by the year 2010. A great deal of work already has been done in the vision developed for Hanford's initial 5-year clean up plan. We found the concept of fulfilling a vision agreed upon by both the State's opinion leaders and the public to be an energizing force for making change actually happen, that all were part of the solution, not part of the carping, and the problem. I challenge those of us who are in the Tri-Cities community to go through a long-range planning process involving every citizen who wants to become involved, and then more importantly than all, to implement it. We stand ready as a State to help and to participate. Make the vision a reality. In conclusion, I think Leo's theme of commitment is music to all of our ears. We share those same commitments that he articulated. Cleaning up Hanford and the rest of the nuclear weapons complex is a challenge of immense proportion. The State of Washington has pledged to do it's part. We will advise, and yes, occasionally we will criticize, if necessary, to keep the clean up on time and on course. Together, success is within our reach.

Thank you.

John Wagoner
Manager
DOE -RL

Well, let me add my welcome to those that you have already heard. We're very pleased at the turnout. We're very pleased that the topic is of the obvious degree of interest that it is, and while we're talking a lot about Hanford here this morning, I'm sure that those of you who have interests at other locations throughout the country will look at it from the standpoint of trying to see how these issues are relevant to you and will not find this boring. On the other hand, I've also discovered that a few companies who are doing work elsewhere in the United States have an interest in Hanford, and have been paying us visits here in the last year from time to time to find out about what's going on and where we're going. I think that the fact that we're sharing interests in similar problems across the country is an important element of what we're doing and an important reason for having a conference of this type. Obviously, I'm very happy that we're able to get a group together of this type, with my boss and the type of effort. He's been trying to put together a plan. I was sitting there as Leo kept saying it's only been two years, and he's right from a calendar standpoint, but from the standpoint of what some of us feel who have been working on these plans and working with Leo for the last two years, it seems like a lifetime.

The fact that we've now completed 3 Five Year Plan documents seems impossible. Everybody thought that Leo and Pat were absolutely crazy when they started talking about putting together this Five Year Plan and there was an incredibly short time to prepare it. It think it was done essentially as most government, or at least most DOE projects seem to be, in the field, you're allowed two weeks to prepare the document, prepare all of the details and all of the supporting information, and then there will be 6 to 12 months of review of your two weeks effort that will go on. But we've now, I think, gotten the message, we understand that whether it's the Five Year Plan, or whether it's the federal budget, it is a 12 month a year effort -- you never stop. Some of us were perhaps a little slow to finally get the message and to understand that we needed to do a lot of work on our processes and on our basic approach to these things in order to really have a good product. Maybe we'll get to the great plan, someday. I agree, I think we do have a good plan, and compared to where we started from, it's a fantastic accomplishment. It does give us all something to look at, it gives the regulators something to look at, and to toss back at us, and the public and the other people who are interested, and obviously it gives contractors something to look at to see what kind of a business picture they should be planning on in the future.

It's interesting that when the government built Hanford, starting in 1943 and we're very close to that 50-year anniversary, that's kind of amazing too, the number of people who are still around that were involved in making that happen. It has been almost 50 years, and at that time we were trying to win a war. Winning a war in the shortest possible time, and the challenge was to beat the clock, and in an extremely literal sense, to get the biggest bang for the buck. That's what the program was all about. At one time, Hanford was the largest construction project in the history of the United States. Today, it is the largest environmental restoration project in the history of the United States. Our challenge is to deal with the waste and the contamination that came from that four decades of weapons production, and in a little different sense this time, again, to get the biggest bang for the buck. This challenge demands several keys for us to be successful, and I think the first one is, we do have to solve problems together in the best interest of the public. I was very pleased with the remarks that we heard this morning prior to this discussion, in that I think it's very clear that there is a climate in the regulatory side, and I feel that, in our side, the people who are responsible for carrying this out, that we're going to proceed with a team approach.

Our Tri-Party Agreement represents that we have gone through some difficult negotiations this year to make some changes to that agreement, and I think the fact that we have succeeded in reaching a negotiated agreement on a number of changes to the Tri-Party Agreement, the first significant one since it was signed two years ago, helps to reinforce that this can be a living document and reflect the realities that we learn about as we proceed through the process. It is important that we obtain funding for carrying this program out. This is a public commitment. It is one that requires the public throughout the United States to support what we're doing, and that means that their representatives have to be convinced that we are showing the progress that is necessary and that they are receiving good value for their tax dollars which are invested in the Hanford clean up. Otherwise, we're going to have real difficulty in getting the support that we need from the legislative side, and Leo referred to that in his remarks; we saw some signs of that this year. We're very sensitive to that and we're looking at what we can do to make sure that we contribute to the success of getting that funding support from the Congress, and we don't contribute to the problems that could arise.

We need good people. That's another key to our success. We need a lot of good people, at DOE, and the regulatory organizations, and in our contractors, and we're going to have to do a lot of work, I think, to attract, and recruit, train, and motivate the kinds of people that we need. We're working in this area very closely with the educational community to look at those areas where we are lacking certain specific skills and get their assistance in helping to provide that training opportunity. We're also looking at Hanford. At ways we retrain people who came here to do a certain job, to operate chemical processing plants, or operate reactors, and now to take those skills and turn them around and apply them to the environmental restoration program.

New technologies are the fourth key I'd like to refer to. We need these to find and characterize our waste sites,

stabilize them, and then remove the material, and, as Leo and others have said, we have to find better, smarter, faster, and cheaper ways to do this. We're looking at a key element of this at Hanford being the evolution and the construction, and the operation of the Environmental and Molecular Sciences Laboratory (EMSL) as a part of our Pacific Northwest Laboratory. We have been going through a very thorough process here this year too. For the first time, to really document how does the laboratory role, and not only the laboratory here, but those we have in other parts of the DOE complex, fit in to take us from the problem that's out there to the solution that we need to have in the future. But EMSL for Hanford is going to be an important element with that. That has been referred to this morning, and that is a very critical problem. We don't have that agreement today as to where is all this going, so not only do we lack the specific technologies, but we don't even know for sure what we're trying to accomplish in some of these areas. We know that saying that we will comply with environmental laws is not specific enough. We have to find out how clean is clean and what are the costs to achieve a certain risk reduction versus the benefits to the public. And, as Rich commented, that's something that EPA recognizes as very important.

It's obvious we can't just tap the taxpayers forever, unless we can show them that we're getting something and we have to develop ways of communicating what is the value. We found that locally. We found that as we approach describing this change in mission from defense production to the environmental side, we have a big problem to do to just convince the people who live in the area that there is a problem! People who have worked in the facilities, and so on, from the standpoint of industrial safety, feel that we've had a good record, and from the standpoint of obvious environmental problems, in many cases, they aren't obvious. But it's clear, we understand technically what the problems are, and that they're there, and we have to do a better job of communicating with the public who supports this, as to what is the problem, and I think Chris' suggestion that we need to show better what our vision is of what we're trying to achieve and provide a progress report as we go along the way, is going to be an important part of achieving that credibility and continuous support.

This public confidence is something of no minor import. Every time we have a public meeting in this part of the country, we're reminded of that by the folks who don't feel that we're doing all that we can or should, and are still very unhappy with what has happened in the past. They constantly remind us that credibility is the key, and they say, "You don't have it." So I think we have to accept the criticism, and continue to work on demonstrating why we should have that confidence and support from the public, and from the regulators, and that's something that we and many of you who are in the contractor community must accept as a legitimate element of the scope of work that we have to accomplish. I think that we have made a lot of progress as the Five-Year Plan process was developed, in going out and telling the public what we plan to do and getting their input into those plans. What we still have to do is to figure out the best way we can give them feedback to show them we heard what they said, and here's what we're doing about it. The teamwork element is the key. We have a teaming arrangement between our scientists and our engineers from across the country, that's tied in with industry, the people who will provide the equipment and hardware that we need to do the job, as well as the governmental elements, the regulators, and the public.

The people who are managing and overseeing these waste sites in addition to the people who are cleaning them up, all have to get a better means of working together than we've had in the past. But on the positive side, for the first time in memory, I guess, since people discovered exactly what was going on here at Hanford, we have, we believe, the entire region in agreement with the mission that we're carrying out, and I think that's what's happening at other DOE Sites around the country. We may not have agreement on the best ways of cleaning up the sites, but we agree that that's the objective. We have the advantage, if you will, perhaps at this site, of not having so many conflicts between missions, in that we've essentially said the defense mission is complete, and we're working on the environmental mission, whereas some of you at sites where you're still in defense production, obviously, still have that dichotomy and the difficulty of dealing with the various public interests on your program. But what we have here is people coming in saying, "Good, we're glad you're doing clean up -- just do it faster. We don't care what it costs; we want to see it cleaned up." Now we hear that, but obviously we do have to care what it costs.

We have developed more contact with regulators than ever before. We have an increasing presence right here at our facility of the regulatory employees. It's a different world than it has been in the past. That is helping us to communicate; we find more frequent meetings are extremely important, but not only meetings with the regulators, more frequent discussions that come and provide data to the public on the progress that we're making. We've expanded the opportunities for private industry to be involved in our program, whereas, in the past, we operated these sites essentially within a fairly closed framework with our management and operating contractors, and DOE, and some supportive subcontracts, but with most of the work being done internally. That is changing, and we'll be seeing in the next year, Hanford will join Fernald in requesting proposals and obtaining a contract for an environmental restoration management contractor, that this will be a new element of the way that DOE does business with private industry to accomplish it's goals. We see a greatly expanded role; many more companies involved in what's going on here at Hanford than we've ever had in the past. Some of our accomplishments you've heard about. Dana reported on the expedited clean ups that we have. You'll see around on the walls in here are some photographs of some of those accomplishments. We think that is an important success story, that we were able to quickly get agreement that it makes sense to get in and start cleaning up some of these specific sites before we complete the overall investigation process that normally has taken so many years to carry out.

We can't do that on all of our clean ups, so the model being set at INEL of achieving a much shorter period of time for achieving a record of a decision on some of the bigger clean ups is another part of what we think is going to be a revolution in the way that these environmental restoration jobs are planned and managed and carried out. As we look at ways to be more cost effective, we run across the fact that, when you're talking about budgets of the size and scope that we are, where this year, we're spending about a billion dollars of Leo Duffy's money at Hanford, as part of an overall 1.4 billion dollar program, and that continues to grow, the management

challenge is extremely significant. Not only are we doing different kinds of work than we've been doing in the past, but we've got a lot of dollars, and a lot of work scope to tackle in a very rapid period of time. That has forced us to reexamine all of our business and management approaches to the job. We have been working for the past year here to develop an integrated overall site management scheme that does lay out the vision for the future which is prescribed by the Tri-Party Agreement, as well as the Five Year Plan, to integrate all of these different activities, and then have that flow into a well-planned business base. We're taking the elements of things that aren't brand new. They've been used in the construction world and in the management of DOD projects for years, but restructuring them to provide the site management system that you need to have to carry out the clean up. One of the things we've found is that the regulators are very interested in how we are managing, because if we come to them and say we can't get this done because we don't have enough money, their logical question is the same as Leo Duffy's questions is, it's the same that OMB asks and Congress asks, "Well, what did you do with the money we gave you last year?" We've got to be able to show that better than we have before.

The result is that we will have a common interest, which may be coming from different perspectives, that improved systems will be not only for delivering widgets out the door, but for cleaning up environmental challenges. What we need are clearly defined schedules, milestones, resource-loaded, that you're able to show your progress against, you're able to measure the performance of yourself, of your contractors, and you're able to show the regulators what you're doing, as well as your appropriators. So that is something that we will have at Hanford, at least in FY '92, a good beginning that will continue to evolve. We recognize that unless we can do that, unless we can show that far worse things will happen, we won't have the support, we won't have the credibility, and we won't have the funds that we need to carry out the job. So it's a team effort, and it's one that we're very interested in having your input from all the perspectives that you represent. It's a challenge for all of us, but it's extremely important. I hope that you find this conference as interesting as it looks to me it's going to be from looking at the agenda. Again, we're very glad that you came to the Tri-Cities to see us, and I hope you find this week worthwhile. Thank you very much.

LUNCHEON SPEAKER

Honorable Sid Morrison
Representative, 4th Congressional District
U.S. Congress

If my constituents will forgive me, let me share with those of you who are guests in town today the process I go through in getting to the real Washington, that's this one. The plane leaves National Airport and always lands at O'Hare Airport in Chicago. I have my favorite men's restroom at O'Hare. This one is my favorite because on one wall is an electric hand dryer on which someone has written, "push the button and hear from your congressman." So listen up folks. It's a delight to have you here. I've been flying back and forth across the district to have a chance to speak to the Nations' Directors of Agriculture this morning with the Governor in Seattle, and now pleased to be here with you.

We're just in the closing days of what we call the August work period. I noticed it stretched over into September; we're good at that. One of the things that is sort of a buzz in this district is, we've been doing some TV serial programs. Twin Peaks, which lasted for awhile, and now, Northern Exposure is big. So my suggestion for my friends at Hanford is that we need a new publicist. Leo, I feel this fits in with the overall program. Now that tank 101-SY has a camera, we're suggesting a new serial. We're going to call it Twin Tanks, or the Burp Heard 'Round the World, or something like that. We want headlines that say, "Hanford scientists discover technique for using waste products to produce hydrogen, the fuel of the future."

My thanks to the organizers for letting me be a part of your program. For me, as Willis indicated in the introduction, this has been a fascinating time, now going on 11 years, representing this area. I'm a farmer, neighbor, and I have to share with you how I got started. First of all, they didn't expect me to get elected. So the day after the election, I got a phone call from a very prestigious team here at Hanford saying that we think you better come down and learn something about this process, which I looked forward to. So the following Sunday after the election, I was down. I still wake up occasionally in the middle of the night and I'm staring up almost as if I was on an operating table surrounded by these engineers and scientist all in white jackets. Well, things have changed in the last ten years.

It's been a marvelous experience and, of course like probably all of the sites represented here, we at Hanford certainly have had our ups and downs through the years. When I first got started--great timing folks--Ronald Reagan wanted to do some buildup. So, of course, during the 1970's, the N Reactor, our only producing reactor here for defense materials, was run during that decade thanks to strength of a Magnuson and a Jackson in the U.S. Senate, just to produce electricity. The defense people didn't like that, but we later made the shift to weapons grade plutonium at the N Reactor. We were able to restart the PUREX facility, so we saw lots of action here and a significant budget buildup. Then, of course as we all know, one of the things that brings us together is that the Soviets became unreliable enemies. We now gather together, probably the largest audience I've seen here for some time because of that, and we have a new challenge in front of us.

I can report primarily today to all my bosses here at the head table, on behalf of Hanford, but I think probably my story will relate to all of you regardless of what facility you represent. This place is mission-oriented, it's had a challenge, it's had a task, and it very proudly has reached out and taken on those tasks as they come through the years. Leo, we want to be out front as far as environmental restoration is concerned. I want to wake up now in the middle of the night and see those white, cloaked scientists chanting "Leo!, Leo!, Leo!," just like we saw Iraqi soldiers on television chanting "George Bush!, George Bush!, George Bush!" as they threw down their weapons.

Let me, just partially in jest, propose a recipe for environmental remediation, the subject of this conference, and I'm so pleased to see all of you here. I would suggest, in the State of Washington at least, we start with the Tri-Party Agreement and the Five-Year Plans as evolved from the U.S. Department of Energy. We squeeze that together with heat, and light, and understanding, part of that understanding being that one of the documents is political, and the other is technical. But that's why we've got to squeeze a little to get them together. You lubricate enthusiastically with adequate funding. You attract the highest quality chefs and keep them stirring. You give them a stimulating place to think, or as here we would like to believe that would be the new Environmental Molecular Science Laboratory. Throw in a large dose of competitive free enterprise. You allow for lots of tasting and sampling and even changing. You sprinkle, as appropriate, with all applicable federal and state requirements, even if that may be terrifying at times. I guess we have to remember we can't be all chiefs and no Indians because the community here wants to be part of the process and they want to be very supportive of it. I sense these things are gradually happening and I hope this recipe applies in other communities represented here by many of you.

I've been out all during this period, I'm almost on overload. One timber town hall meeting tonight in the Columbia River Gorge and a couple of things tomorrow and I fly back. But I want to share with you, and I hope it relates to all of the communities represented here, this Tri-Cities area is eager to get on with environmental remediation. It has very broad support. I was with the Governor this morning. He had several things I was supposed to say to you, Leo, but I won't do it publicly. Actually he wants you to take over some other areas since you've been doing so well with him. The Congressional delegation is united in support of this remediation process and, just for fun, I have to throw in that right here, where we're meeting in the Red Lion in Pasco, this used to be in Speaker Foley's district, and he too has been very supportive and interested.

Also, corporate interest, and a number of you are here from the corporate community, we sort of jokingly say, maybe you are sitting up on the limbs like birds watching and waiting for some opportunity. Westinghouse, the operating contractor here, sees you as vultures. The community sort of hopes

that whatever you are, that you lay golden eggs in the process. We'll poke fun, but I just have to share with you, this is a unique opportunity. One, as we get through environmental remediation through these years ahead of us is going to call really on the best of all of us and so we're delighted to have you here. The latest potential for corporate interest is represented by Mike Lawrence, our former DOE manager here, now with what's called, the TREAT Complex by Chemical Waste Management. And Mike, very frankly, I consider it a gutsy willingness to invest. That has to be measured by the communities here. But I think it will symbolize for all of you how private enterprise can enter and work with the job we have now with restoration at all of these sites.

If I possibly could be so presumptuous, let me share with you what I might consider the congressional attitude and I hope that all of you can help with this. We are looking forward now to putting together, Leo won't like this, a DOE site team of people. So that we're working together as opposed to in a variety of different directions. It's my belief that we have to keep environmental remediation as a national goal, not as a series of parochial interests. I see too many things that sort of fragment out in that direction. The minute they do, then we're warring parties, as opposed to working together to get the money that is going to be necessary to lubricate this recipe as it goes together. I think we've got to pursue environmental remediation as aggressively as we pursued the Manhattan Project. Unfortunately, it's without the authority that General Groves had in those days. We are going to have to rely on the cunning, and the skill, and the charm of one Leo Duffy. And that's a challenge for us. Leo, I would hope that as we look at numbers, I've got two columns; one said "validated", and one "unvalidated" in my Five-Year Plan. I was hoping that you could have just labeled one as "OMB," that was the validated version. The unvalidated was really what you wanted deep down in your heart, and we hope of course that we can achieve, because I think that it will be necessary to accurately do the job.

I think there is a challenge in front of us in keeping the appropriators believing in this plan in process, and that's going to take the help of all of us. There needs to be, maybe, even a better understanding of this evolutionary Five-Year Plan as we go through it. Because it has changed, and hopefully it reflects needs and thinking, and new technology and answers as they come along. Now, we have to be a little careful because the Five-Year Plan runs directly into the Five-Year Budget Plan and that's a complication. There will be increasing pressure, tremendous pressure, to start this internecine warfare among us as we try to blend these two. I also feel very strongly and I challenge these communities that come together here as support mechanisms for Hanford over these last several weeks. We've got to show results, something we can begin to demonstrate, and I know this, and Leo has shared this with me many times.

I enjoy serving on the Science, Space, and Technology Committee and I can tell you now, we share a broad basis of support for the space program. Not so much for the things they do, but the things they spin off. It's my hope that we can rather quickly begin to demonstrate some side benefits from what we do in environmental remediation. Because that's the sort of kicker that gets people to continue to come along with you.

I think also essential, and I know this is a difficult task, are the agency agreements. I've seen Admiral Watkins go from wondering how in the world did he get hung with this Washington State Tri-Party Agreement to holding it up as a model. As different states work within these agreements, I would hope that the interface between DOE and the states through these agreements, can be something to put together the governors and DOE, as we all deal with OMB and the Congress and very frankly, the White House. It's going to take a united front to put this all together. So, as I look at the agencies, particularly EM, the challenge is to relate long-term goals to near term programs. Of course, for Hanford that means justifying six to nine billion dollars in expenditures over these next five years.

The key part, as I see it, will be effective management of this interface between development of new technology and field activities. Leo calls that road mapping. Probably each one of us selfishly hopes that those road maps, all roads, lead to Hanford. In our case, to the technology that we are convinced we are going to help you all with at the Environmental Molecular Science Laboratory, an investment in basics that we think will be good in both the short, and particularly, the long run.

Leo, while I'm placing orders, forgive me, I hope you're making a note there on your napkin. The N Reactor as it goes down, I think, has been a model in the way the department has handled it. And why not a training center for wind down, for shutdown, for decommissioning and decontamination. Maybe an opportunity to share with some other people something that, I think, has been handled very effectively by the Department. We're also looking at a training facility and we call it "Hammer." It's a training center for all hazardous materials and emergency response. I know that strays a little over the line but that's another arena in which we all have to upgrade our personnel and our work force.

We have, like most other sites, our fiftieth anniversary coming up. As I look at these past 50 years, as I've indicated to you, we feel very strongly that Hanford has been mission oriented. It's taken on jobs and it has done them. That legacy of pride and meeting challenges now, I think, leads us into the next half century. But this time, we tie together the U.S. Department of Energy, the Environmental Protection Agency, the states, the counties, the communities, and our indian tribes in a total new program. The challenge is restoring these sites to as close as we can practically get them to their pristine condition. I guess to the people that handle these programs and work on them daily, I just want to say that, at least on behalf of Hanford, if not all sites, we are of like mind and obligation. We all seek action and answers, and we'd like to have along the way, continuity and stability. At least for Hanford, that last one is uncharacteristic of the first 50 years.

So I would say let us help you, our guests, the leaders in this challenge. Help you look good. As we take on a job that's bigger than any of us individually, but together, we can make it work.

Thank you very much.

UNIFIED THEORY OF SCIENCES FOR IMPLEMENTATION OF ENVIRONMENTAL RESTORATION AT DEPARTMENT OF ENERGY SITES

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ABSTRACT

Using the Unified Theory of Sciences to implement environmental restoration (ER) is an innovative approach for the U.S. Department of Energy (DOE) in solving its most pressing ER problems. This approach proposes a cohesive application of all sciences (technical/physical *and* political and social sciences) and would require that DOE increase its emphasis on public involvement, regulatory acceptance, and implementation strategies. Case studies illustrate how difficult ER projects can be successful. A successful ER project protects human health and the environment, conducts remediation expeditiously and cost effectively, and receives acceptance by regulatory agencies and the public.

OVERVIEW

The Unified Theory of Sciences (UTS) for the implementation of environmental restoration is a cohesive application of all sciences, including the political and social sciences. Although the technical emphasis is necessary to identify appropriate solutions to an environmental restoration problem, political and social aspects of environmental restoration must also undergo a rigorous, thorough, and systematic process to identify and eliminate barriers that may be encountered with potentially affected interests (PAIs). PAIs include all those interests (i.e., individuals; groups; institutions; other Federal, state, and local agencies; corporations; and other public officials) that will be affected by the project's direct or secondary impacts; those interests who think that they will be affected; and those interests who, for some other reason, need or want to be involved. These PAIs have the power to stall, derail, shelve, stop, or kill environmental restoration activities if their concerns are not properly handled and addressed. Removal of these social, political, and regulatory barriers is essential to implement technical solutions.

The concept of and principles behind UTS are not the invention of the authors. In fact, the concepts and principles described in this paper have been extensively researched and tested nationwide; extrapolation from results of more than 30 years of study and testing by national experts clearly demonstrates the validity and applicability of the UTS approach to DOE's Environmental Restoration (ER) program (1).

UNIFIED THEORY OF SCIENCES AND THE U.S. DEPARTMENT OF ENERGY

The U.S. Department of Energy (DOE) traditionally devotes large percentages of Environmental Restoration program funds and talents to identify appropriate technical solutions for environmental restoration problems. This technical effort requires a rigorous, systematic problem-solving and decision-making process that leads to specific recommendations (e.g., solutions, plans, projects, and proposals) that are intended to accomplish the DOE's environmental restoration mission. This technical focus requires staffing programs with specialists predominantly from the disciplines of physical, chemical, environmental, and engineering sciences.

However, technical expertise alone does not guarantee successful resolution of ER problems. Public agencies (including the DOE) often fail to solve complex problems *because they cannot implement their solutions.* Most public agencies, like DOE, have strong technical problem- solving capabilities but commonly fail to accomplish their missions because ad hoc, unsystematic approaches are used to resolve the public, regulatory, and political issues that can easily block implementation of proposed technical solutions. In other words, they do not provide sufficient effort and talent to the entire spectrum of problem-solving steps necessary to ensure implementation.

The UTS approach, a cohesive application of all sciences with increased emphasis on implementation planning, is generally consistent with the *planned* changes in DOE's culture. For example, according to DOE's *Environmental Restoration and Waste Management Five-Year Plan* (June 1990), DOE will "...monitor its actions to ensure that they are in the public interest and interface with the public to develop a program of public confidence and to regain the credibility promised to the public and Congress"(2). What is ostensively inconsistent within the *Five-Year Plan*, however, is the human resources needed to accomplish these goals. The *Five- Year Plan* identifies that the human resources needed for environmental restoration and waste operations should consist of 97 percent engineers, technicians, and scientists and only 3 percent other professionals. The UTS strategy encourages a more even distribution among the technical, social, and political sciences.

UTS is a broader approach towards environmental restoration and not just an enhancement of public relations activities or lobbyists activities. Political, regulatory, and social factors need consideration at a project's start and should be an integral part of all aspects of project activities. By applying this strategy and learning from previous successes and failures, DOE can successfully meet its environmental restoration goals.

CASE STUDIES

Four case studies illustrate the importance of using UTS to successfully complete complex projects. The case studies are [1] uranium tailings removal from a downtown business district by DOE, [2] the siting and start-up of a hazardous

waste incinerator and landfill, [3] the Defense Base Closure and Realignment Act of 1990, and [4] the 1976 Winter Olympic Games. Although only one case study involves a DOE project, the lessons learned from these four studies are universal and also apply to DOE. Each case consists of a Case Summary, Case Background, and Case Analysis.

CASE STUDY 1: REMEDIATION OF A DOWNTOWN BUSINESS DISTRICT

Case Summary

In 1987, DOE determined that remedial action was necessary on four blocks of the downtown Main Street Shopping Park of Grand Junction, Colorado, as part of the Uranium Mill Tailings Remedial Action (UMTRA) Project. It was recognized early in the project that remedial action in this downtown area, which was a source of strong community pride, could have severe financial impacts on the businesses. A dedicated effort was made by DOE to build upon previous experiences, apply lessons learned, and develop an approach to successfully complete remedial action of this downtown area. DOE developed an implementation strategy that actively solicited community input to plan, design, and perform the remedial action with the least impact. By developing the cooperative relationship, DOE was able to perform remediation within schedule and budget (3,4,5).

Case Background

Radioactive uranium mill tailings were used as fill and construction material throughout the Grand Junction area during the 1950s and 1960s. As part of the local UMTRA Project, DOE determined that more than 50 businesses would be affected by the removal of these tailings from the Main Street Shopping Park and immediately began efforts to involve all potentially affected interests in seeking appropriate approaches to completing this remedial action. Key contact points were identified to help coordinate this massive effort, including the Downtown Development Authority (DDA), the Merchants' Association, and officials representing the city of Grand Junction. These key contacts were immediately informed of the need to complete environmental restoration of the downtown shopping park.

As radiologic assessments were completed on the individual properties within this area during an 18-month period, public meetings were held with representatives of these key contacts to explain the survey results and report on the status of remedial action activities. In addition, four individual "block" meetings were conducted to obtain individual consent through one-on-one discussions with business and property owners and to ensure consideration of individual perspectives. DOE representatives addressed all liability issues, health risk analysis, and related concerns. These groups and individuals proposed many options that were considered and weighed against the requirements of the UMTRA Project.

As a result of these meetings and discussions, the following approach was developed: [1] allow contaminated areas from utility trench to utility trench to remain in place under the supplemental standards provision of UMTRA, thus avoiding excavation of Main Street and the adjacent decorative planters and established trees and flower beds; [2] perform work only at night so that businesses could remain open during normal business hours; and [3] complete remedial action in a specific spring timeframe that best addressed both weather and business considerations.

During the design and remediation phases, DOE distributed a biweekly newsletter to update all potentially affected interests on progress of the downtown remedial action project. The newsletter provided information that explained the extent and reason for any ongoing activities and provided a point of contact for individuals with special questions or concerns. This newsletter update continued for approximately 6 months, until completion of all remedial action.

To enable DOE to be constantly accessible, a downtown office was staffed at night and periodically during the day. This approach allowed DOE to be on call 24 hours a day to provide immediate response to issues or concerns. In addition, advertising in the local newspaper informed the shopping public that the shopping park was not affected by remedial action activities and updates to the local media kept the public informed of remediation progress.

Remedial action was completed in April 1989, 8 days ahead of schedule. On April 29, 1989, a ceremony involving DOE, the contractor, the DDA, the Merchants' Association, and business and property owners commemorated completion of the project. The ceremony was followed by the "Jackhammer Ball," a street dance and barbecue for the general public. This party, sponsored by the DDA and the Merchant's Association, was to congratulate DOE for its excellent efforts.

Case Analysis

Early involvement of groups and individuals potentially affected by remedial action of the downtown Grand Junction business district led to timely development of a suitable approach agreeable to all parties. DOE listened to the concerns and proposals of all parties and addressed these concerns without compromising the requirements and intent of the UMTRA Project. DOE and its contractor ensured that their personnel understood the importance of listening to and addressing owner and public concerns. By informing the public early in the remedial action process, the opportunity was created for DOE and all potentially affected parties to seek remedial action alternatives that would minimize negative impacts. This same informed consent approach continues to be successfully used with other large UMTRA properties in Grand Junction.

What is particularly insightful about this case study is that it was accomplished concurrently with a highly charged and highly emotional DOE controversy in the same area. This controversy involved the final DOE repository siting and transport plan for excavated mill tailings. While on one hand DOE was being given accolades for its excellent approach to the Downtown UMTRA work, DOE was being severely criticized for its heavy-handed, unilateral approach to siting a repository (5). This latter project eventually was resolved by DOE Headquarters with political pressure from the Governor and congressional representatives at more than close to twice the cost, nearly 2 years' delay, and severe erosion of DOE's credibility. The difference between these two projects is that one respected the opinions and values of the potentially affected interests and the other one did not.

CASE STUDY 2: HAZARDOUS WASTE TREATMENT/DISPOSAL AT MOBILE, ARIZONA

Case Summary

In 1980, the State of Arizona began the process of siting a hazardous waste incinerator and landfill within the State. By 1990, the Arizona Department of Environmental Quality (ADEQ) completed an Environmental Impact Statement (EIS), competitively bid the project for a firm to construct and operate the facility, completed construction of the incineration facility, and was ready to begin start-up procedures. In 1991, because of public, environmental, and political pressures, the State terminated its contract and settled with the hazardous waste contractor of the facility at a direct cost of $44 million (6,7).

Case Background

In 1980, the Arizona legislature authorized the construction of a joint State and private hazardous waste management facility to comply with Federal environmental laws. During the next several years, an EIS was prepared that identified the best site as an area near Mobile, Arizona (population 60). This site, approximately 45 miles southwest of Phoenix, was anticipated to consist of hazardous waste treatment systems (the specific systems were not identified) and a hazardous waste landfill. In 1983, ADEQ solicited bids and awarded a contract to Environmental Systems Company (ENSCO) of Little Rock, Arkansas (January 1986). Under the contract terms, the State would own the site and ENSCO would finance, design, construct, and operate the facility. Revenues received from the operations would provide income to both ENSCO and the State of Arizona. The contract stipulated that the State would receive $150,000 per year plus 2 percent of the gross revenues, and ENSCO would receive the remainder of the gross revenues. During contractual negotiations for the facility, it became evident to ENSCO and upper management of ADEQ that capacity of the facility must be increased threefold to 80,000 tons per year to ensure profitability. By 1990, the expanded capacity incineration facility was near completion and the final public hearing was scheduled on the air quality and three separate State and Federal hazardous waste permits.

During the early months of 1990, the public perceived that the incineration facility was three times larger than the original proposed plans in the EIS and that the majority of the wastes to be treated would be imported from other states, principally California. In May, a public hearing was held in the Mobile school cafeteria. Approximately 400 people attended this meeting, which far exceeded the capacity of the cafeteria and led to disruption of the meeting; 18 individuals were arrested and several attendees were stun gunned by Sheriff's deputies. The public and political response to what was being called the "Mobile Melee" heightened public awareness of the issue. In June, a special public hearing in Phoenix was called by the Governor of Arizona. Approximately 3,000 people attended this session and expressed anger about nearly every aspect of the project. Opposition to the project by the public was supported by environmental groups, notably the Sierra Club and Greenpeace. In addition, every legislative candidate and both gubernatorial candidates ran on an environmental platform opposing the joint State/ENSCO facility. Within less than 1 year, the State terminated ENSCO's contract, reached a settlement agreement (negotiated by the new Governor), and passed legislation to strengthen its environmental laws, particularly pertaining to hazardous waste incinerators (8,9,10,11,12,13,14,15,16).

The major issues raised that contributed to the eventual downfall of the joint State/ENSCO hazardous waste treatment/disposal facility were

- Lack of adequate public involvement throughout the entire process.
- The perception by the public that a small-incinerator facility for Arizona-generated waste grew into a large-incinerator facility designed to handle primarily out-of-state generated waste.
- The perception that hazardous waste incinerator emissions were excessively toxic.
- Transportation safety issues that were poorly addressed.
- The perception of an improper relationship between the State of Arizona and ENSCO that charged ADEQ with the dual task of overseeing the ENSCO contract and concurrently issuing permits for and regulating the facility.

The legacy of the Mobile, Arizona, hazardous waste site was personal, political, legislative, and programmatic--the director and assistant director of ADEQ resigned under pressure; ADEQ lost credibility and confidence with the public; the State's Governor and legislators developed a higher degree of environmental awareness; legislation was passed that makes it nearly impossible to build a hazardous waste incinerator in Arizona; and, finally, after Arizona spent 12 years and $44 million, the State still does not have a hazardous waste facility and will continue to export hazardous waste out of the state.

Case Analysis

This case illustrates several important points relevant to DOE. First, the security of a solution (whether by contract, agreement, or legislation) is vulnerable throughout the implementation period. Second, continued, active, honest, and open public involvement is essential to implement complex projects in the environmental arena. Third, credibility by the implementing agency is crucial to successful projects. The perceived improper relationship between the State and ENSCO and the expansion of the facility's capacity beyond the State's hazardous waste treatment/disposal needs bred mistrust of the agency (ADEQ) that was responsible for protecting the environment and public health. Finally, a failed project can cause a ripple effect that influences future projects and activities.

CASE STUDY 3: DEFENSE BASE CLOSURE AND REALIGNMENT ACT OF 1990

Case Summary

Historically, congressional approval of military base closures was nearly impossible because of political protection. This protection forced the Department of Defense (DOD) to have an excessive base infrastructure that was mismatched to decreasing defense needs. In 1990, Congress passed the Defense Base Closure and Realignment Act that authorizes a process that is perceived to be fair. To date, the

implementation of this Act has successfully initiated the closure or the realignment process of 82 excessive bases.

Case Background

In the 1960s and 1970s, the Executive Branch was commonly accused of using defense base closures to punish uncooperative legislators. This sentiment prompted Congress in 1977 to pass a law (10 CFR, Section 2687) that greatly restricted these efforts. The stipulations of the law, combined with Congress's reluctance to close military bases, effectively prevented the DOD from closing any major military installations.

By 1988, while the structure of the U.S. Armed Forces had changed, the base structure remained unaltered. In an effort to more effectively approach the difficult task of base closure, then Secretary of Defense Frank Carlucci chartered an independent commission to study the military base structure and to recommend installations for realignment and closure. In October of 1988, Congress passed the Defense Authorization and Amendments and Base Closure and Realignment Act that stipulated the use of this independent commission to recommend base closures. The 1988 commission recommended that 86 bases be closed fully and 59 others be closed partially or realigned. Congress, which could not, by the Act, make changes, accepted the recommendations in their entirety.

After publication of the 1988 list, affected members of Congress leveled three major charges against the commissioner's process. First, they contended that the process was secretive because hearings were closed and information on the ranking of facilities and transcripts of commission meetings were difficult to obtain. Second, Congress noted that many of the affected facilities were not visited by commissioners. Such visits, the legislators believed, might have helped the commissioners verify information included in the staff reports. Finally, they complained that faulty data were used to reach the final closure recommendations. Congress felt that the General Accounting Office (CAO) or another independent organization should have reviewed the information and data for accuracy.

With the dramatic changes in Eastern Europe and proposed further reduction in DOD budgets, Congress passed the Defense Base Closures and Realignment Act of 1990. The independent commission formed by this Act changed the process for conducting its study based on lessons learned following reaction to the 1988 recommendations. The process was changed to be more open and included 28 hearings conducted across the country with hundreds of face-to-face meetings with representatives in surrounding communities; visits to 47 military installations, and independent review of the information and data for accuracy by the GAO. On the basis of review and analysis, deliberations, and input from the public and other agencies, the commission recommended to the President that 34 bases be closed and 48 bases be realigned. President George Bush approved the recommendations and passed them on to Congress. Under the Act, Congress has until October 1, 1991, to enact a joint resolution disapproving the commission's proposal. Changes to the approved recommendations are not allowed under the Act. As of this writing, one proposed piece of legislation to reject the recommendation was attempted but failed by an eight to one margin. (Some of this information was excerpted directly from references 17 and 18.)

Case Analysis

The success of DOD in closing and realigning military bases by the process described in the 1990 Base Closure and Realignment Act is a function of three factors. First, the process established in the Act allows Congress to be responsible to the mission of national defense without forcing individual congressmen to abdicate responsibility to be responsive to constituents that would be negatively impacted by base closures. Second, the approach was intended, as the law says, "to provide a *fair* process." Although a large number of communities will be hurt by base closures (185,000 lost military and civilian jobs), the people affected and their congressional representatives could grudgingly accept the outcome because the process was perceived to be fair. Third, the 1990 commission changed the process to be open, based on lessons learned in 1988.

DOE can benefit from this case because it demonstrates that even a highly controversial project, which may severely impact large numbers of individuals, can be accepted and implemented if the process is both fair and open. By combining social and political science skills with sound technical documentation, the DOD devised a process that permits Congress and the President to be responsible to DOD's mission of a more efficient national defense. DOE, in the same manner, can establish strategies that use the Unified Theory of Science to implement the ER program.

CASE STUDY 4: THE 1976 WINTER OLYMPIC GAMES

Case Summary

In the mid 1960s, a group of citizens in Colorado made the decision to bid for the 1976 Winter Olympics. Although awarded the 1976 Olympic games by the International Olympics Committee, the bid was ultimately unsuccessful when Colorado voters, via a public referendum, refused to provide State financial support. The major reason behind this refusal was a lack of direct communication with all potentially affected interests. Specific areas not addressed were [1] environmental concerns, [2] concerns of rapid growth within the State, [3] potential cost overruns that would become the responsibility of State residents through increased taxes, and[4] a general distrust of the credibility and ability of the people in charge of the pro-Olympics organization (1).

Case Background

After it was identified that the Olympics would have an overall positive economic impact in the State of Colorado, an 18-member committee was formed in 1966 to prepare detailed plans for the Olympic games. Initially, this committee included elected officials (the Governor of Colorado and the Mayor of Denver, the proposed host city), bankers, representatives of the ski industry, and other business interests. Because of criticism that the committee did not reflect a broad spectrum of interests, several prominent environmentalists were appointed to a board that was responsible for reviewing the committee's actions and environmental development plans. One of the initial activities of the committee was to select specific sites for the sporting events. Most of the events were to be held near Denver. During this selection process,

some of the residents of a nearby mountain community learned from the media that the slalom ski race was to take place adjacent to their community. This lack of direct communication with affected interests fostered anti-Olympics feelings in some citizens.

The citizens of that mountain community formed an organization to enhance their influence with the Olympics committee. An important concern to this citizens group was environmental issues. The Olympics committee did not feel that environmental issues were pressing at that point; they were focused on making a successful bid for the Olympic games. The citizens group was convinced that decisions would be based solely on technical and economic factors, while environmental and social impacts would be essentially ignored. The residents of the mountain community who would be directly affected continued to be left outside the planning process with the explanation that they were a small vested interest.

During May 1970, the International Olympics Committee awarded the 1976 Winter Olympics to Denver. One of the local Olympics committee's first activities was to submit a budget to host the games. The initial estimate was $14 million, but the estimate was soon revised upward several times. The publicity received from the numerous increasing cost estimates began to erode the Committee's credibility among some legislators and sectors of the public. The early criticism of the Committee about a lack of concern on environmental issues began to become more diverse, such as a fear of cost overruns. To compound that fear, the Olympics Committee had a policy of decision making behind closed doors. This policy helped set the stage for rejection of plans by the public. Major decisions that would affect many peoples lives were being made without the affected interests' consent. By late 1971, the opposition groups formed an umbrella organization that, for numerous reasons, was opposed to staging the Olympics in Colorado.

In 1972, the persistent, committed, and well-organized anti-Olympics group acquired enough signatures on a petition to force a vote on the use of State funds for the Olympic games. In November of 1972, the voters in Colorado passed a referendum by a five to three margin that did not allow State funding for the Olympics. With a clear expression of no confidence by voters, the Colorado Olympics Committee abandoned any further attempts to host the games and informed the International Olympics Committee. Innsbruck, Austria, was subsequently selected for the 1976 Winter Olympics (1).

Case Analysis

This case illustrates several critical points that are inherent to DOE projects that involve the public. First, it shows the importance of providing early involvement by the potentially affected interests. By listening to the PAIs' concerns during the initial planning stages, the Olympics Committee probably could have made adjustments to its plans to avoid derailment of the entire process. Second, this case points out the danger of underestimating the ability of these interests to organize and block the best-laid plans. Citizens whose "way of life" will be negatively impacted can be significant roadblocks. Third, it reveals that projects that at first appear positive and uncontroversial may become just the opposite. The Olympics Committee never suspected that hosting the Winter Olympics could become such a controversial issue. Finally, this case shows that decision making behind closed doors tends to be ineffective and breeds suspicion among those PAIs not being informed. When citizens perceive that decisions that will affect their lives are being made clandestinely and the basis and rationale for those decisions are unknown, they tend to reject those decisions.

CONCLUSIONS

The Unified Theory of Sciences is an innovative strategy that DOE can use to successfully complete its ER projects. The Unified Theory is a proven approach, based on 30 years of research, that weaves technical and implementation skills into a cohesive strategy that can be used to solve DOE's complex projects/issues. Specific conclusions from this paper are

- Successful projects should have as rigorous and systematic methods for developing informed consent as they do for developing technical solutions.
- Successful projects are based on more participation by the public than is required by the law.
- Decision making behind closed doors is ineffective and breeds suspicion. However, controversial projects that negatively affect many interests can still be successful, *if* decision making is open, honest, and fair.
- It is important to involve PAIs early in the process and to recognize the potential for PAIs to block technically sound projects.
- Projects that may appear noncontroversial may, in fact, be extremely controversial.
- UTS has universal applicability and applies to other important DOE projects that do not involve environmental restoration.
- For DOE to achieve its goal of *faster, cheaper*, and *better* environmental restoration, the most efficient means is through the incorporation of UTS.

RECOMMENDATIONS

Based on DOE Secretary James Watkins' recent initiative to establish an advisory board to explore systematic ways to enhance public trust and confidence, DOE management appears to understand the importance of gaining public acceptance (19,20). Secretary Watkins admits "This is an area where I need a great deal of help." (20). What may not be as obvious, however, is that the tools required to gain public acceptance (such as UTS) are already being successfully used by other organizations. The following recommendations, which are specific to DOE, build on this existing knowledge:

- DOE needs to place more emphasis on implementation strategies by

  [1] Developing a cohesive UTS approach at DOE Headquarters level for the implementation of ER projects, primarily based on existing successful approaches;

  [2] Developing a training program centered around these strategies;

  [3] Training field office personnel in the understanding and use of UTS approaches; and

[4] Providing mentors and coaches to effectively use and interpret these strategies in support of DOE field offices

- Emphasizing social and political sciences in its human resources development and training. [DOE currently has projected its future human resources needs to consist of 97 percent engineers, technicians, and scientists (2); the UTS strategy proposes a more even distribution among the technical, social, and political sciences.]
- Approaching every ER project as potentially controversial and involving PAIs early in the process, using public participation to its advantage, using systematic ways of developing informed consent, and making decisions in an open, honest, and fair manner.

ACKNOWLEDGEMENT

Work supported by the U.S. Department of Energy Office of Environmental Restoration and Waste Management at the Grand Junction Projects Office under DOE Contract No. DE-AC07-86ID12584.

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CASE STUDIES ON DESIGNING MEETINGS FOR EFFECTIVE INSTITUTIONAL INTERACTIONS

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ABSTRACT

The U.S. Department of Energy (DOE) has been actively pursuing opportunities for external input into its programs and plans. This pursuit for external input is a result of DOE's commitment to a culture of openness and public involvement in decision making and policy direction. This input has included interactions between DOE and other institutions such as state and local governments and Indian Nations. One way these interactions occur is in the form of meetings to discuss issues or concerns the various participants have regarding DOE policies. Our involvement with this type of interaction has been as the meeting designer, coordinator, and facilitator for two external review groups - the State and Tribal Government Working Group (STGWG) and a group comprised of DOE transportation officials and local government officials from cities and counties around the country. We'll refer to this second group as the Local Government Network. We coordinate the design and facilitation of the Local Government Network with the Urban Energy and Transportation Corporation.

When designing the structure of a meeting we rely on the formula:

- *Audience + Purpose = Design*

In order to design an effective meeting, it's important to know who your audience is and the purpose of the meeting objectives. Our paper will discuss what we've learned about effective meeting design from our involvement with the two external review groups mentioned above. We'll also discuss the results of meeting evaluations participants filled out following a meeting to help us determine if our meeting designs met their purposes.

FORMATION OF STGWG

In March of 1989, Admiral James D. Watkins, Secretary of Energy, committed to the development of a comprehensive Five-Year Plan for environmental restoration and waste management activities at DOE nuclear-related production, testing and research and development (R&D) installations, and for improved compliance with applicable regulations: Federal, state, and municipal. This resulted in the Environmental Restoration and Waste Management Five-Year Plan. The DOE created STGWG to participate in the development and review of the Five-Year Plan as a means to improve the plan by considering state and tribal concerns in the development stage, to emphasize and support DOE's culture of openness, and to give DOE's cleanup and compliance agenda national visibility.

STGWG Participants

STGWG participants were chosen based on a letter to Admiral Watkins received in April 1989. This letter, co-signed by ten governors of states with DOE facilities within or adjacent to their borders, outlined the governors' concerns regarding federal commitment to the cleanup of DOE installations. The letter outlined some possible courses of action and called for a comprehensive national plan for environmental restoration (1). Using this letter as indicative of the most seriously affected states, DOE invited the following states and groups to participate in STGWG: Colorado, Idaho, Kentucky, Nevada, New Mexico, Ohio, South Carolina, Tennessee, Oregon, Washington, Yakima Indian Nation, Shoshone-Bannock Tribes, National Governors' Association, National Conference of State Legislatures, and the National Association of Attorneys General. Since STGWG's first meeting in June 1989, the group has expanded to also include California, Florida, Illinois, Missouri, New York, Texas, and the Confederated Tribes of the Umatilla Indian Reservation.

STGWG Today

STGWG's purpose is to give affected states and Indian Nations a voice in the annual review and development process of the Five-Year Plan. Today, STGWG meets approximately four times a year with DOE to plan, formulate, and review the Five-Year Plan and discuss related issues.

DOE'S EFFORT TO NETWORK WITH LOCAL GOVERNMENTS

DOE's Transportation Management Program (TMP) is responsible for supporting DOE programs in the movement of all materials, including the development of packaging and systems for transporting radioactive materials. TMP also coordinates DOE's program for regulatory and policy development in this area. In 1989, TMP began an effort to establish a network of local government contacts with interests in transportation issues including emergency management, enforcement, and training.

Since 1989, DOE has hosted several interactive meetings with local government officials from cities and counties around the country. The DOE representatives are from TMP and the local officials are senior and mid-level managers involved in transportation and emergency management.

The purposes of the meetings are to:

- share information that local government officials can apply to their own communities;
- exchange experiences and ideas applicable to other emergency management programs; and
- identify areas of productive action for DOE and local governments to address issues of mutual concern (2).

USING AUDIENCE + PURPOSE TO DESIGN A MEETING

Developing the STGWG Meeting Design

MSL has hosted, facilitated, or observed each of the ten STGWG meetings to date. This experience gives us an opportunity to relate lessons learned from designing these meetings for this particular group.

Planning a successful meeting is similar to planning the design of a document. Let's return once again to our formula:

audience + purpose = design.

The STGWG participants demonstrate the following characteristics:

1. STGWG members are knowledgeable about DOE's environmental restoration and waste management activities;
2. STGWG members agree on some issues and disagree on others because of differing interests;
3. There are some disagreements between DOE and STGWG over issues and their resolutions;
4. STGWG members are, at times, skeptical about DOE's abilities and motives to change; and
5. STGWG members remain the same from meeting to meeting.

The STGWG meeting process has been structured to meet these audience expectations and the meeting's purpose which is, as mentioned earlier, to review and comment on the issues and programs defined in the Five-Year Plan.

For involving diverse, knowledgeable, and skeptical participants, we suggest the following meeting characteristics which represent the STGWG meeting structure: (3)

- Involve a subgroup of STGWG - a planning committee - to help you set the location, agenda, and meeting process with DOE. This supports DOE's commitment to openly receive input into their planning process and improves the chances for a meaningful dialogue at the meeting if both groups, DOE and STGWG, feel they have contributed to the meeting agenda.
- Provide review and orientation materials before the meeting. Advanced distribution of information results in thoughtful review and comment.
- Ensure a minimum of lengthy, technical presentations for participants. Lengthy, technical presentations decrease interest and increase suspicion and perception of an unwillingness to listen and return to the old culture.
- Allow time for an executive session of STGWG members. This permits them to freely collect and discuss group and individual comments and thus minimize differences between individuals and maximize discussion when discussing issues with DOE.
- Don't overplan. A successful meeting plan will bend to the evolving needs of the participants.
- Include time for participants to get to know one another. If commitments are met and working relationships established, trust will be confirmed by action.
- Discuss, during the meeting, the status of DOE's and STGWG's commitments made the previous meeting. Bringing participants up-to-date demonstrates both DOE's and STGWG's 'good faith' in following through with commitments.
- Make feasible commitments on-the-spot or have quick access to a higher authority so that he or she can make these commitments. This is especially true for DOE participants; if DOE is unable to make feasible commitments, STGWG will feel little or no progress is being made.
- Inspect, don't expect meeting logistics. Meeting details can make or break it. Taking care of details for participants ensures their time is spent concentrating on the meeting at hand.

The meeting process for STGWG has evolved over the years to include three main areas:

EXECUTIVE SESSION: During this session, only STGWG members meet. This is a self-led session. They use this time to gather and discuss comments as a group before giving them to DOE.

ROUND TABLE DISCUSSION: STGWG members and DOE participants meet together to discuss issues and comments, many of them derived from the EXECUTIVE SESSION. This session is led by a facilitator.

PRESENTATIONS: Both STGWG members and DOE participants present information on topic areas suggested by the STGWG Planning Committee prior to the meeting. This time is also used by the facilitator to update meeting participants on the status of action items since the last meeting.

Developing the Local Government Network Meeting Design

Let's return again to our formula: *Audience + Purpose = Design*. The audience or participants of the Local Government Network demonstrate the following characteristics:

1. Participants are local government officials (mid- to senior-level managers) with interests in transportation and emergency management
2. Workshop participants are chosen nationally based upon the topic area for discussion. Therefore, the participants are not the same from workshop to workshop.

The purpose of the Local Government Network Meetings is for DOE and local government officials to share information and identify areas of action for both parties to address issues of mutual concern. Since the workshop audience changes frequently and the purpose involves issue identification and resolution, we've used a Program Planning Exercise during the workshop process.

The Program Planning Exercise uses meeting techniques designed to develop ideas for a DOE program plan to address local government concerns about transportation issues such as emergency preparedness for nuclear materials transportation incidents. We ask participants to play the role of a staff member for a DOE administrator, to review a report identifying local government concerns (the "report" is based on the actual product of an earlier workshop), and to develop a program plan to address those concerns (2).

The meeting process is designed to accomplish the objective and maximize limited time. The process is interactive,

collectively building a consensus plan based on both individual participation and team thinking. The exercise places participants in the role of a Federal manager faced with a difficult job--trying to satisfy transportation concerns while staying within organizational constraints. The result of the participative exercise is to (1) generate a program of initiatives to address local concerns and suggestions for their implementation, and (2) foster a better mutual appreciation of the problems facing both DOE and the local governments in developing such a program (2).

The exercise has three main parts. First, we divide participants into teams for the purpose of designing programs to meet the meeting objective. Second, we reconvene the participants to have team leaders report back to the full group on the initiatives and implementing steps developed by each team. Third, the participants discuss various aspects of each plan and achieve consensus on a composite program plan that might serve as a model for continued cooperation between DOE and local governments (2).

MEETING FACILITATION

Some group meetings require strong, active facilitating while others are better served by passive facilitating. In either case, it's important to recognize the type of meeting facilitator needed and adapt to the requirement. For STGWG, strong meeting facilitation has not been needed because the meetings are mostly self-led. This is because the STGWG participants remain the same and thus are used to interacting with each other as a group. In addition, the purpose of the meeting is for review and discussion of the Five-Year Plan; group consensus on issues and a set deliverable or program plan from the meeting is not required. However, even a self-led meeting can benefit from an effective facilitator because effective facilitation can: (1) better organize and direct group discussion, (2) improve the collection of valid comments, and (3) make sure group members have an equal chance to participate (3).

The Local Government Network requires stronger or more aggressive meeting facilitation with a more structured meeting process. This is because the participants do not remain the same; the individuals vary from meeting to meeting. So they are not as capable of being a self-led group. Also, the purpose of the meeting is to list issues or ideas and develop plans for resolving them. The facilitator uses a structured modified Nominal Group Technique which has been proven effective for idea generation (4). The facilitator leads breakout sessions with role playing for participants to develop plans and recommendations.

EVALUATING EFFECTIVENESS OF MEETING DESIGNS

Results of STGWG Meeting Evaluations

Following the conclusion of the last two STGWG meetings, we gave participants, both STGWG members and DOE participants, meeting process evaluation forms. We designed these forms to measure participants' perceptions of their opportunity to express views and the degree their meeting expectations were met. The form also asked for unstructured comments about the meeting logistics and process.

The following scale was used for all questions:

(1) strongly disagree
(2) disagree
(3) moderately disagree
(4) neither agree nor disagree
(5) moderately agree
(6) agree
(7) strongly agree

All means were between 5 (moderately agree) and 6 (agree). The average response rate for both groups was 64%.

We'll be discussing the results to two sets of questions. The first referred to the Round Table Discussions where both STGWG and DOE meet together. Both STGWG and DOE agreed moderately that their individual views were heard, understood, and given full consideration by all participants. Both STGWG and DOE also moderately agreed they were given enough time to express their views. Regarding whether or not meeting expectations were met (which were established at the beginning of the meeting), STGWG participants moderately agreed they were met and DOE participants agreed they were met.

The second set of questions referred to the Executive Sessions (which are for STGWG members only).STGWG participants moderately agreed on the following: their individual views were heard, understood, and given consideration by other members; they had enough time to express their views; and their meeting expectations were met.

There was also a set of unstructured comments regarding logistics and the meeting process. Many of the participants' comments were addressed earlier in the paper under the discussion of suggested meeting characteristics for this type of external review group. However, we will summarize some of the comments made on the evaluation form. The majority of the participants felt the meeting logistics were handled very well and that the process allowed for an open atmosphere which is non-threatening and provides people with an equal opportunity to speak. However, a minority of participants did note the tradeoff between giving everyone a chance to speak and managing the process efficiently. The facilitators have tended to lean towards giving everyone a chance to speak at the expense of running a more efficient process. Encouraging participants to be more concise should help improve the efficiency without limiting the opportunity to express views.

Results of Local Government Network Evaluations

Here is a summary of comments made by participants following the Program Planning Exercise at a past Local Government Network meeting. All of the participants who filled out an evaluation form believed the Program Planning Exercise was useful in providing them with an opportunity to develop specific program ideas for DOE which directly addresses their needs. Some of their recommendations included adding more time during the exercise for thorough discussion (increase the time from a half day to a whole day). (Since that comment was made some workshops have included a lengthened time for the planning exercise if the topic warrants it.) Participants said workshops should be on a regional basis instead of a national one. Currently, participants are chosen nationally depending upon the workshop topic. The location of the workshop is not necessarily tied to its purpose (5).

CONCLUSION

As we've discussed, the key or formula needed to design an effective group meeting is: *Audience + Purpose = Design.*

We've discussed how we've applied this formula to two meeting groups, STGWG and the Local Government Network.

We've learned that with STGWG a flexible and open forum is needed. The STGWG audience is members who are knowledgeable about DOE's environmental programs, yet skeptical about DOE's ability to change to a culture of openness and emphasis on cleanup. The STGWG audience remains the same through the various meetings and there is little changeover of members. The purpose is to have open an dialogue with DOE about DOE's Five-Year Plan and related issues. Group consensus on issues and a resulting meeting deliverable is not required. Therefore, we use a flexible, unstructured meeting process which bends to the evolving needs of the participants. We've developed a STGWG Planning Committee to help design each meeting agenda. Since the meetings are self-led, the facilitator is passive, yet still very effective in ensuring that all participants comments are heard, group discussion is directed and organized, and action items followed.

We've learned that with the Local Government Network, a more structured meeting process is required with a more aggressive, yet still effective facilitator. The audience for this group changes constantly depending upon the topics being discussed. The purpose of the meetings is to share information about transportation related issues and develop some areas of productive action to address these issues. Therefore, we believe the Program Planning Exercise is a successful component of the meeting because: (1) it is a structured method which clearly spells out the steps participants need to take to reach an objective, (2) it uses a modified nominal group technique which gives people time to generate issues and list ideas before they are discussed and elaborated on; and (3) it incorporates consensus-building teaming and role playing techniques, which encourages participation, creativity, and even a little fun!

ACKNOWLEDGEMENTS

The ideas presented in this paper represent cumulative work of hundreds of people over twelve years at Virginia Tech's Management Systems Laboratories. Professional managers from business and industry, and faculty, graduate students, and undergraduates from a wide variety of disciplines have participated in research and development of these tools and techniques. The author thanks them for their good work.

The preparation of this paper is funded by U.S. Department of Energy (DOE) Grant No. DEFG0288DP48058. MSL thanks DOE's Office of Environmental Restoration and Waste Management for providing us a real-world laboratory for the research, development and testing of state-of-the-art management tools and the frameworks for understanding how to make them successful.

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CREATING A CONTEXT FOR PUBLIC CONFIDENCE IN ENVIRONMENTAL REMEDIATION PROGRAMS

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ABSTRACT

Achieving public, political and regulatory confidence in environmental remediation programs challenges every member of every remediation team. Based on review of many controversial projects, this paper proposes a process-oriented approach to gaining and maintaining public confidence. It emphasizes the need to identify and understand potential stakeholders, and to design an overall context that incorporates public and institutional involvement into the investigation and remediation program. It calls for early strategy development, "ownership" of the public confidence strategy by all levels of staff and management, and a pro-active approach. It suggests practical actions that can be taken to implement an overall approach that is tailored for a specific program. Finally, it encourages environmental professionals to recognize the positive elements of remediation and use them effectively to enhance communication, consensus and confidence.

INTRODUCTION

Cleanup of historical contamination at government and industry sites has taken on high priority today. Investigation and remediation of controversial facilities can seem like a thankless job. Remediation teams believe that they are wearing the white hats, doing the right thing, and addressing a pressing societal problem. Yet public and political reaction often seems irrational. Generalized resentment against government, fear of health effects and land value impacts, and lack of acceptance of cleanup plans often result. The public seems to constantly cry that not enough cleanup is being done soon enough. Complaints mount about lack of timely progress and escalating budgets. When it is necessary to set cleanup priorities because of budget and schedule constraints, reaching widespread consensus on those priorities is difficult. Trust and confidence seem to be the missing ingredients.

Achieving public, political and regulatory confidence in environmental remediation programs challenges every member of the remediation team, from top decision makers to field personnel. As remediation professionals face a contaminated site situation, the clear requirement is to plan a process that will lead to an acceptably clean site. Deciding how to incorporate institutional activities into the process in a way that will gain and retain public and political support deserves hard thought and careful planning from the very beginning.

This paper argues for a comprehensive, contextual approach to involving the public in remediation programs. It discusses the types of potential participants that should be considered. Integration of public consultation and involvement into the framework of a typical contaminated site investigation and cleanup is addressed. The paper outlines specific categories of outreach and interaction techniques that managers should consider in designing an integrated program, and the reasons that these techniques have been shown to work. Demonstrating commitment to meaningful public involvement is a key action, accompanying already strong government and industry commitments to technical and policy excellence. Starting early to plan for and integrate effective public involvement into the overall process is emphasized, as well as evaluation of results.

Whether you are starting from scratch to develop and plan for a remediation project, or embroiled in a project or projects that are facing public, political or regulatory scrutiny, this approach can be of use to you. In many ways it is designed to better showcase and take credit for the good work that you are already doing in the technical, management, regulatory compliance, safety, and quality arenas.

PEOPLE -- IDENTIFYING AND UNDERSTANDING THE STAKEHOLDERS

Who has a stake in effective environmental remediation programs? Certainly you do, as environmental professionals engaged in a challenging long-term vocation. But you are already heavily involved, perhaps so involved that it is difficult to conceive of how or why the non-technical public should play a role. Stewards of the public good, such as elected and agency officials, share concern over protection of the environment and their constituents. Citizens, whether organized in groups or as individuals, rate environmental protection very highly and are quick to rally around an environmental problem. American business shares responsibility and concern about appropriate allocation of resources, and regulatory agencies pursue their statutory assignments with significant commitment.

These broad groups make up the pool of potentially interested and involved "publics" that should be identified in planning a remediation program. It is important to identify stakeholder groups and categories, to understand their levels of interest and knowledge, and to address them appropriately. What is also important, however, is not just what you do, but how you do it. There are several primary lessons that have been gleaned from review of many kinds of controversial projects that may help you understand why you get the reactions you do to your well-conceived, technically-appropriate proposals. Try to envision the frustrations of one of these identified stakeholders who is making his or her best effort to understand, comment on, and participate in a remediation decision. The scenario may resemble the following:

> Imagine yourself as a "typical" aware and interested citizen, busy with some other 50-hour-a-week career, your family, your home. You concern yourself with planning issues in your community. You volunteer to coach your

child's basketball team, and you participate actively in school, church, and civic activities. You have a passable lawn, a few hobbies, and an active social life. You try hard to read widely, and you are concerned about the new world order, global warming, national energy policy, and the leaking municipal landfill in your town. You feel reasonably well educated, but you are not a scientist by training. You feel like a responsible citizen, but you are continually frustrated by how decisions seem to be made at the local, state, and federal levels. You feel that you have a long-term stake in the environment, and in the issues that you believe are important.

Assume that there is a project in your community to investigate and clean up a site contaminated with radiologic and hazardous materials. The bureaucrats or contractors, bolstered by reams of scientific and technical justification, roll into town. The team members have been planning their project for months or years; they have funded background research, design, and analyses; they have experts involved to address every conceivable technical issue. They have a community relations program that tells you their proposed approach, presents the environmental advantages, and asks for your comments. Especially if the contaminated site has already been perceived as a problem by the community, the technical team may feel that they can't help but be received with open arms.

You decide to take time from your busy schedule to participate. You attend a public meeting, read a few brochures, and review the technical work plan. You call the technical team once or twice to ask questions and express your concerns about the technical approach, the assumptions used in the risk assessment, or some other aspect of their plan.

Often, your experience is fine. Sometimes, however, you find that you are shunted to a technically-inexperienced "public information specialist" or to an engineer who doesn't want to take time to answer your questions in understandable terms. Or you may offer ideas that you believe are technically appropriate, only to be told that the project is too far along to consider new approaches. The project approach, results of analyses, and environmental impacts are all presented as complete, and you are not sure why your comments are being solicited if they are not going to change anything in response to them. On occasion, you may be treated in a condescending fashion, avoided, or lumped into a group of "opposition" with which no rational, technical dialogue is believed possible.

Within weeks or months, you have decided to take even more time from your busy life to actively oppose the proposed solution. You apply your significant intelligence, community network, media contacts, and stubbornness to fighting the proposal, fighting the proposing organization, and generally digging in your heels. Why?

WHAT HAPPENED?

People get mad when they feel behind on the learning curve, when a project is well along before they become aware of it. People get mad when they believe that they have been or will be needlessly exposed to risk. They want a risk-laden situation cleaned up to absolutely clean levels, or demonstrated to present no new risk. They get mad when they perceive that government or industry are reluctant to expend the necessary resources, or have concealed information, broken environmental laws, or made decisions without public knowledge or input. They get really mad when a technical expert speaks to them of risk-based decisions in either highly technical terms or in over-simplified terminology.

But risk can be only a surrogate for other issues. People may claim unacceptable risk, but their real concerns may be with fairness and equity ("Is our remedy as safe as the one in the next county?), stigma ("Tourists will never come here, and nobody will buy our vegetables."), or tradition ("No state agency has ever come in here and told us what to do, and they won't start now."). Faced with government or big business initiatives, regular people often feel powerless. That makes them mad.

ACTIVITIES -- TECHNIQUES THAT WORK

So how can you avoid making the public fighting mad? In looking at a typical RI/FS process, there are a number of natural junctures where the public can learn and contribute. Listing of a site as a priority site for investigation is in itself based on assessment of the site's imminent and long-term risk to health and the environment. The investigation proceeds, including airing information on the practices that created the environmental problem. Results are used to postulate potential risks to people and the environment, laying the groundwork for a decision on appropriate cleanup techniques and levels. Various technical and engineering alternatives are typically evaluated in terms of effectiveness, cost, and workability. Finally, a recommended cleanup option is presented for public review before implementation. Each of those points are appropriate opportunities to inform and involve those members or sectors of the public that may otherwise oppose, obstruct, raise political issues and pressure, or effectively veto your program.

Frequently, community reaction to a remediation proposal can include the following:

- I don't agree with the assumptions/methodology used in the risk assessment. The risk is therefore unknown, so I won't accept the proposed solution.
- Scientific consensus on risk assessment or remediation engineering methods does not exist, as stated by our local physician/retired engineering professor. I do not accept the results of this assessment.
- You are proposing only a partial cleanup to save money and time, while exposing my family to risk from the remaining contamination. We are not willing to trade human life and health for money and time.
- You had some hocus-pocus scientist from out of state come in and decide what the risks and cleanup options were, and I don't understand how you did it. You have no basis for making a decision on cleanup until we understand the information.
- You lied to us about the levels of contamination at other parts of that property, and we don't believe your numbers now.

Members of the community have normally not participated in the investigation, the risk assessment, or the evaluation of alternatives for remediation. They are often presented

with voluminous documents on the project, so they have not had the opportunity or taken the time to understand the methodology, argue over the assumptions, or observe the results of sensitivity analyses. They therefore don't accept the results, and are likely to dispute the recommendation no matter what it is. If they insist that there is really a greater risk than the technical team's assessment indicates, that is not just "perceived risk," it is their personal, value-influenced translation of the risk. If told that it is an issue of real versus perceived risk, they will probably become angry and frustrated. The result will be opposition to what may seem like the most technically-appropriate decision.

As a remediation manager, here is what you can do to help avoid public outrage and opposition, and the resulting political, media and public pressure:

- Do your homework prior to beginning the process so that you understand stakeholders, historic reactions, and perceptions about the site and about you and your agency. The community interview protocol contained in the EPA's community relations guidance (1) provides excellent results. One-on-one conversations with individuals, even those traditionally hostile to an organization or a process, can be rich with information, nuances, and issues. People are flattered to be approached and listened to, and you will learn much about how to structure your outreach program. Your time will be well spent in planning your approach to identify existing and potential stakeholders, and to understand their historical experience with the site, agencies, or similar issues. File reviews, clippings searches, interviews, and common sense will allow you to gather the appropriate names and information. Anticipate the way in which different people and groups will want to be approached and brought into the project, as appropriate, and how you would like to be treated if in their shoes.
- Preparing public information materials is an area that is often done well, and it is very important. It is not, however, sufficient. Clear, graphic, understandable information that meets the needs of slightly-interested general citizens as well as better-educated interest groups will help build the base of understanding needed to participate meaningfully. All kinds of outreach activities, ranging from public meetings and workshops to speakers' presentations, will need some type of reinforcing information materials. Based on what you learn in your preliminary research, materials may consist of brochures, slide presentations, videos, posters, bumper stickers, white papers, handouts, exhibits and models, hands-on monitoring stations, and others. A common theme that illustrates the overall context for the program will help in overall public understanding. What is typically not done well is to carefully and comprehensively place the information into the right hands and to engage those now-informed people and groups in a participatory process. Often resources go into preparing materials that are not effectively or broadly delivered to their intended audiences. This is a misuse of usually scarce funds, and an avoidable mistake.
- The RI/FS process involves complex concepts, but it is a logical and step-by-step process. One of the benefits of this standardized approach is that it allows for educating interested persons about the results of early steps, the next actions indicated, and the options for remediation. Health risk assessment, one of the more technically complex elements, can be fairly readily understood if broken down with care into its constituent pathways, assumptions, sensitivity analyses, comparative risks, and decision-making ranges. Engineering alternatives lend themselves to models, drawings, and vivid techniques for comparison. Because of its step-by-step nature, the RI/FS process can lend itself to the technique of an advisory or review group formed of representative and interested people who become involved early. They can thus benefit from ongoing instruction and background information, and provide input to comparisons of alternatives, risk assessment assumptions, environmental information, and other elements. Such groups require a significant commitment of resources, openness, and willingness to consider their opinions and inputs. Formal groundrules for all participants and the organizers are recommended, along with an open mind to the topics and sources of information that will be considered and evaluated by the group. Often the results are increased credibility for the process and the agency, information gained on local conditions or preferences, and a broader-based community constituency for the resulting decisions.
- The authors' research in public preferences has shown that local control over environmental factors ranks higher than other kinds of material or conceptual incentives. People want to have independent inspectors, real-time printouts of monitoring data, and access to all pertinent information at the same time it goes to the technical team. They can be accommodated to varying degrees, depending on the project, by forming oversight groups, providing monitoring stations, teaming community representatives with field personnel, splitting samples and sponsoring independent analysis, and other techniques.
- Workshops and working sessions can be effective outreach techniques if care is taken to target participants and participatory style carefully. For example, the team may conduct a tour of a groundwater monitoring installation and the laboratory where the data are being analyzed, then participate in a work session with technical staff to review the data and discuss their implications for the project. Another option could be to combine a site tour, highlighting potential contaminant pathway locations, with a working session with risk assessment, land use and biology personnel to discuss risk assessment assumptions prior to their application. The key is to include as much hands-on involvement as is feasible, and to expose the various technical staff persons to the public. Credibility is enhanced by the opportunity to talk one-on-one and informally with the "real people" who are sampling wells, designing remediation alternatives,

or postulating health and environmental risks. People can be brought to understand the steps in the process, the stringent quality assurance and control systems, and the meshing of various disciplines to create a framework for remedial decision making.

- Print and electronic media are often included as sectors of the public. Rather, it is suggested that they be used more creatively and proactively as a channel of communication to many of the stakeholder sectors. Taking the initiative to form relationships with environmental reporters and editors, to call on and hold discussions with editorial boards, and to issue interesting and creative media information will help broadly expose the positive elements of the program. Cleanup is inherently a good thing, and there is a great deal of excellent technical work that takes place. Showcasing that work, the sincere efforts of the program to inform and involve the community, and the stringent oversight by regulators and the community, will add credibility and confidence.

TOP-DOWN COMMITMENT TO PUBLIC PROCESS

As any program that affects all parts of an organization, the implementation of effective public process in remediation demands top-down management commitment and organization-wide ownership. One striking example of personal commitment that directly addressed public fears and anger comes from the management of the Alaska Pipeline Terminal in Valdez, Alaska (2). Following the horror of the Exxon Valdez spill on Bligh Reef in 1989, the oil company consortium that operates the terminal responded quickly in the public arena. A new president of the company took personal responsibility for forming a regional citizens advisory committee with unprecedented powers to influence the terminal operation. The committee's authority included binding agreements on the consortium's response to their comments, independent funding for technical expertise and research, and public visibility and autonomy. The committee participated actively in review of new emergency response planning, equipment purchase, and other actions designed to avoid future problems. Within a year of its formation, community reaction to the operation of the facility had gone from openly hostile to accepting, and citizens were acting as ongoing watchdogs for the terminal operations.

Interviews with committee members indicated that without the integrity and hands-on commitment of the president, who withstood significant corporate pressure not to carry the program forward, it would have failed. The techniques were important, the funding was important, and the independent oversight was important. What was most important, however, was that individual's integrity, two-way communication and commitment to listen to public input and demonstrate how it had been used. With his commitment, the remainder of the organization realized the importance of the committee approach and carried it out smoothly.

This example is also illustrative of many remediation programs because it involved multiple firms, with the same overall objective but many differing and unique sub-objectives. With the power and energy of the key individual, he was able to coordinate and centralize the commitment of all the involved firms and build the needed credibility for the process. Had the member firms acted independently and without effective coordination, it is hard to imagine that success would have occurred.

TIMING -- PART OF PROGRAM PLANNING

When does public involvement need to take place? People still too often say that "We don't need to do any public involvement. There is no interest in the project now. When there is, we will do some." Waiting until the public is disenchanted, angered, or in open opposition puts you in a reactive mode. Extensive experience with this mode in controversial projects shows that it is hard to clamber back to a neutral position, let alone a positive one. It is also hard on staff and political connections, and takes up more time and resources than a planned program would require.

The recommended approach is to plan for public involvement as an integral part of the program planning, just as you plan for necessary technical studies, analyses, and decisions. Determine up front where public involvement will work, where public information will be needed, and how public input will be considered and documented in program decisions. Only you can tell exactly when the right time is to "go public" with plans, information or decisions, but research shows that earlier is better. It is neither necessary nor wise to wait until you have all of your facts and figures in hand. Work done on risk communication by Peter Sandman and colleagues of Rutgers indicates that "What an agency views as scientific caution, the community may see as a "cover-up" or as bureaucratic intransigence."(3) Techniques are available for addressing incompleteness of information, technical uncertainty, and consideration of options. What has not been identified are effective techniques for winning back public trust when it appears to have been violated.

By creating an entire public process context for your program, you will be better equipped to address each discrete stage, each problem, and each brush fire. A problem that evolves on the project can be addressed in the context of the overall relationship with all relevant stakeholders, with a protocol and established relationships that contribute to its success. It is the difference between being proactive or reactive, and most people are much more comfortable with being prepared.

RESULTS - IS IT WORTH THE EFFORT?

More than a decade of difficult and failed controversial projects attests to the sensitivity of environmental issues today. Whether public involvement per se can make the difference is not clear. For example, the National Governors' Association studied siting success for hazardous waste treatment and disposal facilities. They saw no absolute link between public involvement and permitting success, but found that public participation in some form was associated with most successful sitings in the study (forty of fifty-three). They echoed the concept described earlier, citing that it is not the quantity of public participation that matters, but the quality. "A single, effective element of public participation may be the key" (4).

Thus, assessing the effectiveness of public participation is also important to future planning. Techniques for surveying, interviewing participants, and otherwise evaluating the process overall are recommended periodically and at the end of remediation programs. Successful techniques, approaches, and people should be noted, with problems analyzed. Only by

so doing can future programs be tailored specifically to the program and public needs that pertain.

CONCLUSIONS

Like health and safety training, quality assurance and control, program scheduling, and other elements of a remediation program, public involvement can also become a natural, non-mysterious part of the environmental remediation work plan. Like those elements, though, it only works when it is undertaken with sincerity, commitment, and scrutiny. It should be driven by the overall objectives of the project and planned as carefully as they are.

When we started down this road, we thought that providing public information about our processes and solutions was enough. We moved on to design processes where people could participate more actively, at least commenting on decisions and products. Dialogue was established in ways it had not been in the past. We still face opposition, and must admit that sometimes our commitment to actual public involvement has been less than sincere.

The waste management industry is made up of a lot of experts in many things. People become project managers and program directors because they are especially good at technical work. We are realizing that there is not necessarily anything wrong with our technical work, but most of the roadblocks we face cannot be surmounted by more and better technical work. There is no reason that our best technical, management, and policy minds cannot also excel at human relations, helping all of us achieve important environmental goals. As we struggle with how to communicate with "non-technical people" about risk, let us also struggle with simply how to communicate with people. It is necessary to achieve public confidence, and we must accord it the importance and priority it deserves if we are to reach our overall environmental objectives.

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EFFECTIVE OUTREACH IS GOOD PUBLIC POLICY

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ABSTRACT

Effective public outreach is good public policy. Effective outreach is defined as a proactive attitude, not a function. The attitude must be infused through the organization by enlightened management role models.

Effective outreach can be especially difficult if issues involve complex science and human emotions, including general distrust of science and scientists and government secrecy.

The U.S. Department of Energy (USDOE) must win and keep public confidence if cleanup at the Hanford Site and at other nuclear defense facilities is to succeed. Candor, clarity, and timeliness in public information and involvement are essential to USDOE's success.

BACKGROUND

Outreach describes an attitude, not a function.

The traditional public information attitude is reactionary -- "we'll decide you get it only after you ask for it."

Effective outreach is instead, a proactive attitude. Effective outreach takes the position that "this is information the public needs to know. Let's get it out now in a clear and understandable way." Or, "let's be prepared to answer this question with candor and clarity."

Edward R. Murrow once said, "to be persuasive, we must be believable. To be believable, we must be credible. To be credible, we must be truthful."

Credibility is the product of trust. Trust does not come easy. Trust is earned. No trust, no credibility.

Effective public outreach is a dynamic combination of commitment from the top down. Unfortunately, that commitment to proactive candor may not only begin at the top -- sometimes it seems to end there as well.

In a bureaucracy, commitments often seem to dissipate in direct ratio to the layers of management they must penetrate. The boss may be a born-again true believer. But a worker bee six layers down is in a position not just to resist but to thwart his agency's conversion from a closed bureaucracy to an open one.

Take, for example, the U.S. Department of Energy. For years, USDOE skulked about the dark, outer fringes of believability. Laurence Peter, author of 'The Peter Principle', among other books, once wrote that "the credibility gap is so wide that our suspicions are confirmed by any official denial." He could easily have been writing about USDOE.

When Admiral Watkins arrived at USDOE, he took the bridge, surveyed his battered and tattered flagship, and called all hands on deck. He told his crew that tough times were ahead. They would need citizen support and confidence to achieve difficult missions. From now on, the Admiral declared, the U.S.S. Department of Energy will cruise along the Coast of Candor, through the Straits of Straightforwardness, steer clear of the Shoals of Secrecy, and sail forth on the Sea of Sincerity. The keystone of this new corporate culture, according to the Admiral's public relations people, was to win public trust by admitting mistakes and doing better.

But there's subtle evidence that this philosophy has not received a universal blessing throughout the ranks of USDOE and its contractors.

Take the case of the Hanford Process Review. This document is an inventory of over 100 accidents on the Hanford Site -- all of which were previously documented, but never before compiled in one single report. Richland took the Admiral seriously and was poised to do the right thing -- release the Process Review -- warts and all.

And what happened? Somebody got cold feet. Headquarters pulled back the Process Review on the notion that it has to undergo historical purification before the public can read it.

So much for the Admiral's new culture. So much for credibility. So much for trust.

Fortunately, what was once a pattern is now an exception.

It is encouraging to see evidence at Hanford of the "new culture" that Admiral Watkins has proclaimed. And it is evident here. But the progress made by those who embrace this philosophy is still undermined by troglodytes who drag their heels at any attempts to change from USDOE's old, secretive, self.

Most of the people at Hanford who work for Battelle and Westinghouse and USDOE are doing the right thing: working to serve the best interests of good public policy through your public information attitudes and products.

To achieve the difficult missions ahead at Hanford, that attitude must flourish. USDOE must earn and maintain public confidence if it is to continue to fund the massive cleanup program that lies ahead. The only way to earn and maintain that public confidence is through candor, clarity, and timeliness in public information and involvement.

The Hanford Environmental Dose Reconstruction Project offers some important lessons in public outreach. When the Technical Steering Panel began the process of directing the project, Battelle provided the Panel with a workplan and other Project documents. These documents, the public and media were told, were not publicly available because they were draft documents.

Understandably, change was demanded. Immediately.

Here we had a project which was initiated because of the concerns of the public, financed with public funds -- and a document as basic as a workplan was withheld from the public.

The message from the public and the media was that a credible scientific study was not enough. Of equal importance, was the responsibility to involve the public in the process -- every step of the way.

Not all of the Technical Steering Panel members were convinced. But under the leadership and encouragement of Dr. John Till, the Chair, and Mary Lou Blazek, the Vice Chair, the open way the Technical Steering Panel now conducts business is setting new standards for public involvement and candor.

Another example is the work of the Oregon Hanford Waste Board and Advisory Committee.

After Hanford was eliminated as a potential site of the nation's high level nuclear waste repository, it became clear that Hanford clean up would likely involve transport of nuclear weapons waste. In all likelihood, some or much of this waste would travel through northeast Oregon, along Interstate 84.

In 1988, Oregon's newly created Hanford Waste Board marshalled public support for safe transport of nuclear weapons waste in the state. The Board's Advisory Committee was given the task of soliciting and responding to public concerns. The Committee and Oregon Department of Energy staff conducted eight public meetings in four route communities.

The Committee relied heavily on input from these meetings in writing a set of transport safety recommendations which were presented to USDOE. After some negotiation, USDOE's transport Safety Plan now accommodates all but one or two of those recommendations.

The public in these communities know their concerns were heard. The State proved itself an ally in seeing that these concerns were not ignored, but instead, were addressed. As a result of this process, the public in these communities now have ownership in the waste transport project.

If you're going to spend tax dollars on work like the Dose Reconstruction Project or on Hanford cleanup, be prepared to operate on a different plane than you do on classified government projects and work for private clients.

Why? Because your audience is also your boss.

Communicating honestly and candidly with the public must include clear and understandable writing.

One of the hardest things for technicians who are new to public exposure to learn is that it is no longer acceptable for them to write just for each other.

Taxpayers, for the most part, are not technical experts. They have a low tolerance for jargon, doublespeak and bureaucratic rhetoric. And they know it when they see it.

At the Oregon Department of Energy, clear writing is one of our corporate values. When you write for lay readers your writing will be understandable to someone who reads comfortably at the eighth to tenth grade level -- the same writing standard used by Newsweek and Time. That includes every topic from nuclear physics to wall insulation.

And it can be done.

With the support of colleagues in Olympia, Richland, and at Battelle -- and from Dr. Till in particular, most of the Dose Reconstruction Project's Technical Steering Panel are now convinced that they must write for the public, not each other.

It was not easy. But it was vital. And it's paid off.

Effective outreach does not mean that there is an expectation that you should divulge either government or private secrets to accommodate public curiosity. However, we must not be tempted to extend those legitimate constraints to other kinds of information because the revelation might be inconvenient, embarrassing, or misunderstood. The public's right to know almost always takes precedence over our wish to not be inconvenienced, embarrassed, or misunderstood.

Doing the right thing -- like being virtuous -- must often be its own reward -- and a skimpy one at that. While candor and forthrightness may indeed be virtues, they guarantee nothing. News reporters will always be or always should be suspicious and skeptical.

The last thing you want to happen is a war with the news media and the public. For one reason, nobody wins. There's an ugly standoff that wastes a lot of time and energy and money and leaves nothing but bitterness and distrust.

USDOE and the news media will probably never be great chums. And there will be public activists who always will question everything they say, including their version of the time of day. Is that bad? No, that's healthy. The Lord blesses us with worthy adversaries.

So what's the payoff?

Consider this. A high regard for the public's right to know is not just good public policy. It's good business. A company, or an agency, that plays fair and square with the news media and the public is far more likely to have a good corporate image than one that doesn't. We do not have to look far to find an institution that is struggling mightily against a negative image.

Mark Twain said: "Do the right thing. You will please a few people and surprise a great many."

That's good advice.

HOW PUBLIC ISSUES SHAPE ENVIRONMENTAL RESTORATION PLANS - EXPERIENCES WITH COLORADO UMTRA PROJECTS -

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ABSTRACT

Federal environmental restoration plans are being significantly impacted by "grassroots" public pressure and by community demands, some of which have little relation to the technical standards of remediation and which go well beyond authorizing legislation. These demands often represent significant additional project costs.

A review of Uranium Mill Tailings Remedial Action (UMTRA) Program experiences in Colorado suggests that the more serious "grassroots" issues associated with remediation rarely diminish and, in fact, will intensify over time. This presents program administrators with the dilemma of attempting to adhere to program mandates and keep projects within budget, while at the same time trying to be responsive to community concerns.

Such high-profiled community debates have the ability to delay remediation and even jeopardize important projects. After prolonged public debate, when it becomes clear an issue will not dissipate, project officials may be forced to meet certain community demands. Often, this results in not only increased costs, but a loss of public confidence in clean-up efforts.

Evidence also suggests, however, that when critical public issues can be identified and addressed before they become overly contentious, significant problems and controversy can be avoided; but, the situation is made difficult because project officials often lack the policy guidance to determine which, if any, community demands should be addressed and to what extent they should be met.

The adoption of several key public policy principles by program administrators will provide a greater ability to address community demands in a timely and successful manner.

INTRODUCTION

The Uranium Mill Tailings Radiation Control Act (UMTRAC) of 1978 (PL 95-604) grants the Secretary of Energy the authority and responsibility to perform such actions as are necessary to minimize radiation health hazards and other environmental hazards caused by inactive (Title I) uranium mill sites. The U.S. Department of Energy (DOE) is meeting this responsibility through the Uranium Mill Tailings Remedial Action (UMTRA) Project. The program involves the surface stabilization of 24 uranium mill tailings piles in ten states and on certain Indian lands and the restoration of contaminated groundwater at affected sites. The Act also directs remediation of off-site properties that have utilized tailings in construction. Congress mandated that these sites and contaminated properties be remediated in a joint effort with designated states in a ninety percent federal and ten percent state cooperative commitment.

After years of discussion and debate, Congressional passage of PL 95-604 recognized the responsibility to "minimize radiation health hazards and other environmental hazards" caused by inactive uranium piles. Congressional intent underpinning the UMTRA program was straightforward -- to minimize human exposure to radiation from inactive uranium mills supporting this nation's nuclear weapons program during the 1940s and 1950s, as well as from their nearby contaminated "vicinity properties." What Congress did not anticipate in 1978 however, was the extent to which local public pressure would impact the mill tailings remediation mission by interjecting a number of community demands ranging from alterative site preferences to debates related to the mode of transporting tailings to permanent repositories. Many of these grassroots demands went beyond the mandates of PL 95-604 and virtually all represented additional program costs.

The Colorado Experience

The Colorado UMTRA Project provides an excellent case history of the significant influence which community concerns and demands can have. In Colorado -- the UMTRA state with nine Title I sites -- public demands, many of which went well beyond the goal of meeting radiological health standards, put UMTRA officials in the awkward dilemma of trying to contain project costs while being responsive to local citizens and officials. Program administrators implicitly understood their responsibility to maintain good relations with site communities, but at the same time they were also obligated to seriously consider their legal and fiduciary responsibilities.

It is commonly understood that public opinion cannot always be honored and that from time to time, government officials must make difficult and unpopular decisions. And therefore, many involved with the Colorado UMTRA project anticipated that community demands that were clearly beyond program goals would be rejected. But programs such as UMTRA, involving state matching funds and state and/or local permits, create more complicated situations. These factors give local communities informal, but nonetheless, enormous influence over federal remediation projects. State officials are reticent to appropriate matching funds when local constituents have registered vigorous complaints about a project. And, it's equally obvious that locally elected officials can be expected to use their county and city land use processes to leverage certain community demands against federal

remediation projects. If this were not enough, sympathetic members of a states congressional delegation can often be expected to pick up the banner of local concern.

Thus, community concerns and demands, regardless of their justification, can have the practical effect of substantially increasing project costs and even compromising the completion and success of remediation.

The situation is exacerbated by the fact that program officials must operate in a "no man's land" of public policy. Because of the separate and unique concerns of individual communities, it is difficult to develop policy guidance beyond existing law which can universally help solve such dilemmas.

The Colorado UMTRA Project demonstrates that officials properly support lowest cost alternatives that will achieve technical standards of minimizing human radiological exposure. They naturally resist more costly project additions that do not improve the technical merits of the project. In many cases, issues are raised by narrow interests and they never reach a level of sufficient public concern to threaten project integrity. In other cases however, public concern does escalate and issues become major emotional and policy considerations. In these cases, regardless of legal and regulatory constraints, the project's inability to meet local demands invites further controversy and may inadvertently jeopardize the project. Very simply, project officials feel caught in the dilemma of either making a mistake by saying "yes" and thereby driving up costs, or making a mistake by saying "no" and creating public controversy which may also increase costs and invite a battle regarding state funding and local permitting.

Examples gleaned from the Colorado UMTRA Project provide vivid examples of this dilemma. In the early 1980s the project was caught in a public debate as to whether contaminated tailings would be "stabilized in place" at major sites or removed to permanent new repositories. PL 95-604 did not address these options, but project officials assumed that material would be stabilized in place unless it was found that remediation standards would be compromised. From the beginning however, state and local officials indicated they would not support remedial action plans which failed to remove tailings from their present locations, which for the most part were prominent along certain river banks. To these officials the issue went beyond health and safety and focused on land use considerations and community reputation. They reasoned that if the DOE and State of Colorado were going to spend substantial funds to clean up inactive mill sites, they wanted local jurisdictions to receive a "clean bill of health" by having the material completely removed from tailings areas.

Federal project officials understood the "generic" concern of state and local officials but believed they could not make a program-level decision to remove tailings from major sites. They were therefore, dependent upon site-by-site cost analyses to determine whether redisposal would be costlier than stabilization in place. This lengthy process created a prolonged period of hostility between state and federal project officials, which infected virtually every major policy discussion related to the Colorado UMTRA Project. At one point Colorado officials even considered the potential of "taking over" the UMTRA Project.

Eventually, the alternative remediation dispute was resolved when DOE contractors demonstrated that the costs of stabilization might be higher than the cost of redisposal. This finding was based on the level of engineering demanded to stabilize mill tailings in the event of major flooding. While the technical site evaluation process ultimately delivered a policy answer which met local community needs, it was not without both financial and political costs. The financial costs of developing technical data upon which "removal" options were eventually based, were overshadowed by the uncooperative and hostile intergovernmental climate resulting from this fundamental policy dispute. And ultimately, Governor Richard Lamm and DOE Albuquerque Operations Manager Ray Romatowski met in December 1985 to resolve outstanding policy disagreements and renew the Colorado-DOE Cooperative Agreement.

Stepping back from the dispute, it is easy to see that the issue was a "deal breaker" for the State of Colorado and that it would have never appropriated its ten percent share of remediation funds if "stabilization in place" would have remained the federal preference. Reaching an intergovernmental agreement on this crucial matter earlier in the process would have avoided years of controversy and lack of trust.

Another high profile example of how public concern had a major impact on the UMTRA Program involved the method of transporting mill tailings from downtown Grand Junction to a final repository at Cheney Reservoir, a distance of some eighteen miles. The local community had long opposed transporting tailings by truck because of perceived safety and community disruption impacts. The Denver and Rio Grande Western Railroad proposed moving tailings by train, an alternative which gained increasing support during the late 1980s. However, based on technical analyses performed by the technical assistance contractor, Jacobs Engineering Group, DOE concluded that the train option would at be significantly more expensive than the truck option. A major reason for the cost differential was the fact that rail lines did not extend the entire distance to the disposal site and therefore, the contaminated material would have to be transferred to trucks for the final seven miles of their trip to Cheney Reservoir.

In December of 1986, DOE issued a Final Environmental Impact Statement stipulating the removal of tailings to Cheney Reservoir by truck as the "preferred alternative." However, public concern regarding truck traffic continued to build and a strong consensus emerged favoring what became known as the "train/truck" option. DOE and the State of Colorado, having strong technical evidence to believe the truck hauling option was not only feasible but significantly less expensive, felt compelled to stand their policy ground. As a result, the train/truck versus truck-only dispute raged for exactly three years. During that time, the issue became increasingly more controversial. The transportation issue became tangled up in Mesa County's conditional use permitting process. It attracted the involvement of Colorado's Congressional delegation, local legislators, the Governor and eventually the Secretary of Energy.

In the end, the State and DOE selected the train/truck mode, but only after the $14 million cost "delta" between this alternative and the truck-only option was reduced by $9 million through requirements placed on trucks by the Mesa County conditional use permit. While the local community was relieved that the "correct" decision had been made, substantial additional project costs were incurred and poor relations among UMTRA officials and the local community took their toll.

When considering the Grand Junction train/truck example, an important question is whether such an escalation of public concern could have been better anticipated and the issue earlier resolved. That question is not easily answered because over the course of the public debate, Project officials were successful in convincing two of the three Mesa County Commissioners and the editors of the local daily newspaper, the Daily Sentinel, that the cost differential of $14 million could not be justified in order to move tailings by both train and truck. This led those associated with the project to conclude that truck transportation would eventually be accepted. But as is most often the case, elected officials must bow to the demands of their constituents. And when support for the train/truck alternative continued to build, the commissioners did the logical thing of making the truck option more costly.

The ability to have anticipated this level of public concern and to have avoided three years of controversy would have been extremely beneficial for all parties involved with the Grand Junction project.

Importantly, community interests do not always imply a negative impact on remediation projects. When properly identified and woven into the clean-up agenda, they can have very positive effects.

Two strong examples emerge from the Colorado UMTRA Project. State Legislators were generally skeptical about the UMTRA Project because they did not view tailing piles as posing inordinate public risk and thus openly questioned whether the financial costs were justified. Understanding this, project officials crafted the dual message of environmental health and economic benefit to develop support for the UMTRA Project. Economic concerns were particularly acute in Colorado during the mid-1980s because of the collapse of oil prices. Therefore, the demonstration of economic benefits associated with UMTRA would be the key to success in the state legislature.

This "demonstration" was accomplished in conjunction with the Durango UMTRA project, Colorado's first site to be environmentally restored under PL 95-604. In summary, an "UMTRA jobs pool" was established in Durango under the auspices of the Governor's Job Training Office. With the assistance of UMTRA contractors, unemployed and underemployed local workers were qualified into the pool from which a project labor force was eventually selected. The prequalification and pooling process discouraged unemployed workers from coming to Durango to seek UMTRA work and encouraged contractors to select a local workforce. The result was that 95 of the 115 UMTRA jobs created in Durango went to residents of the local area. This integration of concern for local jobs into the UMTRA program resulted in strong loyalties in the legislature and continued state appropriations.

A second example involves the Grand Junction project, in which the UMTRA mill site was located adjacent to land that being acquired by local officials for a major greenbelt and urban park. PL 95-604 would obviously not allow UMTRA funds to be used for park facilities. However, close cooperation between the Riverfront Park project and UMTRA officials will allow for the mill site to be physically reclaimed, contoured and diked in such a manner that the site can easily and inexpensively be integrated into the park system upon UMTRA Project completion. This integration concept has been memorialized in Mesa County's conditional use permit bringing some formality and confidence to the arrangement.

We have learned that high-profile local issues can develop a public life of their own and can have a major impact on environmental restoration projects. Although strongly held local views are often contradicted by clear technical evidence, some nonetheless develop sufficient political clout and dominate the public policy discussion. Thus, they must be addressed in order for remediation projects to succeed in local communities.

In order for such extraordinary issues to be identified and successfully engaged, a number of public policy principles should be considered.

PRINCIPLES OF PUBLIC POLICY

Principle #1 The Significance of Community Opinion Should Be Recognized

Fundamentally, federal and state officials must recognize and accept the fact that issues outside of the strict program scope can have a direct program impact and therefore, must be addressed.

The instinct of project officials will almost always be to resist community demands, particularly those which are beyond program mandates and standards. However, the record is clear that certain public policy disputes have the ability to seriously impact remediation projects. And, it is equally clear that when an issue emerges to the point of jeopardizing a project, officials nearly always attempt to retrieve the situation. Thus, from a practical standpoint, the issue is properly identifying "deal breaking" issues and properly handling them, not whether they are proper to engage.

Principle #2 The Importance and Impact of Public Pressure Should Be Anticipated

The fact that local community pressure will play a role in project decisions, must be anticipated and discussed among federal, state and local officials. Candid discussions should be held regarding the costs of add-on program features, the costs of project delay and the costs of having unnecessary policy disputes dominate public attention. It is most effective to discuss these public policy issues and how they will be handled in the "abstract" before an actual dispute has polarized parties.

Principle #3 Remediation Projects Should Be Monitored to Identify Major Policy Disputes

Federal and state officials, having significant program and policy responsibilities, should continually monitor local issues to identify those which may present significant difficulties to the Project. When these are identified, they should be openly discussed among responsible parties. Above all, there needs to be accountability for positions advocated and actions taken. The primary issue becomes which issues should be "legitimized" and which should be left to their own devices? The obvious answer is that those which will escalate should be engaged and those which will not should be ignored. The key of course, is being correct in this identification and analysis.

While predictive analysis is fallible, there are several useful "rules of thumb" to consider. First, determine whether the issue "at hand" is one which easily allows the public-at-large to have a personal point of view. For example, a debate regarding whether "site A" or "site B" is more suitable may not elicit a strong personal opinion. But issues relating to transportation, water and the economy are the type which result in

strong personal opinions. Disputes which center upon these personally "validated" issues will likely accelerate over time, not diminish. Further, one can make reasonable judgments by observing who supports a particular point of view. If those advocating a certain position are key "opinion shapers," then the issue is also likely to accelerate.

Principle #4 Project Officials Should Be Encouraged to Engage Community Issues and Intervene Before They Become Out of Control from a Policy Standpoint.

The evidence is clear that major community controversies will not dissipate by ignoring them. Issues having significant emotional content and those which "connect" with strong and basic community values have the ability to completely sidetrack a remediation program regardless of whether they expressly relate to "project standards." These issue should be engaged early in the public process and should not be allowed to fester into major controversies.

Principle #5 Leadership and Accountability Must Be Instilled at all Project Levels.

In order to keep a project on track strong leadership and accountability must be sought from federal, state and local officials. That is, officials should be allowed to intervene in policy disputes at an early date. At the same time however, they must demonstrate a certain "toughness" and leadership to resolve policy disputes and to hold their individual entities accountable to follow through on decisions that must be made.

In conclusion, environmental remediation projects are significantly impacted by factors, such as public opinion and community pressure. Rather than ignoring key policy issues and allowing them to accelerate into major disputes, they should be properly identified and engaged early in the process in order to prevent an erosion of public confidence in the clean-up program.

FUTURE SITE USE AND CLEANUP STRATEGY ALTERNATIVES: THE HANFORD APPROACH

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ABSTRACT

Nuclear weapons materials production is no longer the mission of the Hanford Site, a 560-square-mile area in southeastern Washington's Columbia Basin. Environmental remediation, including removal of radioactive and hazardous contaminants, waste management and disposal, decommissioning of old facilities, and restoration of land and groundwater, has become the site's major mission. The mission is conducted within the framework of the Tri-Party Agreement between USDOE, USEPA, and the State of Washington. There is broad public interest in cleanup and the future of the Hanford Site. A facilitated process to develop alternative future use and cleanup scenarios is about to begin. The process will introduce some traditional tools of land use planning alongside environmental regulations and cleanup technologies in order to develop an integrated vision. Many interests, including local governments, Indian Tribes, state and federal agencies, business, agriculture, labor, environmental, and recreational groups will be involved. It is hoped a widely shared vision of the site's future will both guide and sustain support for cleanup and restoration.

BACKGROUND

The Hanford Site, a 560-square mile complex located in south eastern Washington State, was operated from 1943 to 1989 by the U. S. Department of Energy and its predecessor agencies for the production of nuclear materials for national defense programs. Radioactive, hazardous, and other wastes have been disposed of in or discharged to the air, soil, and water at the site. Large portions of the soil and groundwater underlying the site are contaminated. Numerous operating and retired facilities, most of which contain some residual radioactive or hazardous material, remain at the site. With the completion of its nuclear materials production mission, the attention of all those concerned with the site has shifted to waste management, cleanup, environmental restoration, and potential new missions.

The Hanford Site covers a semi-arid, varied landscape of the Columbia Plateau. (See Fig. 1.) It straddles the Columbia River to the north and northeast. The river becomes the eastern site boundary. On the south, it is bounded by the lower Yakima River Valley and the City of Richland. Further to the west, the Rattlesnake Ridge separates the site from the Yakima Valley. Prior to 1943, indigenous peoples moved through and camped in the area for many hundreds of years. Some landmarks, like Gable Mountain, now near the center of the site, were spiritual centers for them.

When white settlers came, the area was "ceded" by Indian tribes and nations in the Treaties of 1855, however, the tribes retained customary usage and possessory rights. White settlement within the boundaries of what became the Hanford Site was never large; but a railroad came into the area from the north, irrigation projects were developed, and prosperous farming communities sprouted at Hanford and White Bluffs, in the northeastern part of the present reservation, and Richland, at its southeastern corner.

The Hanford Site came into existence during World War II. In March of 1943, to make room for nuclear materials production, the federal government condemned private holdings, withdrew public lands, and relocated the area's residents. Farms and villages were simply abandoned. A massive construction project began. Eventually, nine production reactors, several plutonium and uranium recovery plants, laboratories, waste storage facilities, roads, railroads, and other ancillary facilities were developed. Tens of thousands of military and civilian workers came to the site.

In the 1960's and 1970's, a few non-defense related activities developed on the Hanford Site. An arid lands ecology reserve was designated along the southwestern border, which is on the eastern slope of Rattlesnake Mountain. Secured land north of the Columbia River became a wildlife refuge. A commercial low level radioactive disposal site was opened near the reprocessing areas in the middle of the site. The commercial Washington Public Power Supply System's nuclear reactors 1, 2 and 4 were commenced to the southeast. Nuclear Plant #2 is in operation. The Fast Flux Test Facility was developed nearby. (See map, Fig. 1.)

With the cessation of nuclear weapons material production and the region's and nation's increased focus on environmental restoration, the future of the site is evolving as a major focus of public discussion. What about the activities and rights that were so abruptly terminated in 1943? Are there new missions that can capitalize on the physical and human resources accumulated over the last 50 years? Do the large, relatively unspoiled tracts of land provide a unique opportunity to protect habitat and provide recreational opportunities? Can land be put "back on the tax rolls" in productive use that provides community services? Is the site so

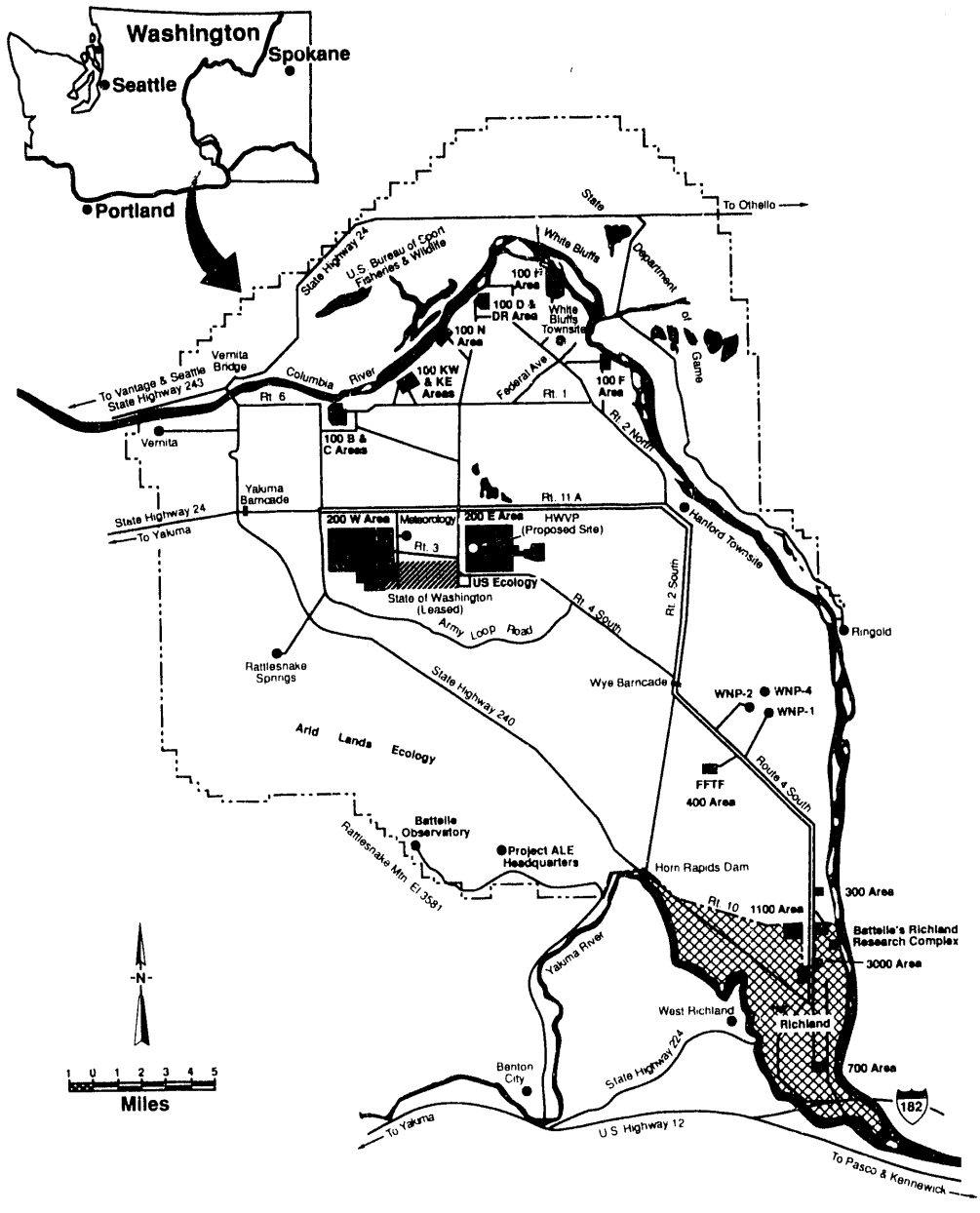


Fig. 1. Hanford site.

contaminated--or at least parts of it--that it can never be used for other purposes?

CLEANUP AND FUTURE SITE USE

The Tri-Party Agreement

The framework guiding environmental cleanup at the Hanford Site is the Hanford Federal Facility Agreement and Consent Order, usually called the Tri-Party Agreement. In May of 1989, the U.S. Department of Energy, the U.S. Environmental Protection Agency, and the Washington Department of Ecology signed this landmark agreement, establishing milestones and schedules for cleanup. The agreement is principally based on state and federal hazardous and dangerous waste laws and regulations.

The three parties to the agreement soon recognized the need to develop a vision for the future of the Hanford Site that will help define what is adequate cleanup under its terms. The answer to "how clean is clean enough?" at Hanford will depend on several things: hazardous waste and other environmental regulations, technologies available, and future land uses. Proposed future land uses will affect decisions, for instance, about isolating contaminated soils in place or excavating, treating, and moving them.

What Future Site Use Planning May Add To Cleanup

Planning for potential types of uses at Hanford is especially appropriate now, as the site's mission has changed from defense materials production to environmental restoration. An integrated planning approach will address the natural environment, the availability of water, power, and transportation, existing uses and development, cultural resources, existing legal rights and obligations, available cleanup technologies, and regulatory requirements.

Future site use planning will use some traditional tools of land use planners to make this integration possible. Traditional land use planning focuses on such key areas as protection of natural systems, like aquifers and riparian zones,

supply of land for socially desirable purposes, availability of public services, and benefits of the already-built environment.

Land use planning approaches also emphasize desirable "process" features. The process itself is visual. It enables participants to relate visually to complex physical information about what's "on the ground" and to how desirable futures might look.

Traditional land use planning is also respectful of stakeholders. It gives plenty of opportunities for input to people who have legal, financial, community value, or other interests--property owners, government agencies at all levels, neighbors, tenants, economic and environmental interest groups, and so forth.

Finally, land use planning tends to break broad, abstract issues into many smaller, concrete ones. In a land use planning process, one moves from broad questions of "to build or not to build" in a large area, to much less sweeping questions of to build what specific kind of thing, where, and in what relation to what is next to it. By balancing many interests in answering many small questions, a land use planning approach encourages identification of common or overlapping interests, early settlement of non-contentious issues, and "give-and-take" approaches by all participants.

The Tri-Party Agreement signatories hope that instituting a future site use planning process, using some of the precepts of land use planning, will augment the environmental cleanup now underway. It may be that the process, as described below, will develop a positive stake in the outcome for many players. A rich and complex vision of Hanford's future will provide more momentum for cleanup and environmental restoration than either fear of contamination or the threat of legal penalties.

The First Step: Future Site Use Alternatives

Consultations with local governments, Indian Tribes, and other state and federal agencies in the latter part of 1990 indicated strong interest in moving ahead with a future site use planning process. There is strong feeling among local government officials that the process must be complementary to their land use planning under Washington's new Growth Management Act. By law, it must also be related to the congressionally-mandated study to recommend future management options for the "Hanford Reach of the Columbia River."

The initial development of a future site use vision, or strategy, will occur as part of the Hanford Remedial Action Environmental Impact Statement (HRA-EIS). The purpose of the HRA-EIS is to address the complex issues associated with cleanup of about 1100 waste sites at Hanford. The development of the future site use/cleanup strategy as part of this EIS will also provide a framework for many future decisions related not only to cleanup, but to future development at the site, placement of potential future facilities, and potential disposition of land for non-USDOE users.

Preparation of the EIS will use extensive public involvement to establish reasonable alternatives for the future site use/cleanup strategy. It is envisioned that the strategy will consist of two parts--the overall cleanup strategy and the future site use categories. Each part will consider the entire Hanford Site by major geographical area.

Cleanup strategies considered for each area may include: stabilization in place of contaminants, with or without groundwater monitoring; removal to onsite waste treatment and disposal facilities; and removal to off-site repositories. Site use categories may include unrestricted, restricted, or exclusive, depending on the hazard left in the soil or groundwater.

At the request of the local government, agency, and Tribal officials consulted earlier, the three parties to Hanford Cleanup Agreement have just retained a neutral facilitator to organize this process to develop future site use alternatives and cleanup strategies. The facilitator will recommend to the "organizing committee", (a small group of officials who gathered earlier,) how to form a broadly based working group, including local government, business, labor, and agricultural interests, tribes, environmental groups, and other interests.

The facilitator will work with these groups to help them define how best to identify and evaluate future cleanup strategies and site use scenarios, as well as how best to take account of the concerns of the general public. Technical information and staff support will come from the three Tri-Party Agreement agencies. Development of alternatives to be considered in scoping for the Hanford Remedial Action EIS may be expected by mid-1992.

CONCLUSION

Hanford's site use planning will involve many interests and values, such as public agencies, tribes, local governments, land owners, economic interests, recreation, natural resources, environmental systems like wildlife habitat and aquifer recharge, and compatibility with surrounding uses. By accommodating a broad range of interests and dividing big issues and parcels of land into smaller ones, such a process can often identify scenarios that improve outcomes for all parties.

Federal, state, local, and tribal governments and other interested parties are just about to begin developing alternative visions for future uses at Hanford. There is widespread agreement that the process must be open and representative, and that a widely shared vision, if achieved, will motivate people and agencies to work together for cleanup.

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EFFORTS TO EARN PUBLIC SUPPORT AND CONFIDENCE IN HANFORD SITE CLEANUP WORK

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ABSTRACT

Public involvement is needed for Hanford Site cleanup to succeed. If people do not know about, understand, and support cleanup, it will be more difficult and expensive. The Tri-Party Agreement (1) calls for public involvement in decisions about cleanup options and schedules. This paper defines what public involvement means and how the Washington State Department of Ecology (Ecology), U.S. Environmental Protection Agency (EPA), and U.S. Department of Energy (DOE) have conducted it. Experience and survey research have shown ways to improve our performance. While we have improved our conduct of public meetings, we must identify other ways to involve the public. Efforts continue to open decision making earlier in the decision process, to share information that is clear and understandable, and to open the channels of communication. We have made good progress. We have many opportunities to continue to improve. This paper describes some of the highlights and lessons learned in public involvement in Hanford Site cleanup.

INTRODUCTION

Public support and confidence are key ingredients to successful cleanup of the Hanford Site. Without public and resulting political support, funding falls short and efforts are diverted from cleanup to organizational survival. Public support and confidence are necessary but not sufficient; also required are new technologies, good plans and management, skilled workers, and adequate funding. These too are necessary but not sufficient. They may engender support but they won't assure it. Technical and management challenges are daunting enough. Some may ask, "Do we really have to deal with the public?" The answer is yes. No longer can the government dismiss citizens' and leaders' concerns by invoking national security. Resources for cleanup are limited. Without vital external support, those limited funds will go to other national priorities rather than cleanup. We must earn the public's confidence and demonstrate to its leaders that we spend tax dollars responsibly.

PUBLIC SUPPORT AND CONFIDENCE THROUGH PUBLIC INVOLVEMENT

The Tri-Party Agreement

In recent years the Hanford Site has begun to face a great challenge. It must build new facilities and bring old facilities into compliance with new and complex environmental laws. It must clean up old sites with wastes from before this era of regulation and environmental awareness. The DOE and its regulators, the EPA and Ecology, formed an agreement to guide these cleanup efforts. This Tri-Party Agreement lays out the environmental problems according to their risks, sets a schedule for tasks to bring the site into compliance and defines participants' roles and responsibilities.

The agreement calls for public involvement in decisions about cleanup options and schedules. It upholds the public's right to be informed about and involved in Hanford Site issues. Tri-Party Agreement public involvement includes more than fulfilling regulatory requirements for comment periods and reading rooms. The agreement's community relations plan (2) calls for quarterly public meetings to explain to the public our progress and problems with cleanup, and to gather public comments. It calls for other public meetings when the three parties deem them necessary. It requires public review of major changes to the agreement. It requires public hearings on draft permits, if the public requests them. The goal of the three parties is to provide information and opportunities for involvement that meet the public's various needs and interests.

People get information on any topic from a variety of sources. The community relations plan is flexible. It allows the three parties to try new and creative public involvement efforts. Under the plan, all that is needed is for the three parties to agree.

1991 Public Information Survey

In April and May 1991, we conducted a region-wide survey. Its purpose was to help find ways to improve efforts to inform the public about Tri-Party Agreement cleanup activities. Some of the survey's findings surprised us. Fifty-one percent are somewhat or very interested in contributing to decisions about cleaning up the Hanford Site. But most respondents, 64 percent, think we don't want to involve the public in cleanup decisions!

The survey showed that most people got their information not from us, but from the news media. This fact isn't surprising. But it does renew our awareness of the challenge of allocating our efforts. We must determine how the news media gets its information and look for ways to improve. We may need to spend more of that limited resource talking with reporters to make sure they understand the issues... and know where to turn for information when they don't. These are the people the public listens to and trusts.

We spend tremendous efforts on public meetings. While feedback from the meetings generally is positive, few of those surveyed had ever attended one, and few listed it as something they would do to influence an issue they were concerned about. We are reassessing our use of meetings. They cannot serve as all things to all people, and shouldn't be expected to.

Implementing Public Involvement in Cleanup

Involving the public--integrating the views of interested and affected parties into Hanford decision-making processes--is a guiding statement of the Tri-Party Agreement's Hanford Site cleanup mission. Here is what that means.

We must identify the public's various needs and interests. One size does not fit all. We must recognize and identify our many publics. Their needs and resources vary. In the Tri-

Cities, for example, public meetings are largely attended by Hanford Site employees and consultants. They are mostly fluent in "Hanfordese;" they are more patient and likely to hear out the speakers, and their views on the Hanford Site differ markedly from those we hear further away from the Hanford Site. Even in the Tri-Cities, however, a citizen who attends a meeting may have just moved to this community. This person may not know a CERCLA from a LERF, and may think "TPA" refers to the traffic pattern altitude. Is a "vit plant" a new kind of legume?

We must understand that specific concerns vary depending on where a citizen lives. We have downwind, downstream, and down the road communities. Downwind communities have more concerns about past releases and airborne releases. Downstream communities are keenly interested in the discharges and impacts to the Columbia River. Communities down the road are more concerned about transportation of wastes. Economic impacts to the local community cannot be overlooked either.

We must communicate with the public about waste issues, what has happened, what is happening, and the plans for the future. The challenge here is to describe the bad news as honestly and willingly as the good news. We can't ask for credit for our accomplishments unless we openly describe our delays and setbacks and put both in perspective to overall cleanup.

In March the three parties--DOE, Ecology, and EPA--held public workshops to explain the proposed changes to the Tri-Party Agreement. While not the first changes, they were the largest in scope. They involved delays to major agreement milestones--delaying construction and operation of the plant to convert high-level liquid waste to glass, delays to the program to solidify low-level liquid waste into large blocks of grout, and delays to the plan to build a plant to test and package wastes before they are shipped offsite for disposal.

Hanford Site officials presented the programs, schedules, proposed changes, and the reasons for the changes. Changes were presented as driven primarily by technical requirements. In part, they were. The DOE official at the meetings acknowledged, however, that the technical issues also impacted the budget. This too was true, and it was harder to bring out. In retrospect, we could have done it better. The budget process was the issue many in the audience felt drove the change package. The budget issue should have been addressed head-on, not as a side issue.

We learned other lessons from the change package experience. We learned that delays in presenting information will be perceived as having something to hide. We learned that part-truths are seen as whole lies. We learned we must call things what they are, or credibility suffers. And we learned that public participation has to mean more than public meetings.

We must provide opportunities to increase public awareness of issues and access to information and key people. We have successes here. Our public meeting announcements differ from the standard Hanford Site ads, which look like enlarged legal notices. At the quarterly meetings we offer the usual fact sheets and information displays. We also provide space for watchdog groups to share their information. And, we schedule into the meeting time for informal discussions with the Tri-Party Agreement officials. They wear nametags, stand in the back of the room, and talk with anyone who approaches them. All public information materials give three information contacts. All materials list our information centers. For the Tri-Party Agreement we exceed the usual requirements. We have four information centers: (1) Tri-Cities, (2) Spokane, (3) Seattle, and (4) Portland.

We must develop and use ways for the public to express its views. We have built into meetings scheduled time slots for citizen input. We record public comments and provide project managers and the information centers with near-verbatim records. We require cleanup managers to attend meetings to talk with, and listen to, our citizens. We continue to look for other ways to reach people.

We must give feedback to the public on its questions and comments. Failure to respond to concerns is usually interpreted as not caring. Even when the public does not agree with an answer, we must demonstrate we considered it by giving a response. At present, each party answers the letters and calls received. Every effort is made to respond with the most information at the appropriate technical level. This often involves the participation of the technical people in the writing and calling of concerned individuals. We find this heightens their awareness of the public's concerns about cleanup, and makes them more understanding of these questions.

We must coordinate these activities with other public involvement activities on Hanford Site issues. People do not differentiate between current cleanup activities and past production. "Hanford" means many things to many people. It's important that as we go out to talk with people about cleanup, we know where to send them for more information on other Hanford Site issues, such as studies of radiation exposure from past releases, or plans to site new defense missions here. We often focus so intently on one activity at the site, we "can't see the forest for the trees." In this area we have improved somewhat, but we still have a way to go.

Above all we must consider the public's views in cleanup decision making. Recovering trust lost earlier due to secrecy means we have to "go the extra mile." The outcome of negotiations on DOE's proposed changes to the Tri-Party Agreement reflected some of the concerns we heard in the public comment period. We increased the number of enforceable milestones. The public called for us to study the impacts to the river. We will. The public called for us to involve regulators in the formulation of the DOE's request for funding to cover Tri-Party Agreement costs. We will. The public called for Ecology to take more control of the public involvement process. It will. We will continue to approach public involvement with a team approach, as three parties working together.

More About Meetings

Our emphasis on meetings stems from traditional government practices and our experiences with the Tri-Party Agreement. We have learned how to conduct better meetings through practice. And our recent survey has shown we must develop other ways to reach people. We have learned what works well and have identified a number of areas for improvement.

Past public interactions gave little opportunity for meaningful participation in decision making. Opportunities for comments were infrequent, usually only when mandated by law, such as public hearings required by the *National Environmental Policy Act*. In this environment most audiences were hostile and meetings were contentious.

The Tri-Party Agreement is based on decisions formulated in the High-Level Defense Waste Environmental Impact Statement (3,4) in 1986-1988. This was the most substantial public involvement effort at a DOE facility.

After the Tri-Party Agreement was signed, quarterly public meetings began. The process of conducting them becomes easier each time. The meetings are scheduled to end at 9 p.m. Usually project managers and support staff are involved in one-on-one meetings with the audience well after 10 p.m. These after-meeting meetings can be very productive in helping to define or clarify issues. They also enhance the credibility of the people involved in cleanup.

Tri-Party Agreement quarterly meetings receive mostly good evaluations from those who attend. Even at the most hostile meetings, the attenders indicate they have a better understanding of the issues. Just as importantly, they report they feel that the project managers wanted to hear what they had to say.

We hold "live" dry runs before we present information to the public. We do this to make sure the information is understandable. We are not weaned from viewgraphs, but we try to make sure they can be read from the back of the meeting hall. We continually work at speaking in English, not the unique Hanford Site dialect. We have made much progress here; in recent meetings, most of the "Hanfordese" came from informed members of the public!

Another key purpose of dry runs is make sure we will discuss what we think the public wants to hear, not just what we'd like them to hear. In this regard, we have made some progress.

We have used our meetings for too many purposes. We have tried to insert too much information into them. We intend to start focusing the meeting on current topics that people are concerned with, not just what we think is important. We'll be watching the news media more closely for the "hot topic" of the day. We are working to get away from someone else telling us what the "big deal" is, and facing issues head on. But we can also use meetings to tell people when what they're concerned about isn't a crisis. It's a two-way street, and we need to use all of it.

We are working to focus the meetings on fewer specific topics to be less confusing. We also are developing a video to be shown before the meetings to give people a background of what will be discussed. We've found that more than half the audience at any given meeting has never attended before. Many are confused about the Hanford Site, and become even more so when the discussion quickly becomes technical. Our recent survey showed that of those who believed they knew what's happening at the Hanford Site, 28 percent said "provides electricity," 12 percent said research, 12 percent said storing nuclear waste, and 9 percent said making nuclear weapons materials. Only 4 percent said cleaning up nuclear and hazardous wastes. We still have some work to do.

Cooperative Public Involvement Challenges

Bringing together three agencies with different perspectives and histories to implement public involvement has not been easy. It has been a long and involved process, but we are continuing to improve. A yearly plan will map out monthly activities under the overall community relations plan. Activities are assigned to the parties. For example, Ecology will exercise editorial control of the quarterly publication, the Hanford Update. It will serve as the contact point for public questions and comments. It will install a toll-free telephone line so people can call with their questions and concerns. That is the role the public asked the state to play.

Until recently the parties turned over much of the responsibility and decision making in public involvement to Westinghouse Hanford Company, the site operating contractor. While this had some advantages in terms of resources, it led to more serious problems. The public involvement process became a point of criticism, and the focus on process detracted attention from content the process addressed. In response to this concern of the public, EPA and Ecology have asserted more authority in public involvement decision making.

We have enjoyed some success. Hanford Site cleanup officials have received praise from their critics. We are learning to do business in a way that engenders public confidence and support. We are sowing the seeds of trust. With nurturing, that trust may grow.

CONCLUSION

After decades of secrecy and self-regulation, old habits die hard. Efforts continue to bring the public into the decision-making process earlier. We are working to retire the practice of withholding bad news. Our role is not to sell our programs. Our role is to give citizens and their leaders the information they need to form their own opinions. We are learning to admit when we make mistakes. Efforts continue to share information that is clear and understandable and to open the channels of communication, internally and externally. While we have made a lot of progress, we still have a long way to go.

We've learned we need to work together and be honest about our concerns with the process with the other parties and the public. It moves cleanup forward. We've learned that those individuals and groups we might want most to avoid are the ones we most need to be honest and open with. They can stop the whole show.

If people do not know about, understand, and support the cleanup of the Hanford Site, it will be more difficult and expensive. With public involvement we may not get the public's agreement with our decisions; what we need is public acceptance.

These measures will permit cleanup officials to make better decisions. They will allow the officials to make decisions that are publicly acceptable. These measures will create public confidence that we are doing this work well, and strong broad public support for resolving Hanford Site waste issues.

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ROCKY FLATS COMMUNITY RELATIONS "COMING OUT OF THE DARK"

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ABSTRACT

Community relations is becoming an increasingly prominent aspect of the environmental restoration business. Historically the DOE has been closed to public scrutiny, dating back to the origins of the weapons complex in the Manhattan Project. Rocky Flats community relations can be viewed as having its painful start on June 6, 1989, when over fifty FBI agents entered Rocky Flats to gather information on alleged operational and procedural violations of environmental law. The Plutonium Recovery Modification Project (PRMP) was the first initiative to hold public meetings and provide for real dialogue in May 1990. Building on this start, the last year has seen a phenomenal growth of Rocky Flats community relations activities, now averaging over one public forum of some kind per week. We believe the effort has been very successful in building understanding and credibility within the local community. Although community relations is not a panacea, neither is it an ogre. Community relations for environmental restoration is mandated by law, and for good management is a necessary part of the DOE for the 1990's and beyond. Properly utilized, it can augment an ongoing environmental program and help smooth the road to success.

INTRODUCTION

Community relations is becoming an increasingly prominent aspect of the environmental restoration business. The requirements of the National Environmental Policy Act (NEPA) and Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) mandate public involvement. Recent Rocky Flats experience also has shown that the public does have a real impact on the Department of Energy (DOE) decisions, making a meaningful dialogue with the public critical to maintaining the necessary latitude in our decision process. Rocky Flats has discovered that public dialogue is continually challenging, but can be made to be a productive process which supports rather than confounds the goals of the DOE. With that realization, Rocky Flats is coming out of the dark into a new age of community relations.

THE PUSH FOR PUBLIC INVOLVEMENT

The need for solid community relations continues to increase in importance for environmental restoration activities. The elected representatives at the state and local level are asserting their authority and severely impacting DOE activities nationwide. These impacts are most obvious in the environmental and waste areas. Most notable are the actions by Governor's of Idaho and Nevada to block shipments of wastes to DOE repositories within their state boundaries. While these actions have questionable legal basis, the weak political stature of the DOE has allowed the actions to disrupt DOE activities.

The DOE environmental restoration program continues to expand. The Five-Year Plan for FY 1993 thru 1997 reflects growth for environmental restoration activities from $1.48 billion in 1992 to $2.15 billion in 1997 (1). The increased budgets signal increased activity throughout the DOE complex in environmental restoration. A Community Relations Plan must be developed and implemented according to CERCLA, the Superfund Amendments and Reauthorization Act (SARA), and the National Oil and Hazardous Substances Pollution Contingency Plan (NCP) (2,3,4). Public meetings to accept comment are required before key environmental restoration decisions, and information meetings to review progress are required quarterly at a minimum. The results of these public exchanges are captured and documented in the Administrative Record. Clearly the environmental restoration activities will be visible to the public. The increasing number of environmental restoration activities throughout DOE means that a public dialogue is no longer optional. It must be done, and it must be done well.

The Secretary of Energy has also committed the department to being more open in our activities. His commitment to the NEPA process, expressed through his Ten-Point Plan and Secretary of Energy Notice 15 (SEN-15) requires more complete NEPA documentation of all DOE activities. The programmatic Environmental Impact Statement (EIS) preparation for Environmental Restoration and Waste Management will provide public visibility of our actions at the highest level. All the NEPA activities will ensure continuing public involvement in DOE decisions through Environmental Impact Statement (EIS) scoping meetings and draft reviews.

THE HISTORICAL PERSPECTIVE

Historically the DOE has been closed to public scrutiny. This policy dates back to the origins of the weapons complex in the Manhattan Project, when the participants at Los Alamos, New Mexico were completely sheltered from family and friends. The cold war era and the strict classification requirements for nuclear information continued the veil of secrecy. Initially this was generally accepted by the public in the interest of national security. However, with the expansion of the peace movement in the 1970's came considerable negative sentiment against all aspects of the industrial-military complex, including anti-nuclear sentiment. Secrecy, once accepted for national security, was becoming viewed with suspicion. Anti-nuclear activist groups used every means at their disposal to discredit the industrial-military complex, including blatant lies and distortions in the media. Unfortunately the DOE policy of "neither confirm nor deny" allowed most of these distortions about the weapons complex to stand completely unchallenged. So, as suspicion grew, the public was given a one-sided story to feed the negative attitudes.

The nation's environmental awareness began to increase in the 1980's, creating another group of activists. Many environmental groups also began to join the chorus of unchallenged protest against the DOE and its contractors. Suspicion which had begun in the 1970's was fueled with further allegations of environmental disaster at DOE sites. Concerns regarding nuclear war and excess profits for contractors were moral concerns in the 1970's. But with environmental problems the public began to see itself as being directly impacted, through water, air, soil and food. The secrecy and suspicion were now becoming seen on a very personal level as health and risk issues. Public inquiries were similarly motivated by personal concerns, and limitations on information based on the same historical security basis caused outrage. For activists still pursuing anti-nuclear goals, this situation provided the perfect opportunity to exploit the public sentiment from an environmental standpoint for their own goals. The protests and media distortions continued, but now with increased popular support from the blend of anti-nuclear and pro-environmental forces. This in turn increased the involvement by elected representatives at both the state and federal level. The DOE is now to the point where decades of misinformation and distortion have severely damaged our credibility in the minds of a large portion of the public. We face a monumental challenge to recover the public trust. From a community relations standpoint, we are starting from the bottom of a deep, dark hole.

THE COMMUNITY RELATIONS START AT ROCKY FLATS

The climb out of that deep hole for Rocky Flats can be viewed as beginning on June 6, 1989. This date was the start of "Operation Desert Glow", an unannounced raid by over fifty agents of the Department of Justice and the Environmental Protection Agency who entered Rocky Flats to execute a search warrant and gather information on alleged operational and procedural violations of environmental law. The most spectacular allegations, since disproven, included "midnight" burning and dumping of wastes. Media coverage was sensational and shocked Departmental management all the way to the Secretarial level. The first DOE "Tiger Team" review followed close on the heels of the raid, in July and August 1989. The Tiger Team identified hundreds of shortcomings, mostly procedural in nature. However, amongst the other shortcomings finding IWS/AF-1 identified the lack of a positive community relations program (5). This was "understatement" in the fullest sense of the word. More than anything, the FBI raid clarified the extent of suspicion, mistrust, and misinformation within the public around Rocky Flats. The DOE management determined that continued operation of Rocky Flats would be dependant on the public attaining a much better understanding of the plant, its operations, and the associated risks.

Several public forums were started to begin the painful process of educating a confused and mistrustful public. The most visible was the Rocky Flats Environmental Monitoring Council, a citizen's panel appointed by the Governor to oversee Rocky Flats' activities, particularly related to health, safety and environmental issues. The panel began monthly public meetings to discuss key issues at the plant. During the same time frame, the Plutonium Recovery Modification Project (PRMP) at Rocky Flats was coming to a key decision milestone. It was determined that the PRMP, a $600 million renovation of the failed Building 371 project from the 1970's, would require an EIS. Meetings were planned to provide information to the public and explain the need for the facility, to overcome the strong sentiment against any expansion of plant activities. The PRMP EIS public exchanges and scoping meetings acted as a lightning rod for public and activist concerns about every aspect of Rocky Flats. The meetings also provided the first official "on the record" chance for the public to express decades of frustration with DOE. The scoping meeting comments numbered over one thousand with every aspect of Rocky Flats operation coming under criticism. These first meetings were difficult and painful. However, they were a necessary first step to allow the venting of the public frustration and confusion. They allowed the DOE to step up to the issues and come out from behind the secrecy veil toward developing a meaningful information exchange.

THE ROCKY FLATS COMMUNITY RELATIONS PROGRAM

Building on the start with PRMP, the last year has seen a phenomenal growth of Rocky Flats community relations activities. In 1990 there were thirty-four public meetings and 156 public tours. In 1991 to date there have been thirty-five public meetings and 77 tours, even with tours suspended during three months surrounding the Persian Gulf War. The environmental restoration and NEPA processes have accounted for the majority of these meetings to provide dialogue on our restoration activities. We believe it is appropriate for environmental restoration to have a lead role. Environmental restoration is a relatively positive activity for the DOE to discuss, as the process of cleaning up the environment is generally seen as acceptable by the public. Credibility gained through public dialogue on environmental restoration activities may facilitate the acceptance of more controversial DOE activities related to weapons production.

The increase in public exposure necessitated that DOE managers become skilled in talking to the public. Training was conducted on 'Communicating with a Hostile Audience' to prepare managers for the inevitable deluge of hostile and distorted questions. At this point, nine DOE managers at the Director and Assistant Manager level have received this training to prepare for the public forums. Many of the Contractor's managers have also been trained. More will be trained in the future as the scope of DOE activities which are made visible to the public increases.

The Community Relations Plan, created to satisfy the requirements of our Inter-agency Agreement (IAG) with the State of Colorado and Environmental Protection Agency (EPA) Region VIII, describes the major aspects of our current community relations strategy for environmental restoration. The plan was prepared based on interviews with sixty-seven activists, federal state and local officials, business leaders, educational representatives, health professionals, news media representatives and local residents to determine their concerns about Rocky Flats and the DOE (6). The intent was to find out what concerns existed, so that the Community Relations Plan could be tailored to address those concerns as effectively as possible. Public comment was encouraged on the draft plan and 155 comments are currently being addressed. While waiting for final plan approval later this year,

the environmental restoration program has been utilizing an Interim Community Relations Plan since February 1991.

The Interim Community Relations Plan requires a number of activities to increase public awareness and dialogue (7). Fact Sheets and Citizen Guides are routinely provided to explain evolving remediation activities, with twenty-five created since initiation of the plan. A bi-monthly Environmental Restoration Update newsletter is mailed out to over one thousand addresses. Public tour opportunities are provided several times each month, and speakers bureau activities have provided 131 presentation thus far in 1991 to over 5600 citizens. A minimum of one, and usually two, public meetings are held before each proposed interim or final remediation decision. A public meeting is also held before implementation of a remedial action to explain the intended actions. A review of the overall environmental restoration program is held quarterly at a minimum. The format of public meetings has become more varied to provide the best dialogue with the public. Formats have included standard lectures and formal question and answer sessions, informal meetings with activists (at their offices), monthly meetings with local community government employees, and public information fairs. Some information fairs have included tables for activists and regulators, so that the public can go from table to table and get all viewpoints on an issue in a one-on-one dialogue. Future activities being considered include "Point-Counterpoint" interchanges at colleges, and outreach activities involving county fairs, elementary schools and shopping malls.

Two other activities to provide direct public involvement have been beneficial. The first is establishment of public reading rooms as a repository for documents related to Rocky Flats activities. Five such Public Reading Rooms have been established in the Denver metro area, providing availability to the public seven days per week, including evening hours (7). Over 5000 documents are currently stored in the reading rooms, the majority related to environmental restoration activities. The full Administrative Record required by CERCLA and SARA will also be available in the reading rooms. The second activity is the formation of a Technical Review Group (TRG) to review and comment on environmental restoration documents and plans in the earliest draft stages (7). The TRG is currently comprised of fourteen community government, citizen and activist members which are allowed to review and provide comment on preliminary drafts of Remedial Investigation Workplans. This early dialogue has provided the greatest involvement yet in the execution of the environmental restoration program at Rocky Flats. The combination of all the Community Relations Plan elements is beginning to convince the public that they do have a say in the DOE activities, and thereby win back some credibility for the DOE.

STARTING A COMMUNITY RELATIONS PROGRAM

Starting an active community relations program is similar to most new initiatives. First the program goals must be defined. Rocky Flats experience indicates that goals directed at increasing public awareness and involvement will be the most successful. Management support for the program is absolutely critical for success, and in fact, a community relations program without management support is probably worse than none at all. Training is strongly recommended for managers who will initially be asked to interface with the public. Coordination with DOE Headquarters is a necessity since a functioning community relations program will create a lot of media attention, particularly at the start. With the basic plan, support and coordination the only thing left is to "just do it." Many examples exist for what to include in a Community Relations Plan, and in fact the EPA Handbook Community Relations in Superfund is fairly prescriptive on minimum requirements for the plan (8). The experience at Rocky Flats says that community relations will be difficult, risky and painful at first. It will also most likely be very uncomfortable for the upper management, possibly including the DOE Headquarters. However, the good news is that if approached with enthusiasm and a sincere desire to have dialogue with the public, the community relations will improve over time.

INDICATORS OF SUCCESS

Rocky Flats has been actively involved in community relations for about eighteen months. We have experienced the following indicators of success from our community relations. First of all, we have seen positive attitude changes in the most radical activist groups. Name-calling and vulgarity, typical of the early meetings, has all but disappeared. Groups focused more toward actual environmental improvement and solutions have taken the forefront over groups focused only on "DOE-bashing". Secondly, public comments have become generally calm and technically-based, rather than emotional and uncontrolled. We have been able in many cases to focus on issues which can be resolved through technical means. Thirdly, DOE has received complements 'on the record', and recently was accused of having too many meetings, making it difficult for some of the activist groups to keep up with the comment opportunities. Increasingly, our relationship with activist groups is based on mutual respect as professionals with opposing viewpoints, but focused toward some common goals. Finally and most significantly, Rocky Flats has been able to more clearly communicate legitimate concerns, receiving fair media coverage and public acceptance of the DOE issues. With the public belief that the DOE sincerely wants to address the real issues, the public and media are more willing to discuss the real issues. This more positive treatment has allowed management the flexibility necessary to address some of the more complex problems with dialogue rather than polarity.

CONCLUSION

Community relations is not a panacea, but neither is it an ogre. It is very clearly a necessary part of the DOE for the 1990's and beyond. It plays a key role in environmental restoration, as well as most other facets of the DOE mission. The history of the DOE interface with the public has made the establishment of good community relations a more difficult task, but not an impossible one. With a good plan, management support, and some committed, knowledgeable participants, a community relations plan can be made to support the goals of DOE and breakdown the barriers of mistrust and misinformation. The environmental restoration organizations are uniquely postured to take the lead in developing pro-active community relations activities at DOE sites. All of DOE, but especially the environmental restoration organizations, must accept the challenge to develop positive community relations and help bring the DOE out of the dark and into the light of progress.

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PROGRAMMATIC ENVIRONMENTAL IMPACT STATEMENT FOR THE OFFICE OF ENVIRONMENTAL RESTORATION AND WASTE MANAGEMENT

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ABSTRACT

The paper will describe the background for the Programmatic Environmental Impact Statement and activities influencing this document. The results of scoping meetings will be described in detail. The new management structure, contracting vehicle and future activities will be explained.

BACKGROUND

A Programmatic Environmental Impact Statement (PEIS) serves several purposes. A PEIS provides a broad environmental analysis of a program or policy; evaluates environmental effects when actions are connected and may have cumulative impacts; addresses national, program wide alternatives rather than site-specific actions; and provides for subsequent NEPA documents of narrower scope tiered to the PEIS that would evaluate site-specific and/or project-specific actions.

In assuming a national perspective, the PEIS for the Office of Environmental Restoration and Waste Management (EM) will help the Department of Energy (DOE) achieve a principal programmatic goal of minimization of risks and impacts to workers, the public, and the environment, across the complex.

For the Office of Environmental Restoration (ERM), the PEIS will assess the cumulative attendant risks, benefits, and costs of alternative approaches to site cleanup; as well as provide the sites with a refinement of the risk assessment paradigm discussed in the National Contingency Plan. The intent is for DOE to manage the ERM program in a consistent fashion while ensuring a comparable level of protection to those potentially affected by its activities. This analysis, and associated technical constraints, will help to identify potential land uses and determine where resources can best be placed to reduce risks. The information from the analysis will be used by DOE under the current Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) process in negotiating cleanup levels and in proposing cleanup actions.

With regard to the Office of Waste Operations (WO), the objective of the PEIS is to develop a waste management facility siting strategy. This strategy is to be based on analysis of the risks, benefits, and costs associated with different configurations of the DOE waste management complex.

SCOPE

Activities covered by the PEIS include the assessment and physical cleanup of contamination at DOE installations and other properties; decontamination and decommissioning or dismantling of DOE's surplus facilities; and the treatment, storage, and disposal of wastes generated by ongoing nuclear energy, energy research, defense, restoration, and other activities for which ERM has management responsibility. Related issues to be addressed include land use; cleanup levels; the environmental basis for deciding cleanup priorities; and transportation of waste.

The Office of Technology Development (OTD) provides support to ERM in identification and resolution of technology needs and problems. A key goal of the program is to enable ERM to do its job "better, cheaper, and faster". The relationship between ERM, WO, and OTD; the process for setting technology development priorities; and technology transfer are topics that will also be discussed in the PEIS.

As appropriate, DOE also identified a number of issues/activities that are not within the scope of the study. These include disposal of high-level waste in a central repository; demonstration of the disposal of defense-generated transuranic waste in the Waste Isolation Pilot Plant (WIPP); management of commercial spent fuel; management of commercial low-level waste; and cleanup and disposal activities (excluding groundwater) associated with the Uranium Mill Tailings Remedial Action Program.

THE SCOPING PROCESS

In a effort to solicit public input, DOE held 23 scoping meetings. The purpose of these meetings was to ensure adequate opportunity for public participation in developing the scope of the PEIS, including identification of the issues to be addressed and alternatives to be analyzed. The public scoping meetings began on December 3, 1990, and ended on February 1991. The comment period extended for 120 days, from October 22, 1990, with the publication of the Notice of Intent (NOI), through February 19, 1991. Many comments were received after the close of the public comment period, and were incorporated into the formal record to the extent practicable.

To facilitate evaluation of the oral and written comments received, to provide pertinent information for inclusion in the PEIS Implementation Plan (IP), and to delineate specific issues raised at each of the scoping meetings, a comment tracking system was developed to identify and categorize the public's comments. Over 2,000 people provided comments either through participation in the meetings or in material and letters submitted to the Department. Results of scoping will be recorded in the IP. In addition, often raised out of scope issues will also be addressed in factsheets to be appended to

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the IP. This is being done to enhance communication efforts, to inform people about DOE activities in areas of concern, and to be responsive to issues raised at the scoping meetings.

Scoping comments covered a wide array of topics. The following is an overview of some of the most frequently mentioned issues.

Many people demanded that DOE stop production of nuclear weapons. Some wanted production discontinued at least until a safe and successful method for managing the resulting waste was available.

Another common issue was the separation of Defense Program's (DP) PEIS from EM's PEIS. Scoping participants commented that the impact statements are inextricably linked and should be combined.

Issues of resource management in the areas of funding, budget, and personnel were also raised. People stated that there was a need for a dedicated cleanup fund which should be available to meet agreement schedules; EM funds should not support production (production related waste management costs should be included in DP's budget); workers should be reassigned from production activities to cleanup; and workers at facilities with changing missions should be retrained.

Two of the most frequently mentioned topics were future land use and cleanup levels. Comments ran the gamut from requiring removal of all contamination and release of the land to the public for unrestricted use; to permitting minimum dedication of land; to providing for the maximum of in situ or on-site remediation with waste transport when necessary for protection of human health and the environment, and then only to the nearest contaminated site. Development of land use strategies and plans that would guide the selection of cleanup methods and help to determine an acceptable level of clean was also suggested. Several people indicated a strong desire for increased public involvement in land use decisions.

Occupational and public health concerns were also emphasized. Many of the participants in scoping demanded the issuance of all health records and studies, as well as complete information on releases and contamination, both to the public and to an entity independent of DOE for analysis. Scoping participants also requested that dose reconstruction and epidemiologic studies should be done for all potentially affected parties.

Transportation issues were often discussed. Comments addressed the viability of the TRUPACT-II containers for wastes to be shipped to WIPP; the need for DOE to ensure adequate training for drivers and funding for communities for emergency response; early notification in the event of an accident; and evaluation of the reliability of existing transportation risk assessment models.

The public identified a number of waste management issues. Several want the PEIS to include WIPP and Yucca Mountain, primarily to reassess the viability of geologic disposal and the suitability of these potential repositories. In addition, a number of people want existing treatment methods identified and evaluated for associated impacts to determine both which and where treatment technologies should continue to be used. With regard to storage, people suggested that the Department consider above-ground storage of wastes in vaults to permit monitoring and retrieval. Long-term storage was viewed as a certainty. It was therefore recommended that DOE complete a comprehensive review of needed improvements in containment to ensure full compliance and protection. Two significant issues that DOE is including in the scope of the PEIS as a result of public comment are the long-term storage of transuranic and high-level waste in the event the current sites under investigation do not open, and continued storage of transuranic waste in the event WIPP opens and fills to capacity.

All scoping comments have been and will continue to be reviewed as the PEIS alternatives and issues are being re-evaluated and revised for inclusion in the IP. EM plans to issue the draft IP for public comment. This decision was based on the fact that the alternatives in the NOI were vague. This ambiguity was, in part, a reflection of the desire to allow for significant public input into the formulation of the alternatives. This additional opportunity for public involvement will allow for substantive comment on better defined alternatives.

Development of the scope of the PEIS has necessitated significant internal coordination as well. Very early in the process, those responsible for the PEIS invited DOE headquarters and field office staff to attend internal workshops to help define the purpose and scope of the study. PEIS staff have also worked closely with the Office of General Counsel, the Office of NEPA Oversight, and DP PEIS and to a lesser extent, the New Production Reactor (NPR) staff. These ongoing coordination efforts have resulted in identification of cross-cutting issues that are being addressed by the project staffs.

PROPOSED NEAR-TERM OPPORTUNITIES FOR PUBLIC INVOLVEMENT

DOE is considering holding a series of regional interactive meetings on the IP. The goals in holding them would be:

- To provide an opportunity for direct exchange of ideas or concerns relative to the adequacy of the alternatives;
- To enable the public to provide more specific comments or suggestions for modifying or expanding the definition of alternatives;
- To provide DOE an opportunity to modify the scope of the PEIS before extensive evaluation is performed; and
- To provide an interactive format that is conducive to focusing on the specific tasks of the PEIS - identification and evaluation of potential impacts of the proposed action and alternatives.

The proposed format would be similar to that of the National Workshop which was held just prior to the scoping meetings. The Department is considering, within this structure, a day time session that would include a plenary session with presentations on the IP followed by a question and answer period; small working groups with PEIS and other DOE staff representing ERM, WO, and TD, facilitated by professionals independent of DOE; and a closing plenary session with presentations summarizing the small group discussions. The evening session would also begin with presentations on the IP; a presentation on the results of the workshops; and a question and answer session that would allow all those in attendance to participate.

If the public meetings are held, DOE would also conduct an evaluation of the meetings to determine whether the content and format allowed the goals of DOE and the participants

to be met. The evaluation would be conducted by professionals who would utilize questionnaires and interviews to try to measure the success of the meetings. This information could be used to plan future public meetings on the PEIS.

Federal Advisory Committee

In response to a letter dated May 24, 1990, from representatives of 25 public interest groups and the Secretary's initiative to be more open with the public, EM is considering establishing a Federal Advisory Committee under The Federal Advisory Committee Act (P.L. 92-463). If approved, the group may have approximately 15 members and represent a wide range of interests including national environmental groups, labor organizations, local environmental groups, state and regulatory agency officials, and scientific and waste management experts from industry and academia.

If approved, the Committee would advise EM on the scope and process of the PEIS. The committee could also review documents prior to release to the general public, and potentially identify issues that EM had not adequately considered in the PEIS process before EM released the documents. This would allow EM to revise those documents as appropriate. If approved, this group may help DOE to be more sensitive and responsive to the public and present a PEIS that fully covers all issues of concern. The wide ranging interests of the committee would help EM reach a balanced approach to problems and issues.

MANAGEMENT OF THE PEIS

On July 15, 1991, Mr. Leo Duffy, Director of the Office of Environmental Restoration and Waste Management, asked Glen Sjoblom of his staff to manage the PEIS and integrate it with the efforts of other Program Senior Officials (particularly the Office of Defense Programs which is engaged in a parallel reconfiguration study and PEIS.) Since being asked to manage the PEIS, Mr. Sjoblom has been developing a management organization to ensure that the PEIS is written in a timely and comprehensive manner. This organization will encompass all of EM at various levels.

The Associate Directors of EM-10, 20, 30, 40, and 50 will serve on a steering committee to periodically review the scope and direction of the PEIS. This steering group will also resolve issues arising from the PEIS process that cannot be resolved at lower levels.

Within EM there will be a task force comprised of a PEIS staff and midlevel managers committed to the project who will serve as division leaders for EM-30, 40, and 50. Each division leader will have a staff whose primary duty will be to support the PEIS.

The separate PEIS staff will be detailed to Mr. Sjoblom and work full time on the PEIS. The PEIS staff will consist of the following:

- a contracting officer's technical representative (COTR) to manage the contractor selected to write the PEIS;
- a public liaison staff to plan and coordinate public meetings and act as the support staff to the Federal Advisory Committee, if approved; and an administrative aide.

See Fig. 1 for the wiring diagram of this management structure.

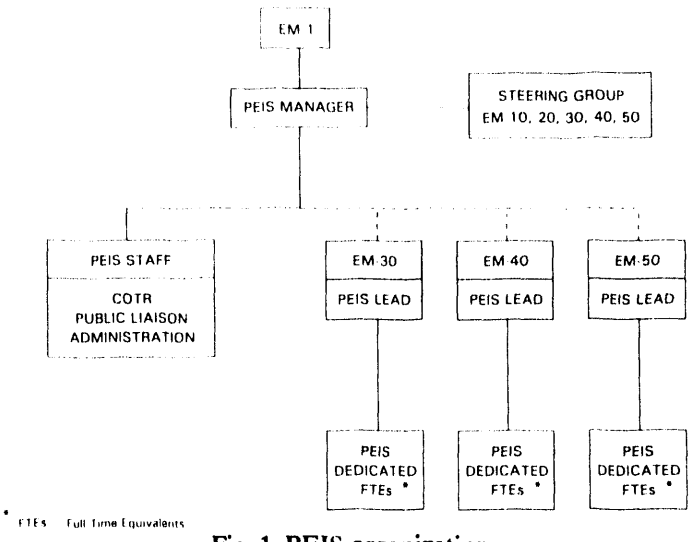


Fig. 1. PEIS organization.

CONTRACTING FOR THE PEIS

DOE is using a variety of contracting resources to move the PEIS process along. The Technical Support Services contractor to EM-40 has done a lot of the preliminary work for the scoping meetings and development of the Implementation Plan. The support services contractor will probably continue to be extensively involved in supporting and reviewing the PEIS.

DOE has also been exploring use of resources at various National Laboratories' to assist in gathering data and performing modeling tasks associated with environmental analysis requirements. The National Laboratories experience in assembling and analyzing large amounts of data as well as utilization of various modeling techniques could be of great benefit in trying to streamline the PEIS process.

The contract vehicle for writing the PEIS has been identified as a "fixed price labor hour; level of effort; task order contract (2)." Under this type of contract, DOE and the contractor identify the qualifications of individuals to perform work on the contract, and then negotiate a fixed rate for the labor category. When a task order is identified under the contract, the contractor estimates the level of effort and cost to complete the task. The contractor is held to this estimate regardless of the actual cost of doing the task.

This type of contract is different from the type of contract usually used by DOE to write an EIS. Normally DOE would use a cost plus fixed fee contract. The Department of Defense has extensive experience in the fixed price, labor hour type of contract and has had great success. This type of contract places more emphasis on DOE management of the contractor. The position of COTR is a very important job. He must adequately identify tasks and insure the contractor complies with its commitments concerning those tasks.

NEXT STEPS

The Draft PEIS is presently scheduled to be released for comment in November 1992. Prior to that time many activities must be completed.

The proposal on the Federal Advisory Committee is being finalized for presentation to the Secretary. If approved, the members should be identified quickly and start getting involved in the PEIS.

The draft Implementation Plan is being completed and will be released for public review. If public meetings are held, they will be initiated approximately 30 days after release of the IP.

Data requirements and modeling needs are being identified. The data needs may have a significant impact on the DOE Field Offices if existing data bases (i.e., the Waste Information Network (WIN) and Integrated Data Base) do not provide sufficient level of detail for environmental analyses in the PEIS. Modeling needs also need to be assessed. If present modeling capabilities are not sufficient, then long lead times may be necessary to develop and validate the desired modeling capabilities.

CONCLUSION

The PEIS process is a long and complicated journey. The results of the PEIS could go a long way toward influencing future DOE policy and restoring DOE'S credibility.

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DEPARTMENT OF ENERGY POLICY FOR ACCEPTANCE OF FACILITIES FOR ENVIRONMENTAL RESTORATION

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ABSTRACT

This paper summarizes the policy of DOE's Office of Environmental Restoration for accepting new facilities into the Environmental Restoration Program. Facilities that are eligible for acceptance include DOE buildings, structures, and sites that are currently the responsibility of operating programs of the Office of Nuclear Energy, the Office of Defense Programs, and the Office of Energy Research. The policy states that the Office of Environmental Restoration, under DOE's Office of Environmental Restoration and Waste Management (EM), will accept DOE-contaminated facilities that are surplus to DOE needs and have no future intended use. The facilities will be turned over to EM for remediation or decommissioning when they are completely shutdown and when stored nuclear and hazardous materials have been removed.

INTRODUCTION

With the creation of the Office of Environmental Restoration and Waste Management (EM) in 1989, the Department of Energy (DOE) consolidated its environmental restoration activities within a single Headquarters office. These environmental restoration activities included decontamination and decommissioning as well as remedial actions at surplus, inactive facilities. Environmental restoration projects that were part of similar programs under the Offices of Nuclear Energy, Defense Programs, and Energy Research were transferred immediately to EM for management. As additional facilities become surplus and require decommissioning or remedial action, they will be transferred from the operating programs to EM according to the criteria and the process that are set forth in a policy document (1) summarized below.

SCOPE OF POLICY

The policy applies to any DOE-owned, contractor-owned, or privately-owned facilities that are inactive, surplus to DOE needs, and have been contaminated with radioactive, hazardous/toxic, or mixed wastes or substances as a result of DOE nuclear program activities. The term "facility" refers to structures, land (soil), surface water, and ground water that require decontamination and decommissioning or remedial action. Facilities that are eligible for acceptance by EM include those of the Offices of Nuclear Energy, Defense Programs, and Energy Research. The policy does not apply to facilities of the Office of Uranium Enrichment and the Office of Naval Reactors. EM has accepted and will continue to accept Uranium Enrichment facilities for decommissioning, however, the transfer process is developed on a case-by-case basis. Naval reactors facilities will not be decommissioned by EM.

ACCEPTANCE CRITERIA

The transfer of facilities from an operating program to EM for environmental restoration follows a two-step process. First, the facility must meet the acceptance criteria. Second, once accepted, the facility must meet the turnover requirements with respect to physical condition and documentation.

The key acceptance criteria that must be met are:

- Facilities have been contaminated with radioactive, hazardous/toxic, or mixed wastes/substances as a result of DOE nuclear program activities.
- Facilities have been declared surplus and inactive by the responsible operating program (NE, DP, or ER).
- Facilities can have no future planned or intended use by the operating program.

EM will not accept caretaker or restoration responsibilities for facilities to be used in continued or future radioactive operations. Further, EM will not accept surplus portions of large facilities (e.g., rooms within a building), when the total facility will subsequently undergo remedial action or D&D. This is a departure from past DOE practice, where one of the objectives of the previous "surplus facilities" programs was to return contaminated facilities to productive service. Under this EM policy, it is possible that facilities may be decommissioned and left in a condition that would permit facility reuse, but reuse is not an objective. If contaminated facilities need to be cleaned up to permit further use by operating programs, such clean up is the responsibility of the operating programs, not EM.

Acceptance of a facility by EM can occur when the criteria listed above are met, in advance of actual turnover of the facility to EM for management. Formal acceptance will be documented in a memorandum of agreement (MOA) between EM and the responsible program office. The MOA will identify the actions required to effect actual turnover of the facility to EM, the turnover schedule, and funding responsibilities.

TURNOVER REQUIREMENTS

A facility must meet the following turnover requirements before EM will take responsibility for managing the facility:

- Facility must be shut down and placed in a safe, secure condition.
- Special nuclear materials, nuclear fuel, high-level waste, liquid wastes, and stored hazardous chemicals/materials/wastes must be removed from the facility.
- An assessment of facility compliance with applicable environmental and safety requirements must be provided.

These requirements should be built into the plans for terminating program operations at each facility. Safe shut down and removal of wastes and stored materials are often not planned for by the operating programs and funding is often not readily available. EM will not accept the large

funding liabilities that could result from taking responsibility for facilities that do not meet these turnover requirements.

TRANSITION PERIOD

There will generally be a "transition period" between acceptance of the facility by EM and turnover of the facility to EM for management, to allow time for meeting the turnover requirements and the appropriation of EM funding for the facility. This transition period may be as much as three years, if funding requirements are significant and funding is requested through the normal budget process. The transition period may be accelerated if alternative funding arrangements are made and the turnover requirements can be quickly met.

Figure 1 illustrates the role of the transition period relative to acceptance and turnover. The operating program retains responsibility for funding and managing turnover activities and any requirements for surveillance and maintenance between the time of acceptance and the time of turnover. Following formal turnover, EM takes full responsibility for surveillance and maintenance, followed by D&D or remedial action. EM will accomplish the D&D or remedial action of the facility according to the prioritization process that is incorporated into the DOE's Five Year Plan for Environmental Restoration and Waste Management.

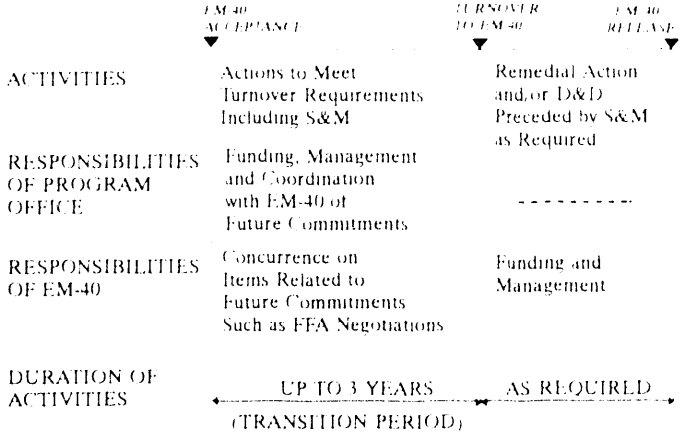


Fig. 1. Responsibilities of program office and EM-40 after acceptance of a facility for environmental restoration.

ACCEPTANCE AND TURNOVER PROCESS

The process of facility acceptance and turnover requires close coordination between EM, the operating Headquarters program office, and the responsible field office. The basic steps in the process are generally as follows:

1. A field office identifies the facility through preparation of an Activity Data Sheet for the Five Year Plan, or through correspondence with the program office.
2. The field office prepares an application for acceptance, as provided by the policy (1).
3. The operating program office forwards the application to EM with a request for EM acceptance of the facility.
4. Upon meeting the acceptance requirements, an MOA is prepared between the program office and EM which documents the conditions of acceptance The facility is accepted.
5. The field office takes any actions necessary to meet the turnover requirements.
6. EM includes the facility in program planning and requests budget appropriations for surveillance and maintenance or D&D/remedial action, as appropriate.
7. When turnover requirements are met and EM funding is available, EM takes responsibility for the facility.

A common misconception is that the preparation of an Activity Data Sheet and the inclusion of a facility in the Five Year Plan constitutes EM acceptance of the facility. This is not the case. The application must be completed and formal agreement reached between EM and the operating program office before a facility is accepted.

The application to be completed by the field office requests information needed to evaluate the facility against the acceptance criteria and the turnover requirements. The requested information includes:

- Physical condition of the facility
- Site surface, subsurface, and environmental conditions
- Environmental compliance status of the facility
- History of facility use
- Identification of stored radioactive and hazardous/toxic materials
- Identification of radioactive and hazardous/toxic contamination
- Surveillance and maintenance requirements

It is not the intent of the application to initiate extensive studies or investigations to produce the requested information. All available information is requested, followed by discussions with EM to determine whether the information is adequate to decide on acceptance and turnover.

Although the policy applies to remedial action as well as D&D projects, it is expected that the primary application of the policy will be for D&D. The DOE has many facilities that will become surplus and require in the coming decades. The DOE is currently evaluating the numbers, types, and decommissioning costs of such facilities through an inventory conducted at all DOE field offices. Preliminary results indicate that the total inventory of facilities for D&D is more than 1000 and that the total cost of D&D will reach into the tens of billions of dollars. More than half of these facilities have not yet been accepted by EM and will be required to go through the acceptance process.

STATUS OF POLICY

The policy document (1) has been approved by the Director of EM and has been concurred on by the Office of Nuclear Energy. The concurrences of the Office of Defense Programs and the Office of Energy Research has also been requested but have not yet been received. Comments received from these two offices on a draft of the policy earlier this year (1991) have been addressed, and their concurrence is expected in the near future. In the meantime, the draft policy is being implemented as described above.

REFERENCES

1. Department of Energy Policy for Acceptance of Facilities for Environmental Restoration, DOE Office of Environmental Restoration and Waste Management, Draft, February 1991. Attachment to March 15, 1991 DOE memorandum from L. Duffy, EM-1, to NE-1, DP-3.2, and ER-1.

AN OVERVIEW OF THE MAJOR PROGRESS IN THE ENVIRONMENTAL RESTORATION PROGRAM AT THE SAVANNAH RIVER SITE

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ABSTRACT

The SRS vision of demonstrating major environmental remediation progress is being achieved to a high degree. In FY91 four large RCRA waste sites have received state (SCDHEC) certification of successful closure. These sites include the M, F and H area seepage basins (8 total), and the Mixed Waste Management Facility (MWMF). Combined, they encompass about 85 acres of remediation work, and originally the basins represented a capacity for treatment of over 85 million gallons of effluent annually from various separation and fuel manufacturing processes.

We believe that the MWMF is the largest closure of its kind (i.e. mixed solid waste) accomplished in the DOE complex, and perhaps in the world. The F and H seepage basins may similarly be the largest closures of their type achieved to date. Also particularly noteworthy is that these projects, which had various challenging aspects, were completed in a relatively short time, on schedule and with certain cost savings. A Total Quality approach which is described has been integral to our progress.

Other significant closures, such as the acid/caustic basins (four) and the metallurgical laboratory basin, have also been initiated. In total, 23 additional investigation plans have been submitted to the regulators for approval, and another 29 are currently in preparation. Again, we are committed to environmental remediation progress, and continue to pursue progressive initiatives to further demonstrate waste site closure accomplishments.

INTRODUCTION

The SRS Environmental Restoration (ER) Program, to include both DOE and Westinghouse, is responsible for all aspects of assessment and cleanup of sites and facilities that are no longer a part of active operations but are contaminated with various quantities of hazardous, radioactive, or mixed waste materials. The ER program is also responsible for inactive waste sites which are nonhazardous and nonradioactive. ER fundamentally performs two types of activities: Remedial Actions and Decontamination and Decommissioning (D&D). The Remedial Action tasks include 1) site and groundwater characterization, analysis of cleanup alternatives, and selection of the remediation approach; 2) cleanup and site closure; and 3) site/groundwater compliance monitoring and maintenance. D&D is concerned with the safe caretaking of inactive nuclear facilities, and either their decontamination/in situ fixation or their complete dismantling and removal.

REGULATORY REQUIREMENTS

The basic framework for assessing all waste units and developing closure, post-closure, and remedial action plans is based on the hazardous waste requirements of RCRA, CERCLA as amended, and South Carolina regulations. Waste units at the SRS are identified in the draft FFA and will be addressed under an integrated RCRA/CERCLA Program. The RCRA Requirements have been the primary regulatory driver to date at the SRS waste units.

The State of South Carolina is authorized by the EPA to administer the RCRA, except those requirements under the 1984 Amendments. Permitting under the RCRA is a two-part process. The first part involves the submittal of a Part A Permit application that contains certain basic facility information. The second part involves the submittal of a Part B Permit application that contains detailed information about the individual hazardous Waste Management facilities, including closure and post closure activities. The SRS Part B Permit was applied for in February 1985 and has been revised, as needed, to incorporate additional facilities. A permit was issued in September 1987 to authorize certain closure and post closure activities for the site.

The CERCLA/Superfund Amendments and Reauthorization Act is administered by EPA. According to CERCLA, agencies of the federal government are subject to compliance with this law. The SRS was placed on the National Priorities List (NPL) in December 1989. DOE is currently in the process of negotiating an FFA with South Carolina and EPA-Region IV.

Translating these requirements into procedures which also implement NQA-1 Quality Assurance requirements has been one of the early crucial steps of our work progress. This important relationship is detailed more fully below.

APPROACH

Key to the very real SRS environmental remediation progress has been a commitment to a Total Quality (TQ) approach which builds on the general imperatives identified in the TQ methodology, depicted in Fig. 1, that Westinghouse as well as DOE have embraced. Some of the specific elements adopted in the SRS Environmental Restoration Program in relation to the conditions in Fig. 1 and which we feature in this paper as integral to the overall waste site closure success, current and future, are as follows:

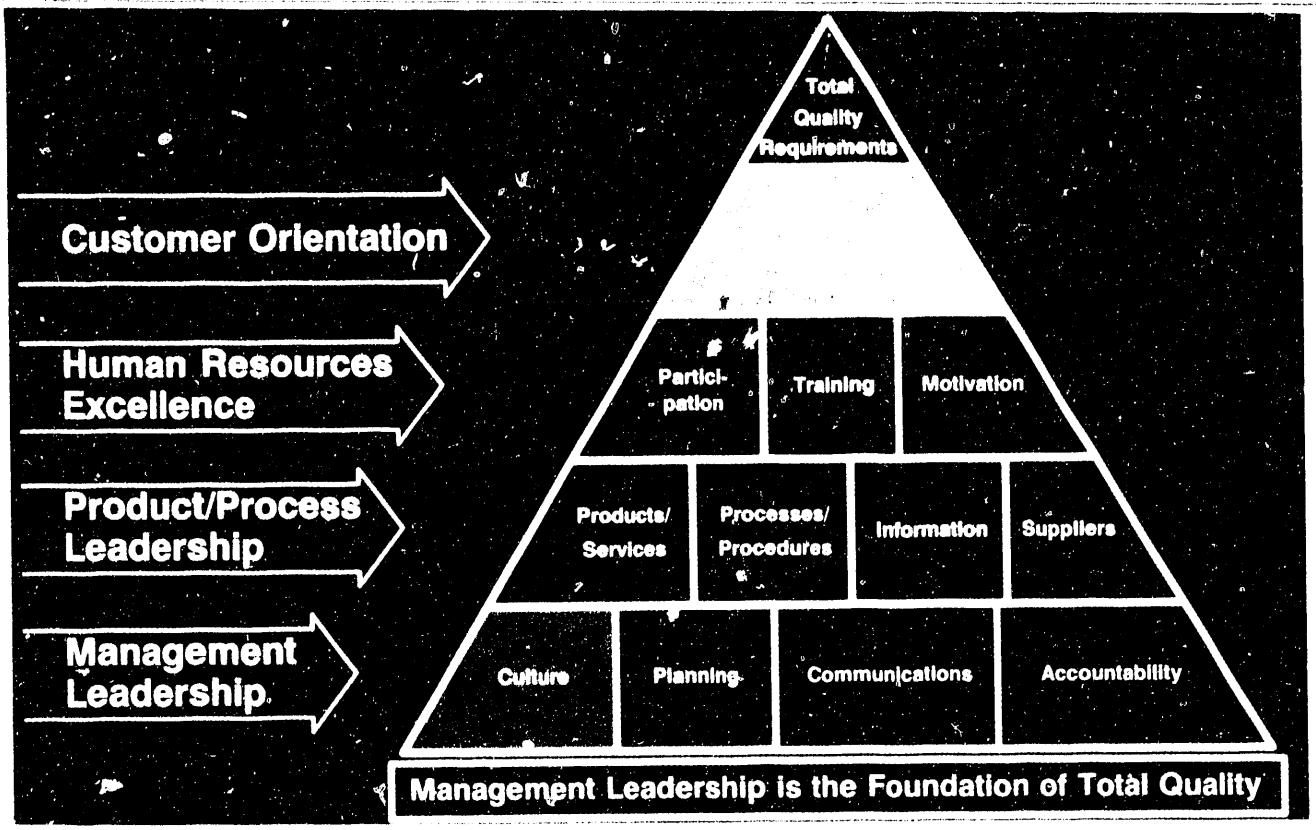


Fig. 1. Conditions of excellence for total quality. These are integral at the Savannah River Site to the environmental cleanup progress achieved.

PARTICIPATION

Teams are formed at the RI/FS process outset and comprise expertise which transcends all organizations to be involved in the closure project. The team leader resides in the custodian Environmental Restoration organization. The individual roles and responsibilities are articulated in Memoranda of Understanding written among the custodian and interfacing groups. Experience from previous related work is one of the first considerations captured in a formal manner to ensure its in-depth analysis as well as access to all the lessons learned at SRS and other sites.

Regulator involvement throughout the RCRA/CERCLA process has also been integral to the progress realized. As is expanded later, EPA is holding scheduled monthly meetings and other face-to-face discussions with the EPA Region and the CERCLA project and with SCDHEC to expedite RCRA work plan activities. The cost benefits realized to date have been significant and the potential for future cost savings is still large.

PLANNING

Activity planning begins at the outset and evolves into detailed time-phased work charts for each of the work scopes:

- To ensure that all team members are aware of the common work path forward.
- To establish all requirements, institutional issues, critical path activities and the necessary activities for resolution.
- To generate costs pending cost estimates to achieve work site acceptance in the DOE HQ remediation program (i.e. proper project prioritization), and
- To form the basis for the work plan schedule justification to the regulators, e.g., SCDHEC as part of the RCRA/RFI process.

COMMUNICATION

Involvement of the regulators as early as possible in the planning, complemented by frequent performance status meetings, is imperative to technology alternatives considered, path forward selected, risk analysis parameters evaluated, etc.

Internal communication is also viewed as paramount to our ER Program success. Biweekly meetings, whose subjects alternate between budget milestone performance (earned value) and detailed work progress, are held between DOE-SR and WSRC. All organizations supporting the ER activities typically attend the detailed work progress meetings to maximize integration of efforts and priorities. A representative from DOE-HQ participates in most of the budget schedule status meetings which ensures their understanding of our performance and controls and, also very importantly, enables us to anticipate in a timely manner any specialized needs on their part. At least biannual program reviews are conducted by a broader spectrum of DOE-HQ personnel.

We feel that in-depth technology discussions, for example, with Savannah River Laboratory, require a separate forum to ensure that the needs of the restoration program are articulated and, correspondingly, the technical progress, open items, etc. are understood. A key "living" document which has resulted is the Technology Needs Assessment.

PROCESSES/PROCEDURES

A Project requirements matrix showing the implementation of environmental and NQA-1 requirements via the Site or ER procedures is provided in Fig. 2. Documenting the

NQA-1	ANSI/ASQC-E4-19XX	QAMS 004	QAMS 005	ER/WSRC PROCEDURE
1	A1	4.0	5.3, 5.4	1, 2, 3
2	A2, A3, A4	4.0, 3.0, 5.0, 7.0	5.3, 5.5, 5.16	1, 2, 3, 7
3	B2, C2	6.0	5.5	1, 2, 8
4	A5	6.0	NA	1, 2, 3, 4, 5, 6
5	B2, C2	4.0, 7.0	5.6, 5.9, 5.14	1, 2, 3
6	A6	4.0	NA	1, 2, 5
7	A5, B3, C3	6.0	NA	1, 2, 3, 4, 5, 6
8	B3, C3	6.0, 7.0	5.7	2, 3, 7
9	A3, B3, C3	6.0	NA	2
10	B4, C4	6.0	5.11, 5.14	2, 3, 4, 8
11	B4, C4	6.0	5.10	1, 2, 7
12	B3, C3, C4	6.0	5.8, 5.13	1, 2, 3, 7
13	B3, C3	6.0, 7.0	5.7	2, 5
14	B4, C4	6.0	NA	2
15	B4, B5, C4, C6	10.0	NA	1, 2, 3, 4
16	B4, C6	10.0	5.15	1, 2, 4
17	A6, B4, C6	8.0	NA	1, 2, 3, 5, 7
18	B4, C6	4.0	5.12	1, 2, 3, 4
NA	A7, A8, A9	6.0, 8.0	5.9, 5.10	1, 2, 3, 4, 5
NA	B1	7.0, 11.0	5.0 (All)	3, 7
NA	C1, C5	7.0, 11.0	NA	1, 2, 8

NQA-1

1 Organization
2 Quality Assurance Program
3 Design Control
4 Procurement Document Control
5 Instructions, Procedures and Drawings
6 Document Control
7 Control of Purchased Items and Services
8 Identification and Control of Items
9 Control of Processes
10 Inspection
11 Test Control
12 Control of Measuring and Test Equipment
13 Handling, Storage and Shipping
14 Inspection, Test and Operating Status
15 Control of Nonconforming Items
16 Corrective Action
17 Quality Assurance Records
18 Audits

ANSI/ASQC-E4-19XX

A1 Management Commitment and Organization
A2 Quality Assurance Program
A3 Personnel Training and Qualifications
A4 Management Assessment
A5 Procurement of Items and Services
A6 Documents and Records
A7 Use of Computer Hardware and Software
A8 Operation of Analytical Facilities and Laboratories
A9 Quality Improvement
B1 Planning and Scoping
B2 Design of Data Collection Operations
B3 Implementation of Planned Operations
B4 Quality Assessment and Response
B5 Assessment of Data Usability
C1 Planning
C2 Design of Environmental Engineering Systems
C3 Implementation of Engineering Systems Design
C4 Inspection and Acceptance Testing
C5 Operation of Environmental Engineering Systems
C6 Quality Assessment and Response

QAMS - 004

1.0 Identification of Office, Region, or Laboratory Submitting Quality Assurance Program Plan
2.0 Introduction
3.0 Quality Assurance Policy Statement
4.0 Quality Assurance Management
5.0 Personnel Qualifications
6.0 Facilities, Equipment and Services
7.0 Data Generation
8.0 Data Processing
9.0 Data Quality Assessment
10.0 Corrective Action
11.0 Implementation Requirements and Schedule

QAMS - 005

5.1 Title Page
5.2 Table of Contents
5.3 Project Organization and Responsibilities
5.4 Project Description
5.5 QA Objectives for Measurement Data
5.6 Sampling Procedures
5.7 Sample Custody
5.8 Calibration Procedures and References
5.9 Analytical Procedures
5.10 Data Analysis, Validation and Reporting
5.11 Internal QC Checks
5.12 Performance and Systems Audits
5.13 Preventative Maintenance Procedures and Schedules
5.14 Specific Procedures to be used to Routinely Assess Data Precision, Accuracy, Comparability, and Representativeness of Specific Measurement Parameters Involved
5.15 Corrective Action
5.16 QA Reports to Management

ER/WSRC Procedures

1 WSRC-C1 Manual; ER Administrstive Procedures
2 WSRC-1Q QA Manual
3 WSRC-RP-89-994: RCRA Facility Investrigation Program Plan
4 WSRC-1Q45 Manual; ER Quality Procedures
5 WSRC-1B Management Requirements and Procedures Manual
6 WSRC-3E; Procurement Specification Manual
7 DPSOP 254: Hydrogeologic Data Collection
8 WSRC-1E: Engineering and Engineered Services Procedures Manual

Fig. 2. Environmental requirements and implementation cross-reference matrix.

interrelationship has been invaluable to ensure that all requirements are identified and that their implementation uniformly meets acceptable quality standards.

The overall process implemented can be represented by Fig. 3. It depicts the primary considerations in the waste site characterization phase and the integrated roles of the various involved organizations. We have maximized the standardization of the design phase documents to minimize approval cycles and cost effectiveness. Procedures are in place and training provided to ensure that the process is understood and followed.

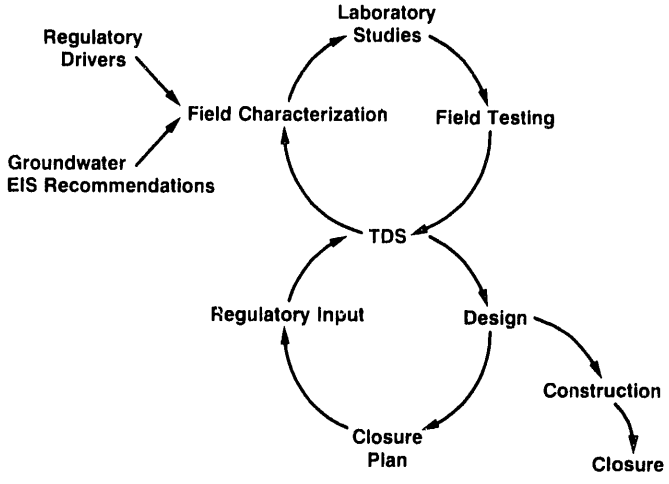


Fig. 3. Waste site closure process approach.

Any modification to the schedule or cost baseline is addressed by a formal change control process. Such a disciplined configuration management approach satisfies DOE Orders, e.g., 4700.1, and also will form the basis for Major Systems Acquisition funding authorization which is expected to be required for all future SRS closure and decontamination/decommissioning activities. Our typical approach to such Project Controls is depicted in Fig. 4.

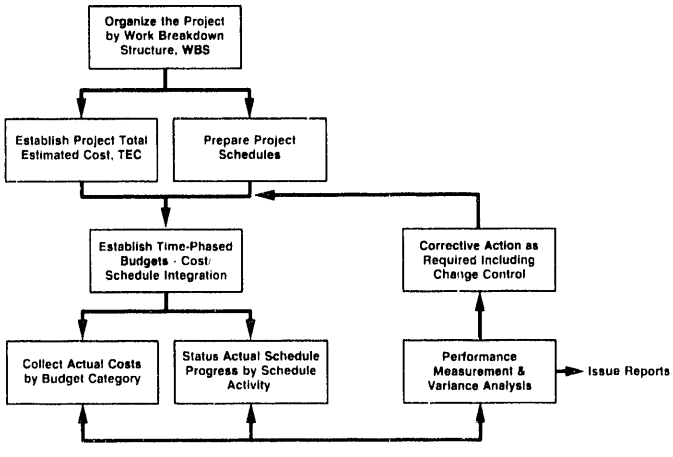


Fig. 4. Approach to environmental project control for effective management to baseline cost and schedule.

ACCOUNTABILITY

A Commitment Tracking System is utilized to effectively monitor performance and open work activities or issues. A formal biweekly review is held, but informal "plan of the week" meetings take place between counterpart personnel. A formal surveillance program is proactively used to ensure comprehensive ownership.

CULTURE

Our vision is to perform the highest quality work, meeting schedule requirements and budget allocations, while having the utmost concern for personnel and environmental safety. This has been effectively instilled and demonstrated based upon the following:

- No lost time accidents in all of the waste site closures work to date (and some of these appear to be the largest closures ever accomplished).
- No personnel contaminations.

Training in various forms, sometimes specialized, has been integral to these accomplishments: 1) Formal training for OSHA 1910.120 requirements, radioactive/hazardous waste handling, etc. has been clearly prescribed. 2) Personal commitment and ownership has been creatively achieved through our Total Quality indoctrination program. 3) Interactive technical workshops, e.g. addressing bioremediation or dense non-aqeous phase liquids (DNAPL), have been held to ensure that the latest developments and experiences are factored into our path forward activities.

CLOSURES

F&H Area Seepage Basins Closure Project

There are three F-Area Seepage Basins and four H-Area Seepage Basins, which were constructed in 1955. These were shallow earthen pits which were originally excavated to a depth of approximately ten feet. Waste streams discharged to the Seepage Basins originated from a variety of process and/or waste streams within the Separations facilities. Primary sources of basin influent included the nitric acid recovery unit, and various evaporator overheads.

This closure project was necessary for compliance with the Hazardous and Solid Waste Amendments of 1984 (RCRA), which state in part that an unlined surface impoundment may not receive, store or treat hazardous waste after 11/8/88. The wastes in the basins are hazardous because of the low pH and the presence of RCRA metals (chromium and mercury). Flow to the Seepage Basins was discontinued on 11/7/88. The F/H Effluent Treatment Facility replaced the seepage basins.

Soil core samples, sludge analyses, extraction procedure toxicity tests, influent characterization studies, basin liquid analyses, and groundwater sampling and analyses all provided data which were utilized in characterization efforts. The major contaminants in the stream were tritium, nitrate, sodium and mercury.

These characterization efforts led to design and construction which included placement of:

- aggregate for mechanical stabilization
- limestone and blast furnace slag for sludge stabilization
- soil fill
- a low permeability kaolin clay cap
- a sand drainage layer
- a geotextile membrane
- vegetative soil and cover

	F-Area Basins	H-Area Basins
Size	6.5 acres	15.5 acres
Average Received/ Year	35 million gallons	45 million gallons
Closure plan SCDHEC approved	6/23/89	6/23/89
Closure Completion Date	1/4/91	5/31/91
Closure Completion Due Date	1/23/91	8/23/91

Total Cost for Basins Closure = $17 M

"Before and After" photographs depicting the work performed are given in Figs. 5 and 6.



(a)



(b)

Fig. 5. H-Area seepage basin before work start (a) and during closure process (b).

MIXED WASTE MANAGEMENT FACILITY CLOSURE

The MWMF is a 58 acre section of the currently operating Low-Level Radioactive Waste Disposal Facility. The MWMF was identified as having received radioactive solid waste which contained some materials classified as mixed waste (radioactive and hazardous) under RCRA, such as lead, silver, cadmium, and waste oils. Consequently, the MWMF was closed per South Carolina Hazardous Waste Management Regulations.



Fig. 6. F and H-Area basins after closure.

Wastes were received in the MWMF from 1972 to 1986, it is estimated that wastes disposed in the MWMF consisted of job control waste (rags, gloves, overalls, etc.), soil construction debris, failed equipment, spent air filters, spent Li-Al targets, irradiated scrap metal, lead shielding, waste oil, etc.

Major construction activities consisted of dynamic compaction (waste stabilization, dropping 20 Ton weight from 42 ft.), fill placement, kaolin clay cap placement, vegetative soil placement, seeding, and concrete drainage structures.

Closure Plan approved by SCDHEC on 12/14/87

Closure complete per closure plan - 12/14/90

Cost = $35 MM

Photographs showing the MWMF and its closure are given in Fig. 7.

M-AREA SETTLING BASIN CLOSURE

The M-Area Settling Basin and associated areas are located in NW portion of SRS in the 300 Area. The M-Area HWMF consisted of (1) a settling basin, (2) an overflow ditch, (3) a natural seepage area, (4) a Carolina bay known as Lost Lake, and (5) an inlet process sewer line. The basin was an 8 million gallon (2.6 acre), unlined surface impoundment designed to settle and contain uranium and other metals discharged from the fuels and target fabrication process. Under South Carolina Hazardous Waste Management Regulations (SCHWMRs)promulgated in 1976, the waste stream was classified as F006-electroplating waste. Consequently, the basin was closed per SCHWMR.

Wastes were received in the M-Area Settling Basin from 1958 to 1985. The M-Area waste effluent contained metal-rich solutions, primarily nickel, aluminum, uranium, with high concentrations of nitrate, phosphate sulfate, and metal degreasers.

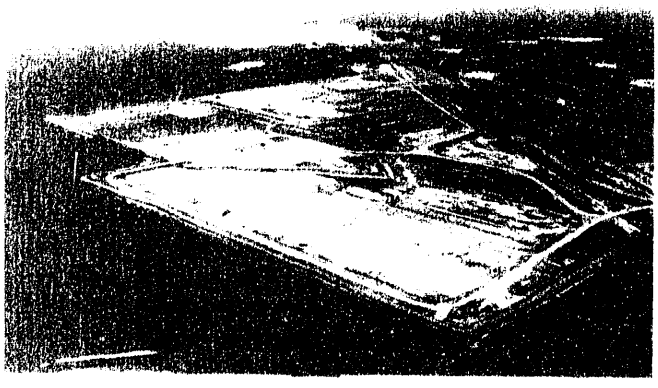
Major construction activities consisted of: basin dewatering with wastewater treatment, stabilization of basin and Lost Lake contaminated soils, backfilling these to the basin, placement of a kaolin clay cap, and placement and cultivation of a vegetative layer.

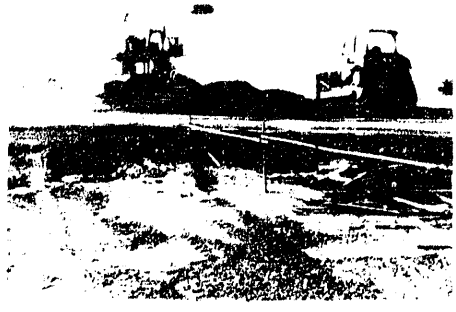
Closure Plan approved by SCDHEC - 7/87

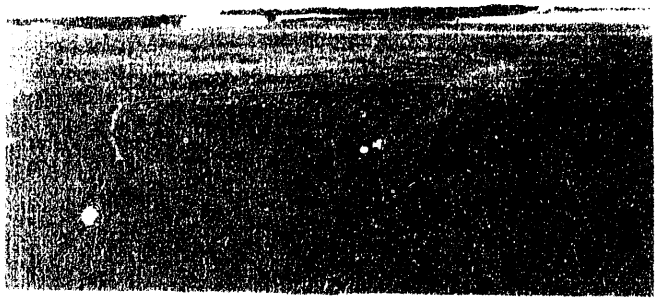
Closure complete per closure plan - 1/91

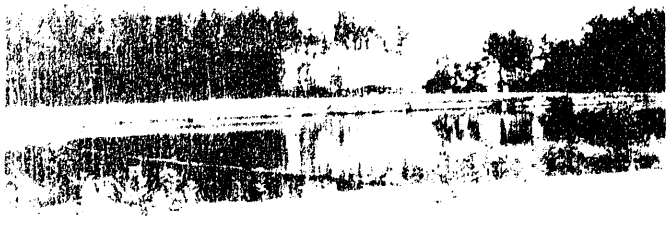
Closure certification accepted by SCDHEC - 5/91

Cost = $5 M











can begin as soon as the initial characterization data are attained. Early alternatives identification will proceed once the site characterization results are produced, with a Risk Evaluation of Remedial Alternatives accompanying these results. Significant cost and time savings have thus been achieved.

Another advancement is the development of Functional Performance Requirement (FPR) in parallel with the Feasibility Study (FS). As cited above, teams comprising experts responsible for the FPR, FS and Treatability Study interact closely to utilize an observational approach to optimize (overlap) document generation. Details of this optimization effort is detailed in W. D. Hoffman's paper, also available in this Conference Proceedings.

In addition, to facilitate the review of documents, a review group concept is being established and will be the subject of a future paper that will hopefully report on a very successful expedited process of regulator and DOE acceptance of remediation actions. The concept is referred to as the Technical Review and Acceptance Committee (TRAC).

SUMMARY

The Savannah River Site has reached a hallmark achievement in waste site closure progress. This progress represents a national milestone that was accomplished with a combination of a new, proactive attitude plus a commitment to a rigorous, Total Quality way that we conduct business. Using this philosophy, we are determined to continue our progressive approach, now to include regulatory documentation simplification, expedited review process, standardized design documents, etc.

ACHIEVING TECHNICAL CONSISTENCY AND MEETING TECHNOLOGY DEVELOPMENT NEEDS IN THE OAK RIDGE ENVIRONMENTAL RESTORATION PROGRAM*

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Martin Marietta Energy Systems, Inc.

ABSTRACT

In FY 1990, environmental restoration activities in progress and planned for the Oak Ridge Reservation (ORR) (the Oak Ridge Y-12 Plant, the Oak Ridge National Laboratory, and the Oak Ridge K-25 Site) and those programs in progress at the Portsmouth Gaseous Diffusion Plant and the Paducah Gaseous Diffusion Plant were consolidated into a single program operated by Martin Marietta Energy Systems, Inc., for the U.S. Department of Energy (DOE). The primary objectives of this consolidation are to ensure that the environmental restoration activities previously conducted independently at each of these five sites are being approached and managed consistently and key technical needs and issues are being resolved in a consistent manner. With the ORR designated as a National Priorities List site on December 21, 1989, and schedules and agreements negotiated as part of a Federal Facility Agreement for restoration of contaminated sites on the ORR, as well as Consent Orders and Consent Decrees affecting the Portsmouth and Paducah sites, the urgency and necessity of achieving technical consistency among the restoration activities being conducted under the auspices of the DOE Field Office, Oak Ridge are paramount. This paper describes the activities in progress and the needs and outlook for achieving technical consistency throughout the Oak Ridge Environmental Restoration Program. In addition to a description of the activities required to achieve technical consistency, requirements for technology development that address the unique contamination problems and geological settings of the ORR and the Portsmouth and Paducah sites and the similarities and differences between technology needs at other DOE sites are discussed.

INTRODUCTION

Martin Marietta Energy Systems, Inc., manages five major facilities in three states for the U.S. Department of Energy (DOE). Environmental restoration (ER) activities at these facilities involves interaction with regulators from three states and two regions of the U.S. Environmental Protection Agency. To improve the reliability and efficiency of these activities, a Central ER Program has been established to provide a focus in all aspects of regulatory activities, public relations, technology development, and management needed to conduct decontamination and decommissioning (D&D) and remedial action. The Central ER Program provides a mechanism for coordinating all restoration efforts to ensure that they are carried out in a technically consistent manner so that priorities at any site receive the attention needed and to ensure that lessons learned can be applied to all sites.

Representatives from the ER Program reside at each of the five sites to implement the restoration efforts and provide on-site management and technical direction. This paper describes the activities in progress and the needs and outlook for achieving technical consistency in the Oak Ridge ER Program. In addition, requirements for technology development recognizing the unique contamination problems and geological settings of the Oak Ridge Reservation (ORR) and the Portsmouth and Paducah sites are also described, as are the similarities and differences between technological needs at other DOE sites.

Following a discussion on the background leading to the establishment of the Oak Ridge ER Program and an overview of the five facilities, a description of the approach to achieving technical integration will be presented, followed by a summary of the Oak Ridge ER research and development needs.

BACKGROUND

Energy Systems manages five facilities for DOE in Tennessee, Kentucky, and Ohio. Three of these facilities are on the ORR in eastern Tennessee. The facilities were constructed in the early to mid 1940s as research, development, and production facilities in support of the Manhattan Project. ORNL was originally constructed to pilot production reactors and nuclear fuel reprocessing, but the facility has since evolved to engage in a variety of research and development activities. The Y-12 Plant originally tested electromagnetic separation of uranium isotopes but has since become a major manufacturing site for nuclear weapons components and materials. The K-25 Site contains the original gaseous diffusion facility. The gaseous diffusion plant is now shut down, but the site continues to be used to test several technologies, many related to waste handling and processing and ER. Besides the three facilities within the ORR, Energy Systems manages two gaseous diffusion plants, one near Paducah, Kentucky, and one near Portsmouth, Ohio. Both of these plants were built in the early 1950s.

The Oak Ridge ER Program consists of two major program activities: D&D and remedial action. The D&D Program activities on the ORR consist of five individual programs that are coordinated/integrated (along with the Paducah and Portsmouth D&D programs) through the DOE Field Office, Oak Ridge (DOE-OR) ER Division, with the Energy Systems Central D&D Program Office as integrating contractor. The central D&D Program Office was established in 1991. The five

* Managing contractor for the U.S. Department of Energy under contract DE-AC05-84OR21400.

programs are the Oak Ridge K-25 Site D&D; K-25 Site Gas Centrifuge Enrichment Facilities D&D; and D&D for select facilities from ORNL, the Oak Ridge Y-12 Plant, and Oak Ridge Associated Universities (ORAU). D&D, including surveillance and maintenance, provides for the safe caretaking and disposition of retired, DOE-owned nuclear facilities.

At this time, the D&D Program on the ORR consists of the 22 gas centrifuge enrichment structures at the K-25 Site, 52 other facilities at the K-25 Site, 17 shutdown projects at ORNL, Building 9201-4 at the Y-12 Plant, and some possible experimental animal facilities on the south campus of ORAU. The facilities currently included in the D&D Program are varied, including mercury-contaminated equipment and structures, hot cells, experimental reactors, and uranium enrichment equipment and structures. The various facilities have a wide variety of contaminants such as polychlorinated biphenyls (PCBs), friable and nonfriable asbestos, chlorofluorocarbons, chromates, lubrication oils, miscellaneous materials regulated by the Resource Conservation and Recovery Act, uranium, and other radionuclides.

The Oak Ridge ER Program was established in October 1989 with the specific purpose of integrating previously separate remedial action programs into a single, comprehensive program to focus the required regulatory, financial, managerial, and technical activities necessary to conduct needed cleanup actions. The Oak Ridge ER Program is responsible for cleanup actions on the ORR and at the Portsmouth and Paducah sites. The ORR, which consists of about 37,000 acres, contains over 600 identified solid waste management units (SWMUs) that require investigation and, perhaps, remediation. Similarly, the Portsmouth site covers 3800 acres in southern Ohio and contains 77 SWMUs distributed across the site, and the Paducah site consists of about 1350 acres in western Kentucky and contains 96 SWMUs distributed across the site.

Key responsibilities of the ER Program are as follows.

1. Identify sites for possible remediation (everyday operation of each site shall remain the responsibility of the site operator)
2. Perform health, safety, and environmental assessments of the sites. Assess the radiological or hazardous condition; determine the nature and extent of the contamination; determine the need for action based on assessments of the risk to the health and safety of the public, the environment, implementation safety, etc.; and evaluate remedial alternatives
3. Prepare documentation supporting the Record of Decision (ROD) for each remediation project
4. Perform the remedial design engineering for the sites
5. Remediate potentially contaminated DOE-controlled sites
6. Treat, store, or dispose of any collected or processed (treated and/or untreated) waste
7. Plan for postclosure surveillance and maintenance
8. Verify completion of each cleanup task
9. Provide complete permanent records of activities, decisions, and actions taken

APPROACH TO ACHIEVING TECHNICAL INTEGRATION

Achieving technical consistency within the Oak Ridge ER Program is being accomplished through the Technical Integration Programs Office in the Central ER Program. The Technical Integration Programs Office is responsible for ensuring site-to-site technical consistency, maximizing a single focus on common technical drivers and needs in the ER Program, and providing a technical resource to the individual site-implementation programs. Common technical drivers and needs in the ER Program are being met through the establishment of (1) a Central Groundwater Program Office, (2) an Office of Risk Analysis, (3) an Analytical Project Office, (4) an ER Waste Management Office, (5) a Technical Oversight and Review Team to provide technical consistency reviews, (6) an Oak Ridge Environmental Information System, and (7) a Regulatory Compliance Program that will focus regulatory compliance assessments, resolve noncompliances, implement National Environmental Policy Act (NEPA) requirements, and coordinate ER requirements called for in the state oversight agreements.

In a broader context, integration and consistency will be achieved through implementation of the integrating contractor responsibilities, which include not only a technical focus but also an administrative and managerial focus in the Oak Ridge ER Program.

Organizationally, the Oak Ridge ER Program involves several prime contractors, each fulfilling a valuable function in the overall accomplishment of the ER Program. The ORR ER Program roles and responsibilities are shown in Fig. 1. A similar organizational relationship exists at Portsmouth and Paducah. The Central ER Division at Energy Systems has been designated as the integrating contractor for remedial actions in the Oak Ridge ER Program.

The primary purpose of the integrating contractor role in the Oak Ridge ER Program is to ensure that all participants approach and conduct their tasks in a technically consistent and operationally similar manner and ensure a common focus for technical and administrative management. On the ORR, the primary contractors to DOE as of the date of this document are Energy Systems; Radian Corporation; Ebasco, Inc.; and MK-Ferguson. At Portsmouth and Paducah, Energy

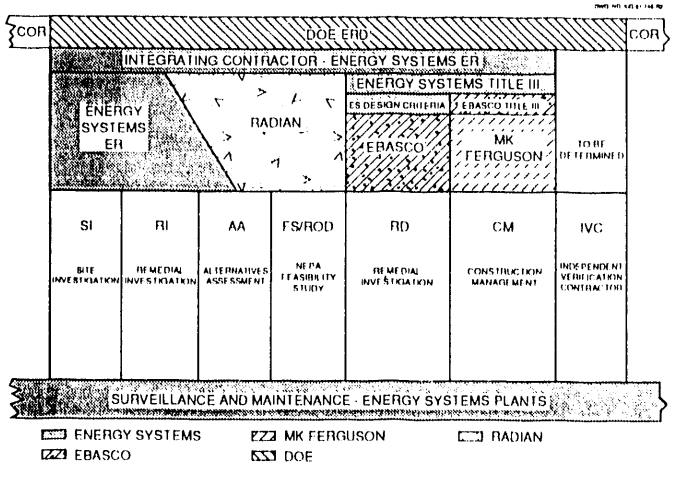


Fig. 1. ORR remedial action.

Systems; Science Applications International Corporation; Ebasco, Inc.; and MK-Ferguson are the primary contractors.

In fulfilling its role as integrating contractor, Energy Systems is the focal point each year for coordinating the preparation of the activity data sheets, contributing to five-year planning efforts, the site-specific plans, budgets, schedules, and budget packages for the prioritization process. In this integrating contractor role, the ER Division conducts meetings, collects information, and assembles total packages related to these activities for use by DOE-OR. The ER Division ensures that technical consistency is achieved among the participants in areas such as risk assessment, NEPA compliance, analytical services, and waste management among others. The ER Division also has primary responsibility for reporting the total program cost and schedule status each month. Budget, cost, schedule, and progress information is obtained from the technical support contractor (Radian Corporation), the remedial design contractor (Ebasco), the construction manager, and DOE-OR each month, and this information is consolidated in the monthly status report.

Additional responsibilities of the integrating contractor involve the following:

- Evaluating other DOE prime contractor, subcontractor, and prospective subcontractor ER programs, procedures, systems, processes, and policies regarding health and safety, housekeeping, environmental requirements, radiation protection, security, quality assurance, and related operations
- Providing coordination with plant operations with respect to any field work, including remedial investigations and remedial actions
- Evaluating design, strategies, and sequencing of work with respect to the remedial design architect and engineer, in accordance with existing project management procedures
- Preparing ER Program technical and administrative policies and procedures for use by ER Program participants
- Participating in and operating the Levels I and II Change/Configuration Control Boards chaired by DOE-OR. The Energy Systems ER Division will process and maintain all change requests and approvals for DOE-OR ER Program projects
- Coordinating technical reviews of all products, plans, schedules, and documents prepared by all ER Program participants in fulfillment of regulatory deliverables to ensure consistency of technical approach, adequacy, and completeness of the assessments and to ensure that regulatory requirements are being met
- Providing waste management treatment, storage, and disposal services for management of ER-originated wastes in a manner that is consistent with regulations
- Conducting a rigorous self-assessment program to evaluate regulatory compliance and procedure adherence during the conduct of ER activities
- Developing and operating the Oak Ridge Environmental Information System, which will be used to manage all environmental data produced on the ORR
- Coordinating and evaluating priorities for ongoing and proposed activities designed to ensure that the highest priority remediation projects are funded and pursued commensurate with DOE funding availability balanced against public/community concerns, regulatory requirements, human health and environmental risk assessments, and institutional considerations

TECHNOLOGY NEEDS

With the establishment of the Central ER Program, the need for less expensive and more technically effective technologies at each facility has become apparent. In evaluating the overall restoration needs at Portsmouth, Paducah, and Oak Ridge, it has also become apparent that there will be difficulties in meeting those regulatory expectations and requirements within expected budgets unless new technologies become available. Thus, the identification and development of innovative technologies for ER has become an important part of the ER Program.

Each DOE-OR facility in the ER Program includes different types of facilities and a wide range of geological settings. These conditions may give the DOE-OR ER Program the widest range of environmental challenges in the DOE system and, subsequently, some of the greatest needs for research, development, design testing, and evaluation.

Some challenges are being addressed with current technology; many other challenges are similar to those encountered at other DOE sites. The program acknowledges problems common to other sites but also points out other problems believed to be sufficiently different from those at other sites such that innovative technologies or modification of existing technologies will be needed to meet our goals. For some technologies not currently available, there are integrated demonstrations that address the problems. There is special concern for needs that are likely to require solutions before the planned integrated demonstrations can be performed.

Although the technology needs described here are all of high priority, no attempt is made to place them in an absolute order of priority. Priorities in technology needs often change with time. In many cases, new problems are discovered or situations occur that make problems more urgent. Regulators use their own assessments, and this also plays an important role because their assessment of priorities must be considered.

Two technology needs assessments have been performed during the past year. An internal evaluation assessed technology needs and opportunities generally but focused upon the better known needs. The results of that assessment drew particular attention to the need for better methods of characterizing contaminated sites to determine the location, amount, and chemical state of pollutants. Results of the internal evaluation are given in Table I. The second assessment was carried out by Geotech, Inc., under contract to the DOE Headquarters Office of Technology Development. This study focused on specific environmental problems at each ORR facility. Results of the Geotech study are given in Table II.

Although the two studies approached the problem in different ways, there is similarity in the final results. The internal study assembled a group of experts, accumulated their opinions and recommendations, and used a workshop

environment to discuss and assess the summed opinions. The Geotech study used a smaller team of outside experts who interviewed principals from each site and discussed the environmental problems. Thus, the input to the Geotech study was from those directly involved in ER, but the assessment was done by an outside contractor. The internal study emphasized the use of internal technical experts. Because of its approach, the Geotech study focused upon specific site needs and then raised questions of the technology available and technology needed to solve those problems. The internal study looked for general areas where technologies could make important differences, preferably at several sites. The general agreement between the two studies probably results largely because there are many similar needs that appear at site after site.

The highest priority needs identified by the Geotech study were methods for reducing and controlling groundwater contamination at ORNL, treatment and control of surface water and sediments at ORNL, remediation of low-level waste tanks at ORNL, remediation of groundwater contamination at the former gaseous diffusion plant (K-25), correction of groundwater contamination at the Y-12 Plant, control and remediation of groundwater contamination both on site and

TABLE I

Summary of Oak Ridge ER Programs Technology Needs: Self Evaluation

Site Characterization Needs	Nonintrusive or minimally intrusive leak testing of underground storage tanks
	Nonintrusive techniques for locating waste trenches and auger holes
	Nonintrusive methods for characterizing drummed contaminants and other buried objects
	Methods for sampling hot vaults through building floors
	Nonintrusive methods for characterizing the extent of free contaminants in burial grounds
	Methods for defining deep and intermediate groundwater flow systems
	Groundwater flow and contaminant transport models
	Field methods for real-time measurement of organics, radionuclides, and heavy metals
	Data base of trends and patterns for various types of data generated
	Qualitative field analytical methods that can be adopted by regulators
Site Remediation Methods	Remediation of soils contaminated with radionuclides and/or other metals
	Remediation of soils contaminated with organics
	Remediation of soils contaminated with mercury
	Methods for confining/fixing contaminants in soils and sludges
	Treatment of groundwater contaminated with radionuclides
	Treatment of groundwater contaminated with organics
	Treatment of groundwater contaminated with mixed wastes
	Treatment of groundwater and runoff to remove tritium
	Confinement of contaminated groundwater
	Treatment of groundwater containing soluble anions (nitrates, sulfates, halides, etc.)
	Decontamination of concrete surfaces contaminated with heavy metals
Miscellaneous Needs	Development of consolidated data base/information system
	Development of more appropriate information and methods for risk assessments

TABLE II

Summary of Oak Ridge ER Program Characterization, Treatment and Remediation Technology Needs Identified by Geotech

High Priority	Groundwater contamination at Oak Ridge National Laboratory (ORNL)
	Surface water and sediment contamination at ORNL
	Low-level waste tanks at ORNL
	Groundwater contamination at the Oak Ridge K-25 Site (K-25)
	Surface water contamination at K-25
	Groundwater contamination at the Oak Ridge Y-12 Plant (Y-12)
	Groundwater contamination on site and off site at Paducah
	Surface water and sediment contamination at Paducah
	Off-site mercury contamination at Y-12
Medium Priority	Buried wastes at ORNL
	Buried wastes at K-25
	Soils and buried wastes at Y-12
	Buried wastes at Paducah
	Buried wastes and soil and groundwater contamination at Portsmouth
Lower Priority	Biota (trees) and soil contamination at ORNL
	Soil contamination at K-25
	Soil contamination at Paducah
	Surface water contamination at Portsmouth
	Off-site groundwater contamination at Oak Ridge

off site at the Paducah Gaseous Diffusion Plant, and mercury contamination on site and off site in Oak Ridge. The lower priority needs identified by the Geotech study are given in Table I.

As expected, there are similarities in the contaminants that have been found in the soils, burial grounds, and surface water and groundwater around the three Oak Ridge, Paducah, and Portsmouth facilities. Uranium and technetium are the principal radioactive contaminants, but traces of other radioactive materials can be found. There are also significant quantities of chlorinated organic compounds such as trichloroethylene, trichloroacetic acid, dichloroethylene, and PCBs.

Despite the similarities in the nature of contaminants present at the DOE-OR sites, there are important differences in the most urgent environmental problems, due in part to differences in the soil and geology. The geology in the Oak Ridge area is very highly fractured from the extensive folding that occurred with the formation of mountains and ridges in the region. This complicated underground structure often makes it difficult to predict how pollutants travel underground. The underground structure and the heavy rainfall in the region can cause movement of contaminants from the immediate region of buried wastes. In one case, a seep of water containing regulated levels of organic pollutants has emerged from the side of a small hill containing buried wastes. Ponds and lagoons that received organic pollutants and traces of radioactivity will require treatment, and there are locations throughout the facility where solvents and/or uranium have been found in soils near the surface. Better methods for characterizing the soils and the underground environment are needed, as are methods for removing or fixing organics, uranium, technetium, etc., in soils.

The Portsmouth facility is noted for its very tight (nonporous) soils. This often reduces spread of contaminants, but it also makes it difficult to remove materials once the soils become contaminated. Plans to use conventional soil venting to remove volatile organic compounds (principally trichloroethylene) from one site at the facility failed because of the extremely low permeability of the soil. Nevertheless, one cannot rely upon tight soils to retain pollutants; contamination has spread through the facility, perhaps along pipelines and other paths where construction disturbed the low permeable soils. Underlying the tight clays is a region of more porous materials; contaminants reaching the more permeable regions can be transported and spread more easily. Contamination has reached the groundwater in a few cases and even moved near the site boundary. The needs for technology development at the Portsmouth facility are similar to those at the K-25 Site, but the technologies must also be applicable to low permeable soils. This difference is particularly important to in situ remediation technologies that are likely to depend on transport of contaminants and/or treatment agents through the soils. The Oak Ridge ER Program is currently planning tests of deep-soil mixing methods for augmenting conventional air/steam stripping and fixation methods for treating volatile contaminants.

The Paducah facility in Kentucky is built on a site with relatively permeable soil. The major contaminants are similar to those at the other gaseous diffusion facilities, but because of the higher permeability of the soils movement of contaminants is a more serious problem. Groundwater plumes have even moved off site. This situation creates a need for better technologies for controlling the movement of pollutants in such porous soils and a need for more accurate locating and efficient removal of contaminants. Remediation technologies that require injection of treatment agents such as organisms, nutrients, and oxygen for biodegradation of organic pollutants will have less difficulty with the injection step in such soils, but the treatment will have to be rapid to compete with movement of the contaminants.

The Y-12 facility at Oak Ridge has had a varied history, and its environmental problems reflect that history. It began as the site for electromagnetic separation of uranium isotopes. The facility evolved into a site for machining and manufacturing components, including the use of uranium metal and uranium compounds. The Y-12 facility was also used to separate lithium isotopes; large quantities of mercury were used in those operations. In addition, the Y-12 Plant has maintained a significant development effort with its own laboratories and is also host to a portion of ORNL. These operations have produced a variety of general laboratory wastes, including numerous materials that are now known to be hazardous. The need for new technologies for this facility alone are impressive. The main site contains regions with uranium and organic solvent contamination somewhat like that at other sites, but mercury and dense, nonaqueous-phase liquid contaminants are of particular concern. The mercury contamination seeps from tanks, pipes, some buried wastes, and soil under and around the buildings that were used to separate lithium isotopes. Dissolved or suspended mercury has been carried off the site into East Fork Poplar Creek, where it has accumulated in sediment. Improved technologies are needed to locate and remove the sources of mercury, to eliminate or reduce the rate of mercury transport in groundwater, and to remove or stabilize mercury in sediments. The Y-12 Plant, like the K-25 Site, consists of complex and highly fractured geology. Traditional drilling techniques for locating contaminants can actually do more harm than good with both mercury metal and dense, nonaqueous-phase liquids, because the drill holes provide an additional path for the heavy phases to move farther down into the ground and spread the contamination. The Y-12 burial grounds also contain an unusual problem with pyrophoric materials such as uranium metal and potentially explosive chemicals that were buried in pits. Entrance of personnel onto the ground over the pits is likely to be limited and possibly even prohibited. Improved technology for robotic earth moving, grading, and covering is required.

Both the immediate ORNL site and the surrounding burial grounds offer a particularly wide range of environmental problems, and there are no practical solutions to many of these problems. The wide variety of research and development at ORNL during the last 48 years left numerous wastes and disposal problems. The problems were made even more complex when ORNL was designated for a period to receive wastes from other DOE sites. Thus, there are also wastes at the laboratory area that are not even representative of those generated in the laboratory operations. Regions of soil contamination have been found in the immediate vicinity of the laboratory buildings. These areas of soil contamination are believed to result from waste spills and underground pipe failures that may have occurred at any time during the last 48 years. The locations of such pipe leaks are difficult to assess because the contaminants are likely to follow the trenches surrounding the piping where the ground around the pipes

was disturbed when the pipes were laid. The soil around the pipes is less dense and may even contain gravel fill, which provides a preferred direction for flow along the path of the pipe. Contamination in the soils immediately surrounding waste collection tanks could come from either pipe or tank leakage. Assessment and remediation of such problems is difficult when the location of the source of the problem is not certain. Better methods are needed to locate contamination boundaries and to remove or fix the contaminant.

Liquid, radioactive wastes have been pumped to an adjoining valley for treatment and disposal, and solid wastes have been shipped to the same areas for disposal. The region surrounding ORNL contains several disposal sites where pollutants have been buried. As with many sites, the completeness of the records on these burial sites depends on the age of the burial ground; only the more recent records are relatively complete. The radioactive materials in the burial sites include a wide range of radioisotopes from early work at ORNL in nuclear fuel processing, radioisotope production, transuranic element production, and in numerous smaller laboratory experiments. Some of the burial sites are located relatively close to a small creek that flows into the Clinch River, and some contaminants (particularly cesium, strontium, mercury, and tritium) have been detected in the creek and/or in sediments in the Clinch River. Better methods of containing the radioactive materials in these burial grounds are needed, and the burial grounds have been found to be suitable sites for several tests of new and innovative approaches to containment of wastes. These tests have included compaction of the trenches to reduce water flow through the trenches, grouting to control water flow, and the recent ongoing tests of in situ vitrification. The smaller size of the burial trenches and the waste tanks at ORNL make them more appropriate for many tests and demonstrations than the often much larger tanks and burial grounds at other DOE sites.

The sites at Oak Ridge, Portsmouth, and Paducah need improved technologies for both characterizing and remediating environmental problems. Many environmental problems at these sites are similar to those at several other DOE facilities, and the smaller scale of some of the problem sites makes them particularly suitable for testing new technologies. However, these sites also have some problems that are unique and represent specific technology needs.

CONCLUSION

Achieving technical consistency in the Oak Ridge ER Program is essential for the successful conduct of required remediation and cleanup activities. A comprehensive organization has been established and implemented, drawing on the nationally recognized expertise of ORNL and the commercial resources available in Oak Ridge and nationally. The requirements for achieving technical consistency are complex, and the requirements that must be met often conflict. Nonetheless, through the integrating contractor focus in the Oak Ridge ER Program, plans have been implemented in areas such as groundwater monitoring, analytical operations, risk assessment, regulatory compliance, environmental information management, waste management, and NEPA compliance, which will ensure consistency when fully in place.

In addition, an integral part of the Oak Ridge ER Program is identifying and solving technology needs to make the investigation and remediation of contaminated sites less complex and less expensive. The focus provided by identifying technology needs and communicating information to the organization on developed and implemented technologies contributes greatly to achieving the needed consistency.

RCRA CLOSURES AT ROCKY FLATS PLANT
A PROGRAMMATIC PERSPECTIVE AND CASE STUDY

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ABSTRACT

The Interagency Agreement (IAG) integrates a unique mechanism for remediating hazardous waste sites at the Rocky Flats Plant (RFP), which include utilizing RCRA and CERCLA technical/regulatory processes.

Pursuant to the IAG signed by the Department of Energy (DOE), Environmental Protection Agency (EPA), and the Colorado Department of Health (CDH) on January 22, 1991, sixteen operable units (OUs) were defined for characterization and remediation at RFP (1). Of the sixteen OUs, six are classified as Resource Conservation and Recovery Act (RCRA) closure units. The six RCRA interim status closure units are: Solar Evaporation Ponds-OU4, Present Landfill-OU7, Original Process Waste Lines-OU9, Other Outside Closures-OU10, West Spray Field-OU11, and Inside Building Closures-OU15. The IAG will function as a technical/regulatory mechanism for managing/complying with all aspects of the RCRA interim status closure units at RFP.

INTRODUCTION

The Rocky Flats Plant (RFP) is a Government-owned, contractor-operated facility, part of the nationwide nuclear weapons complex which began operations in 1952. Operations at the plant consist of fabrication of nuclear weapons components from plutonium, uranium, and other nonradioactive metals. The plant is managed and operated by EG&G Rocky Flats, Inc. (EG&G), a contractor to the Department of Energy (DOE).

RFP is located in northern Jefferson County, Colorado, approximately 16 miles northwest of Denver along the eastern edge of the southern Rocky Mountain region immediately east of the Colorado Front Range (2). The RFP consists of approximately 6,550 acres of federal land, 400 acres being the Protected Area and 6,150 acres being other industrial areas and the Buffer Zone (Fig. 1).

Pursuant to the RFP Interagency Agreement (IAG) signed by DOE, Environmental Protection Agency (EPA), and Colorado Department of Health (CDH) on January 22, 1991, sixteen operable units (OU's) were defined for characterization and remediation at RFP. Of the sixteen OUs, six are interim status Resource Conservation and Recovery Act (RCRA) closure units. In accordance with the IAG, the interim status RCRA closure units external to buildings (4, 7, 9, 10 and 11) will be addressed in two phases. Phase I addresses the sources and soils and Phase II addresses ground water, surface water, air, the environment and biota. The IAG requires RFP to integrate applicable RCRA and Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) requirements for all environmental related activities associated with the IAG, including RCRA closure units.

INTERAGENCY AGREEMENT

Rocky Flats IAG, signed by DOE, EPA and CDH on January 22, 1991, will function as a technical/regulatory mechanism for managing/complying with all aspects of RCRA interim status closure units at RFP. The IAG dictates the regulatory framework for ensuring compliance and managing RCRA closure units, which include RCRA 40 CFR Part 265/Colorado Hazardous Waste Act (CHWA) regulations (6 CCR 1007-3) Part 265 Subpart G Closure and Post-Closure (Part 264), Part 265 Subpart F Ground Water Monitoring, corrective action requirements of sections 3004(u) and (v) of RCRA, and CERCLA and the National Contingency Plan (NCP) (1). Although the state of Colorado/CDH has primacy for all RCRA closure units at RFP, the IAG requires applicable CERCLA regulations/guidance to be integrated as part of the closure process, including Applicable or Relevant and Appropriate Requirements (ARAR's), Baseline Risk Assessments (BRA), and Environmental Evaluations (EE).

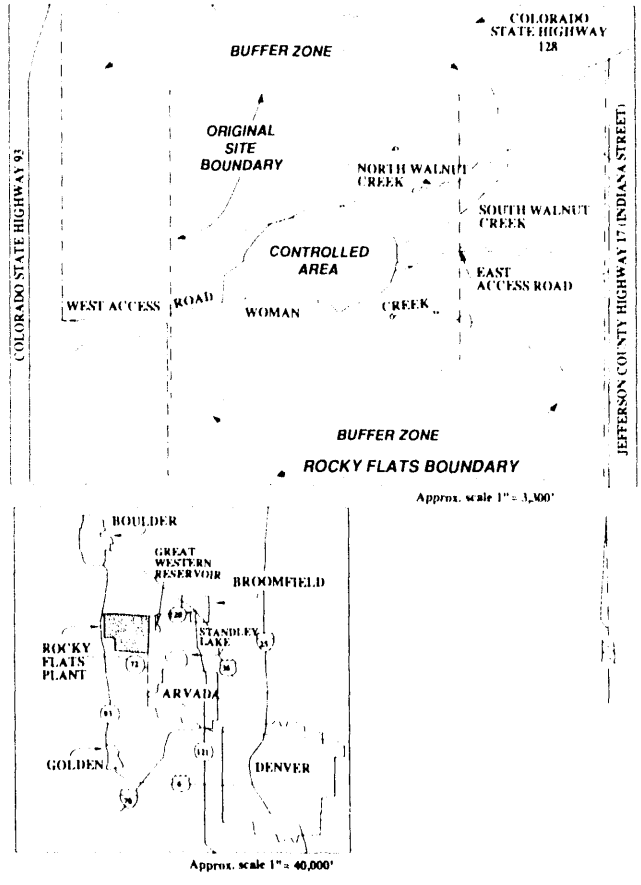


Fig. 1. Rocky Flats location maps.

RESOURCE CONSERVATION AND RECOVERY ACT CLOSURE UNITS

Operable Unit 4-Solar Evaporation Ponds

RFP has operated the Solar Evaporation Ponds (SEP), located in the Protected Area (PA), for the disposal of miscellaneous wastes since 1952 however, process wastes have not been placed in the ponds since mid-1986. They have been used primarily to store and treat (by evaporation) low-level radioactive waste, hazardous waste, sanitary waste and non-hazardous wastes. The SEP consists of five impoundments identified as ponds 207-A, 207-B North, Center, and South, and pond 207-C, with a total capacity of 10.7 million gallons and a surface area of 5.4 acres (2).

A French Drain and Interceptor Trench Pump House (ITPH) System was installed down-gradient of the SEP to collect and pump back contaminated ground water as a result of leakage from the SEP. The primary purpose of this system is to prevent contaminants from entering into north Walnut Creek via ground water flow. Since the SEP are currently under closure, additional measures are being implemented to manage the contaminated ground water.

In accordance with 6 CCR 1007-3 Part 265.93(d), ground water monitoring is required and being conducted at the SEP. Currently, there are 62 wells that are monitored in the SEP area (3). There are 29 alluvial wells, 14 screened in the Rocky Flats alluvium, 9 in colluvium, and 6 in valley fill alluvium (3). Bedrock wells total 33 (3). Sixteen wells are screened in weathered claystone, 7 in weathered sandstone, and 10 in unweathered sandstone (3). Ground water sampling data and hydrogeologic investigations have indicated that the SEP have contaminated alluvial ground water. Down-gradient contaminants from the SEP include: some major ions, nitrates, uranium, tritium, and some metals. Volatile organic contamination is limited and may not be a result of the SEP. Ground water in shallow bedrock in hydraulic connection with the alluvium has also been impacted by the SEP based on ground water sampling data.

Operable Unit 7-Present Landfill

The Present Landfill-Operable Unit 7 is located north of the plant complex on the western end of an unnamed tributary of North Walnut Creek and is comprised of Individual Hazardous Substance Site (IHSS) 114 (landfill) and Inactive Hazardous Waste Storage Area-IHSS 203 (4). The landfill became operational in August 1968 and was originally constructed to provide for disposal of RFP's nonradioactive and nonhazardous solid wastes. In September 1973, tritium was detected in leachate from the landfill (4). During the mid-1980's, extensive investigations were conducted on the waste streams being disposed into the landfill, and consequently, hazardous wastes/hazardous constituents were identified (4). Because records indicate that hazardous waste was disposed at the landfill, it was designated a RCRA Subtitle C regulated unit in 1986.

An alternate ground water monitoring program has been implemented at the Present Landfill in accordance with 6 CCR 1007-3 Part 265 Subpart F 265.90(d).

Operable Unit 9-Original Process Waste Lines

The Original Process Waste Lines (OPWL)-Operable Unit 9 consists of a system of tanks and associated pipelines constructed to transport and temporarily store process wastes. The OPWL system became operational in 1952 with numerous additions to the system through 1975 (5). The OPWL was replaced during the 1975-1983 time period by the new process waste system (5). OPWL transported and/or stored various aqueous process wastes containing low-level radioactive materials, nitrates, caustics and acids. Other liquids were also introduced into the system, including pickling liquor from foundry operations, medical decontamination fluids, miscellaneous laboratory liquids and laundry effluent (5).

Pipe sections of OPWL have an approximate length of 35,000 feet. Approximately 13,000 feet of the pipes are located beneath buildings and a similar amount are located within areas where other utility lines are interwoven with the system (5). At several locations, active and inactive utility lines have been placed in the same trenches adjacent to the OPWL, which has resulted in congestion of numerous underground lines at several locations.

Operable Unit 10-Other Outside Closures

Other Outside Closures (OOC)-Operable Unit 10 is comprised of sixteen individual hazardous substance sites (IHSS) at various locations of RFP. In general, OOC consists of a variety of IHSS, including: radioactive/hazardous waste storage tanks, cargo container storage facilities, acid dumpsters/sumps, and mixed/hazardous waste drum storage units (6). The two substantial IHSS in OU10 include the 750 and 904 pads which are being utilized to store ponderete and saltcrete.

Operable Unit 11-West Spray Field

The West Spray Field (WSF)-Operable Unit 11 is undeveloped land within the Buffer Zone located on the west side of the Plant and consists of approximately 105 acres.

The WSF operated from April 1982 through October 1985 (7). During operations, excess liquids from the Solar Evaporation Ponds (SEP) were pumped to the WSF for spray application. The total combined area of direct application is approximately 14 acres. Liquids applied in the WSF were derived from SEP 207-B North and 207-B Center. Approximately 66,000,000 gallons of waste-water were applied at the WSF during operation (7). Of this quantity, approximately 9,000,000 gallons were taken from Pond 207-B North, and 57,000,000 gallons were taken from Pond 207-B Center (7).

The contents in Pond 207-B North during operation of the WSF generally consisted of ground water collected in the French drain system located down-gradient of the SEP. The liquid collected in Pond 207-B North is characterized typically by high nitrate concentrations, elevated gross alpha, gross beta, uranium, and trace levels of volatile organic compounds (VOC's). The liquid contained in Pond 207-B Center consisted of treated sanitary effluent from RFP sanitary wastewater treatment plant (7). The sanitary effluent was characterized by elevated nitrates, gross alpha and gross beta (7).

The WSF is subject to RCRA ground water monitoring requirements in accordance with 6 CCR 1007-3 Part 265 Subpart F. Twenty alluvial wells and three bedrock wells are sampled quarterly at the WSF to comply with CHWA ground water regulations (3).

Operable Unit 15-Inside Building Closures

Inside Building Closures (IBC)-Operable Unit 15 is comprised of eight RCRA interim status closure units. IBC units consists primarily of mixed and/or hazardous waste drum

storage areas. These units contained a variety of wastes including: oils, coolants, solvents, waste paints and metals. RCRA closure plans have been developed for these units, and in addition, an RFI/RI work plan will be prepared to evaluate the environmental media adjacent to the IBC units.

INTERAGENCY AGREEMENT RCRA CLOSURE PROCESS

Phase I

For RCRA interim status closure units external to buildings (OUs 4, 7, 9, 10, and 11), the regulatory process entails two phases. The first step in Phase I requires the development of "Phase I RFI/RI Work Plans" which are designed to characterize the sources and soils of each interim status unit and provide the information necessary to determine the risk associated with the source of contamination at each closure unit (1). The second step requires the implementation of the approved Phase I RFI/RI Work Plan in accordance with the IAG schedule and, subsequent data validation. Following data validation, a "Phase I RFI/RI Report" is generated which is used by the regulatory agencies to identify additional work/investigations to be performed, if applicable, and provide information to support a "draft Baseline Risk Assessment" (1). Subsequent to approval by the regulatory agencies for the Phase I RFI/RI Reports, a "draft Proposed Phase I Interim Measure/Interim Remedial Action (IM/IRA) Decision Documents" will be prepared for regulatory review. The draft proposed Phase I IM/IRA Decision Documents will be designed to provide the information required to recommend an alternative consistent with the State of Colorado hazardous waste closure regulations (1). The draft Proposed Phase I IM/IRA Decision Document will address all hazardous substance source areas with risk levels greater than $1x10^{-6}$ evaluated at the source, and require the remediation of all source areas exhibiting risk levels greater than $1x10^{-6}$ evaluated at the source. Subsequent steps to the approved IM/IRA Decision Document include, engineering design work plans (title I and II), IM/IRA Implementation Documents, and construction activities (1).

Phase II

The first step in Phase II requires the development of "Phase II RFI/RI Work Plans" which will be designed to evaluate (nature and extent of contamination) the subsequent impact of each interim status closure unit on surface water, ground water, air, and biota. The second step, as with phase I, requires the implementation of the approved Phase II RFI/RI Work Plans in accordance with the IAG schedule and, subsequent data validation. Following data validation, a Phase II RFI/RI Report is generated which evaluates the IM/IRA implemented at each source, as appropriate, and will include draft comprehensive Baseline Risk Assessments (1). The draft comprehensive Baseline Risk Assessments will evaluate risk associated with both the sources and the resultant environmental contamination. The draft Phase II RFI/RI Reports will be used by the regulatory agencies to evaluate the need for conducting additional field work/investigations and provide the information to be used to support the draft "Phase II Corrective Measure Study/Feasibility Study (CMS/FS) Reports" (1). The draft Phase II CMS/FS Reports will evaluate corrective/remedial measures to address both the sources and contamination resulting from the sources, and consequently, a "Phase II Corrective and Remedial Action Proposed Plan" will be developed (1). Following approval of the Phase II Corrective and Remedial Action Plan, a "Phase II Corrective Action Decision/Final Action Decision" document, "Phase II Corrective/Remedial Design" document, and "Phase II Corrective/Remedial Action" plan will be prepared (1).

OPERABLE UNIT NUMBER 7 CASE STUDY

Abstract

Operable Unit Number 7 (OU 7) is one of the 16 Operable Units (OUs) specified in the Interagency Agreement (IAG) signed by the Environmental Protection Agency (EPA), the Colorado Department of Health (CDH) and the Department of Energy (DOE). OU 7 consists of Individual Hazardous Substance Sites (IHSS's) Numbers 114 (Present Landfill) and 203 (Inactive Hazardous Waste Storage Area) (1). The Present Landfill and the Inactive Hazardous Waste Storage Area have been determined to be subject to the Resource Conservation and Recovery Act (RCRA) due to the disposal/storage of hazardous wastes. The IAG requires that two phases of investigation be conducted at the RCRA OU's. Phase I is specified by the IAG to characterize the source/soils of each interim status unit which shall provide the information necessary to determine the risk associated with the source of contamination" (1). Further, the IAG directs the Phase II investigations to evaluate "the nature and extent of contamination resulting from the release of hazardous substances from the interim status closure units" (1). The information obtained from the Phase I and II investigations will be utilized to support a Baseline Risk Assessment, an Environmental Evaluation, and any corrective measures proposed for the site (1). The Final Draft Phase I RFI/RI Work Plan for OU 7 has been submitted to the agencies for review and work is scheduled to begin in August 1992.

Introduction

While undergoing Part B permitting activities for the Rocky Flats Plant (RFP) in 1986, RCRA hazardous wastes were determined to have been disposed of in the Present Landfill (4). Procedures were then implemented to discontinue hazardous waste disposal in the Present Landfill. A RCRA Closure Plan was developed in 1986 for the landfill and revised in 1988, after comments were received from the regulatory agencies. In 1990, an Interagency Agreement (IAG) was drafted between the Department of Energy (DOE), the Environmental Protection Agency (EPA), and the Colorado Department of Health (CDH). Since both Resource Conservation and Recovery Act (RCRA) and Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) guidance are included in the IAG, a combined RCRA Facility Investigation (RFI)/Remedial Investigation (RI) approach must be utilized at the Present Landfill. Individual hazardous substance sites (IHSS) are identified in the IAG and grouped into Operable Units (OUs) for investigation purposes. The scheduled tasks for the landfill contained within the IAG supersede all previous closure activities. The Inactive Hazardous Waste Storage Area lies within the boundary of the Present Landfill and is, therefore included in OU 7. CDH is the lead agency for this investigation because it has RCRA Authorization and the Present Landfill and Inactive Hazardous Waste Storage Facility were initially identified as RCRA facilities.

The IAG requires that two phases of investigation be conducted at the RCRA OU's. Phase I is specified by the IAG to "characterize the source/soils of each interim status unit which shall provide the information necessary to determine the risk associated with the source of contamination". Further, the IAG directs the Phase II investigation to evaluate "the nature and extent of contamination resulting from the release of hazardous substances from the interim status closure units" (1).

The first Draft Phase I RFI/RI Work Plan was submitted to the regulatory agencies in June 1990 and comments were received from EPA and CDH in November 1990 and April 1991, respectively. A second draft of the work plan incorporated agency comments and was again submitted to the agencies on August 28, 1991. The agencies are scheduled to review and approve the work plan by September 27, 1991.

Background

The Present Landfill was designed for disposal of the RFP's nonradioactive solid waste. Operations began in 1968 and continued until September 1973, when tritium was detected at the drainage (4) Forty seven monitoring wells were immediately installed in and around the landfill to locate the tritium source and the extent of contamination (4). In addition, two temporary ponds (the East and West Pond) were constructed to collect and contain any leachate or surface water generated by the landfill (4). Once the boundaries of the tritium source were identified, options to restrict tritium migration were evaluated. The option selected consisted of installation of a leachate collection system, a ground water diversion system, surface water control ditches and two ponds to collect and store leachate, surface water, and intercepted ground water (Fig. 2).

Since the detection of the tritium contamination, many investigations have been conducted at the Present Landfill. These include four geotechnical investigations in the 1970's for landfill expansion and renovation, two hydrogeologic characterizations and two soil gas surveys (4). Thirty five ground water monitoring wells have been installed to satisfy RCRA ground water monitoring requirements, but additional wells are required to achieve full compliance (3). Sampling and analysis of the wells are reported in annual RCRA ground water monitoring reports. The results of these previous investigations were evaluated to determine data gaps and the need for additional requirements for the Phase I RFI/RI project. No previous investigations and very limited historical information regarding waste operations exists for the Inactive Hazardous Waste Storage Area (4).

Between 1977 and 1981, the landfill was expanded and the leachate and ground water collection systems and the West Pond were covered. In addition, two slurry walls were constructed to extend the existing leachate/ground water systems (4).

Presently, the effectiveness of the leachate collection/ground water diversion system is unknown, but previous studies indicate that in several locations it may be ineffective in controlling the movement of leachate and ground water. Additional wells are required to adequately assess the systems effectiveness.

Leachate seeps from the landfill into the existing East Pond. Surface water runoff also contributes to the East Pond. Sampling has indicated trace amounts of volatile organic

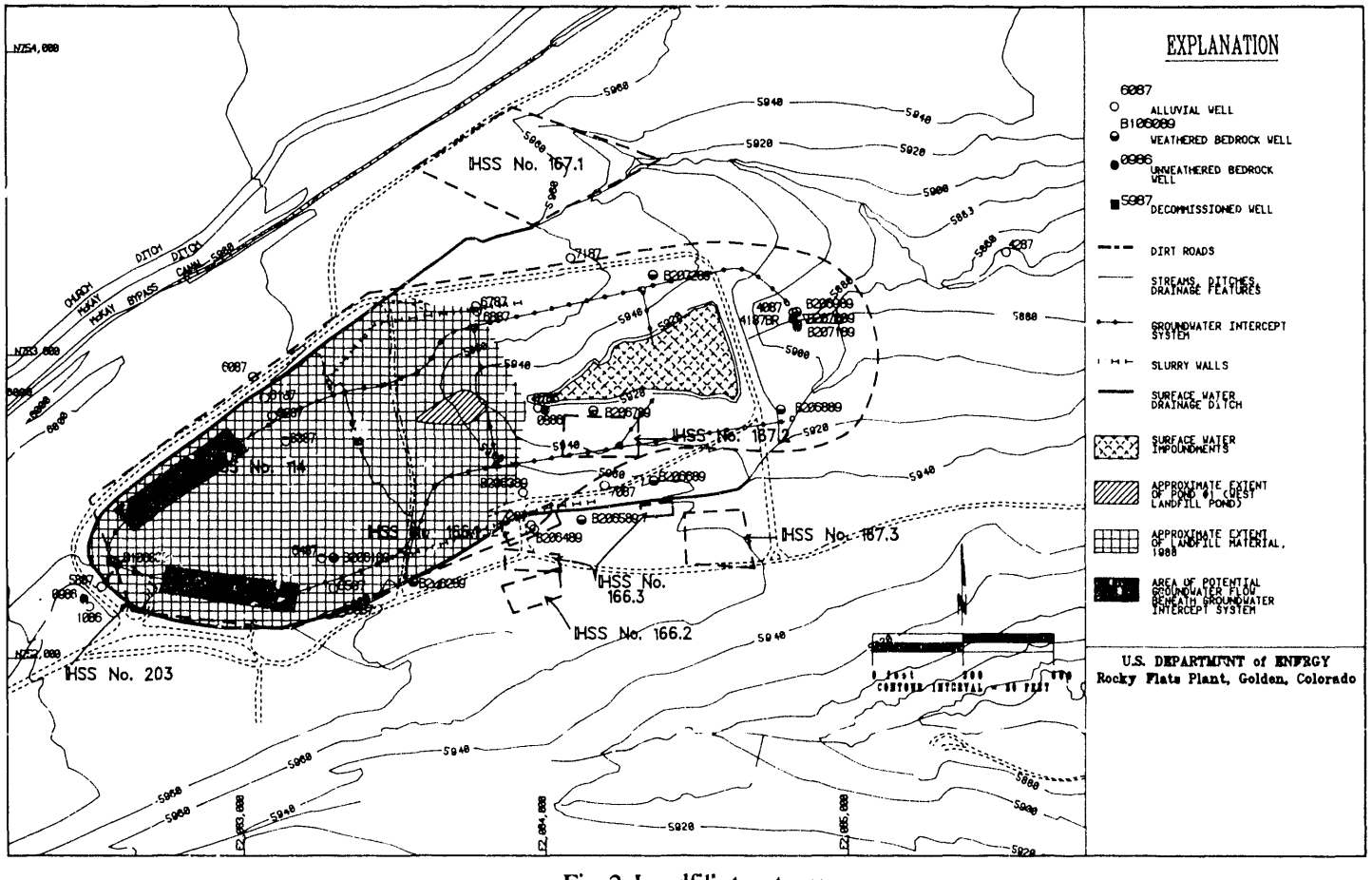


Fig. 2. Landfill structures.

compounds (VOCs) in the leachate but not in the pond itself. Therefore, water from the East Pond is spray evaporated on the pond banks. The East Pond and the adjacent spray area were not included as a part of OU 7. Because any contaminants of concern in the landfill would be entering the pond through the leachate and subsequently sprayed on the pond banks, the East Pond and the spray areas will be investigated as part of OU 7.

The Phase I RFI/RI Work Plan

OU 7 is the first of the RCRA units for which a Revised Draft Final Phase I RFI/RI Work Plan is required. All previous work plans were prepared per the EPA guidance document "Guidance for Conducting Remedial Investigations and Feasibility Studies Under CERCLA" because EPA is the lead agency conducting the CERCLA work plan reviews. As the lead agency for OU 7, CDH requires use of the guidance document "Interim Final RCRA Facility Investigation Guidance", which does not correspond to the EPA CERCLA guidance document. Therefore, the work plan has been formatted to incorporate both guidance documents in order to meet the requirements of an integrated work plan specified by the IAG.

The format of the OU 7 Draft Final Phase I RFI/RI Work Plan includes the following major sections:

- Executive Summary
- Introduction
- Site Characterization
- Applicable or Relevant and Appropriate Requirements
- Data Needs and Data Quality Objectives
- RCRA Facility Investigations/Remedial Investigation Tasks
- Schedule
- Field Sampling Plan
- Baseline Human Health Risk Assessment Plan
- Environmental Evaluation Work Plan
- Quality Assurance Addendum
- Standard Operations Procedures and Procedure Change Notices
- References

The Phase I RFI/RI work plan was developed from a detailed review of existing documentation that included waste inventories, historical photos, operator logs, As-built drawings and reports of previous investigations. The scope of the existing information, document validity and data usability are thoroughly described in the Site Characterization section of the work plan. This material was evaluated to identify additional information requirements. The Data Needs and Data Quality Objectives (DQOs) section then identifies the objectives of the RFI/RI investigation, determines the data users, reviews the existing available data, determines data needs and uses, and identifies the data quality and quantity needs. The field investigation is then designed to obtain sufficient and adequate data to meet data quantity and quality needs identified in the DQOs . The field investigation is based on an approach which is defensible, and the rationale for the field investigation is clearly stated. The field investigation will provide the information necessary to support a Baseline Human Health Risk Assessment, an Environmental Evaluation, and characterize the source and soils in the area of the Present Landfill (1). Lastly, the field investigation will be designed to support potential future investigations by locating sampling points (i.e. ground water monitoring wells) in locations useful to other investigations (i.e. RCRA ground water monitoring). These three sections of the work plan: Site Characterization, Data Needs and Data Quality Objectives, and the Field Sampling Plan are most important to demonstrate that the proposed investigation will achieve the stated goals of the IAG.

The Field Sampling Plan

The objectives of the Field Sampling Plan stated in the Phase I RFI/RI are as follows (4):

Characterize Physical Features

1. Determine representative site-specific background concentrations of analytes in ground water, soils, and subsurface materials;
2. Characterize the flow regime within and around OU 7 to evaluate the effects of the ground water intercept system and slurry walls on ground water/leachate movement;
3. Characterize surface water/ground water interactions; and
4. Evaluate infiltration of precipitation through the existing soil cover material.

Define Contaminant Sources

1. Determine the presence or absence of soil contamination at IHSS 203; and
2. Determine the presence or absence of contamination in soils where spray evaporation occurred;
3. Identify and further characterize waste streams disposed in the landfill, and evaluate the environmental fate and transport characteristics of chemicals associated with the waste streams.
4. Define the area and volume of landfill material;
5. Define the volume and character of the existing leachate;
6. Define the character and volumes (gas production) of landfill generated gases;
7. Characterized the leachate contaminated materials (including soils, bedrock, and West Landfill Pond sediments);
8. Characterize contamination of surface water and sediments in the East Landfill Pond.

To accomplish the stated objectives, the following activities are planned (Fig. 3) (4):

IHSS 114 - Present Landfill Sampling Activities

- Review existing data and information
- Visual inspection
- Cone Penetrometer Testing in area of artificial fill (38 locations)
- In-situ sampling of gas/leachate/ground water in landfill with BAT® sampler
- Drilling and sampling of borings (11 locations)
- Pump-in-borehole packer tests (11 locations)
- Installation and sampling monitoring wells (9 locations)
- Sediment sampling at East Landfill Pond (3 locations)

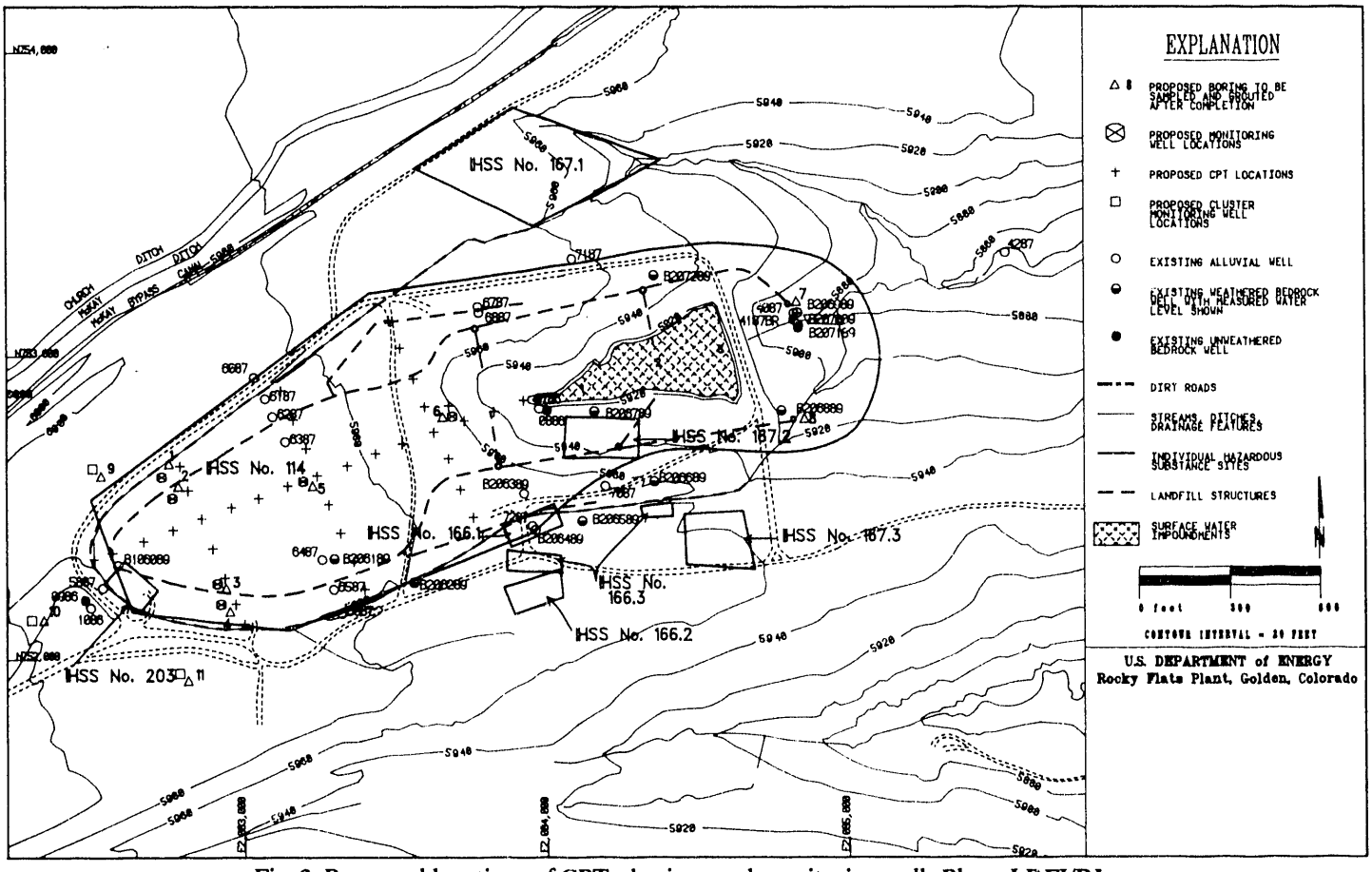


Fig. 3. Proposed locations of CPTs, borings and monitoring wells Phase I RFI/RI.

- Leachate sampling at seep and surface water sampling of East Landfill Pond
- Effluent sampling from ground water discharge points (2 locations)
- Location surveying of sampled points

Areas Around East Landfill Pond Sampling Activities

- Visual inspection
- Radiological field screening (25' grid)
- Soil sampling (25' grid)
- Location surveying of sampled points

IHSS 203 - Inactive Hazardous Waste Storage Area Sampling Activities

- Visual Inspection
- Radiological field screening (25' grid)
- Soil-gas survey/soil sampling (25' grid)
- Location surveying of sampled points

Analytical parameters for leachate/ground water samples collected from the Present Landfill include VOC's, semivolatiles, metals, inorganic analytes, and radionuclides. Primary contaminants of concern at IHSS 203 include VOC's, semivolatiles and polychlorinated biphenyles PCB's. The contaminants of concern in leachate draining to the East Pond include VOC's, semivolatiles, metals, radionuclides, and inorganics. However, the spray area contaminants of concern do not include VOC's or semivolatiles due to dilution and volatilization during spray activities (4).

SCHEDULE

The IAG stipulates that RFI/RI field activities at the Present Landfill begin in August, 1992 (1). At that time, the landfill will still be in operation. The RFI/RI Field Sampling Plan will address procedures necessary to assure data quality. In addition, procedures will be developed to assure that waste streams disposed of at the landfill will not require additional investigations in the future.

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5. EG&G Rocky Flats (1990b). Draft Original Process Waste Lines, Phase I RFI/RI Work Plan (Operable Unit 3), June 1.
6. EG&G Rocky Flats (1990c). Phase I RFI/RI Draft Work Plan for Operable Unit 3, Other Outside Closures, June 22.
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ACCELERATED CLEANUP OF PAST PRACTICE WASTE SITES ON THE HANFORD SITE, RICHLAND WASHINGTON

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ABSTRACT

This report provides a basic description of the Expedited Response Action program currently being implemented at the Hanford Site located in Richland, Washington, including reference to the applicable regulations regarding the program's implementation.

INTRODUCTION

The Hanford Site occupies approximately 560 mi^2 of semiarid land in southeastern Washington. The site was selected by the U.S. Army Corps of Engineers in 1943 as the location for reactor, chemical separation, and related facilities dedicated to the production and purification of plutonium. The mission eventually evolved to include advanced reactor research and development of renewable energy technologies.

As a result of these operations, the Hanford Site presently contains over 1,500 waste management units including waste disposal sites, accidental releases, and contaminated surface structures. Contamination at these sites consists of radioactive and/or chemical waste constituents.

Current regulations under the "Comprehensive Environmental, Response, Compensation, and Liability Act of 1980" (CERCLA, also referred to as Superfund) (1) require the cleanup of waste sites that pose a potential threat to human health and/or the environment. Since the passage of CERCLA, the primary mission at the Hanford Site has been redirected from defense-related production to environmental restoration.

The approach to completing this new mission is documented in "The Hanford Federal Facility Agreement and Consent Order" (Ecology et al. 1990) (2), also referred to as the Tri-Party Agreement. This approach requires completion of remedial investigation and feasibility study work plans for operable units or groups of waste sites, extensive characterization of the sites, feasibility studies to select a method of remediation, and finally, cleanup. This method is consistent with that provided in CERCLA.

During the implementation of these environmental restoration activities at the Hanford Site, the need became apparent for responses to be taken earlier than allowed for in the Remedial Investigation/Feasibility Study (RI/FS) or Resource Conservation and Recovery Act Facility Investigation/ Corrective Measure Study (RFI/CMS). These responses may be made to mitigate a threat to the public and/or environment, make future remedial investigation activities safer or more effective by removing or controlling onsite wastes, demonstrate a promising technology, or where the remedial action to be taken at the site is readily evident.

It was also felt that conducting these early cleanups would improve the public perception of the Superfund program at Hanford by accomplishing some level of site cleanup. It is not necessarily the intent of these early actions to reach final cleanup levels at a particular site. They may often be the final action taken.

Provisions for conducting these "expedited actions" were included during the development of the Tri-Party Agreement and agreed to by the U.S. Environmental Protection Agency (EPA), the Washington State Department of Ecology (Ecology) and the U.S. Department of Energy (DOE). Provisions for performing interim or corrective actions are also included in both the CERCLA, and the "Resource Conservation and Recovery Act of 1976" (RCRA).

Initially, three proposed Expedited Response Actions (ERA), (the term utilized to describe all early response actions taken at the Hanford Site), were selected following a limited evaluation of seven candidate sites chosen jointly by the DOE and EPA. In October 1990, an Agreement in Principle between the DOE, EPA, and the state of Washington Department of Ecology was signed. This agreement stated that initially the three candidate projects would be further evaluated for potential ERAs.

REGULATORY SETTING

Comprehensive Environmental Response, Compensation, and Liability Act

CERCLA provides the regulatory authority for conducting response or removal actions at past-practice sites. The implementing regulations for CERCLA are contained within the National Oil and Hazardous Substances Pollution Contingency Plan (NCP) found in 40 CFR Part 300 (EPA 1990) (3). It is apparent in the preamble to these implementing regulations that the EPA's intent is to streamline the RI/FS process with a 'bias for action'.

The NCP formed the primary basis for establishing the requirements by which ERAs would be performed at Hanford. A summary of the more significant requirements listed in the NCP are provided below.

- Section 300.415 (b)(4) of the 40 CFR states in part that if a 6-month planning period must be initiated before onsite activities occur, an Engineering Evaluation/Cost Assessment should be completed which analyses removal/remedial alternatives. Sampling and analysis plans must be prepared for EPA approval if environmental samples are needed in support of the action.
- ERAs shall, to the extent practicable, contribute to the efficient performance of any anticipated long-term remedial action [40 CFR 300.415 (c)].
- ERAs shall, to the extent practicable considering the emergencies of the situation, attain applicable or relevant and appropriate requirements (ARARs) under federal environmental or state environmental or facility siting laws [40 CFR 300.415 (j)].

The factors to be considered in determining the appropriateness of conducting ERAs (removal actions) are also provided in the NCP and include:

- Actual or potential exposure to nearby human populations, animals, or the food chain from hazardous substances, pollutants, or contaminants
- Hazardous substances, pollutants, or contaminants in drums, barrels, tanks, or other bulk storage containers that may pose a threat of release
- Threat of fire or explosion.

The NCP also provides a list of responses that could be considered appropriate when performing ERAs [Section 300.416 (b)]. The following list provides some of the response actions described in the NCP.

- Fences, warning signs, or other security or site control precautions where humans or animals have access to the release
- Drainage controls; for example, run-off or run-on diversion where needed to reduce migration of hazardous substances, pollutants, or contaminants offsite
- Capping of contaminated soils or sludges where needed to reduce migration of hazardous substances or pollutants or contaminants into the soil, ground or surface water, or air
- Excavation, consolidation, or removal of highly contaminated soils from drainage or to other areas where such actions will reduce the spread of, or direct contact with the contamination
- Containment, treatment, disposal, or incineration of hazardous materials where needed to reduce the likelihood of human, animal, or food chain exposure.

Resource Conservation and Recovery Act

Under RCRA, ERAs are conducted as Interim Measures (IM) when response is appropriate prior to completion of the RFI/CMS. These actions are normally required by an enforcement action or included as a permit condition. The EPA has proposed rules for "Corrective Action for Solid Waste Management Units (SWMUs) at Hazardous Waste Management Facilities" (55FR 30798) (EPA 1990) (4). These rules express EPA's management philosophy for corrective actions that is consistent with CERCLA and the NCP as stated previously. The following is a pertinent citation from the proposed rule:

> In managing the corrective action program, the Agency will emphasize early actions and expeditious remedy decisions. One of the Agency's overriding goals in managing the corrective action program will be to expedite cleanup results by requiring sensible early actions to control environmental problems on an interim basis, and using flexible and pragmatic approaches in making final remedy decisions. The EPA believes that in many cases it will be possible to identify early corrective action process actions which can and should be taken to control exposure to contamination or to stop further environmental degradation from occurring. Such interim measures may be relatively straightforward, such as erecting a fence or removing small numbers of drums, or may involve more elaborate measures such as installing a pump and treat system to prevent further migration of a groundwater contaminant plume. In another example, where it is obvious that the eventual remedy will require excavation and treatment or removal of contaminated 'hotspots', such action should be initiated as an interim measure, rather that deferring it until after final remedy selection.

Hanford Strategy

The U.S. Department of Energy Field Office, Richland (RL), is currently proposing a strategy for conducting restoration/remediation activities at the Hanford Site. This strategy provides new concepts for (1) accelerating decision-making by maximizing the use of existing data consistent with data quality objectives and (2) undertaking expedited response actions and/or interim remedial measures as appropriate to either remove threats to human health and welfare and the environment or to reduce risk by reducing toxicity, mobility, or volume of contaminants (Thompson 1991) (5).

The primary objective of this strategy is to develop a uniform streamlined process to meet statutory requirements and integrate CERCLA RI/FS and RCRA Past Practice RFI/CMS guidance and to ensure the protection of human health and welfare and the environment at the Hanford Site through effective cleanup actions (Thompson 1991).

Under this strategy, ERAs must be consistent with both regulatory requirements for conducting removal actions and the Tri-Party Agreement Action Plan (Hanford Federal Facility Agreement and Consent Order Sections 7.2.3 and 7.2.4). Conditions that might trigger an abatement as an ERA are generally the determination of, or suspected, existing, or future unacceptable health or environmental risk, and a short timeframe available to mitigate the problem (Thompson 1991).

As data and analyses on specific waste sites are obtained, either through the scoping process, limited field investigations, RI/FS, or RFI/CMS activities, they will be assessed by the project engineers for consideration as potential ERA sites. The project managers would then make a recommendation based on this assessment to the EPA, Ecology, and unit managers. These agencies would ultimately decide whether an ERA is appropriate at the waste site.

The candidate ERA site will be classified into one of two categories: time critical or non-time critical. This classification depends upon the severity of the situation and conditions of alternative implementation, as well as availability of resources. Time critical ERAs are conducted when a planning period of less than six months exists before implementation of the response activities must begin. Non-time critical ERAs are conducted when immediate response is not necessary and sufficient time (> 6 months) exists before the response actions are initiated.

IMPLEMENTATION PROCESS

The following sections summarize the flowpath by which ERAs are performed at the Hanford Site. This flowpath is a compilation of the requirements found in both state and federal regulations as well as the Tri-Party Agreement.

Site Selection/Prioritization

Initially, a site is recommended to the project managers as a candidate site for performing an ERA. This recommendation may come from many sources including the Aggregate Area/Operable Unit Managers, Hanford Site employees, and

the public. The project managers will then collect all readily available information concerning the waste site in question. If the data collected on the site warrants further consideration an ERA preliminary proposal will then be completed. This will summarize all the information collected on the waste site, identify the potential response actions, and provide rough cost estimates and implementing schedule based on the preliminary determination of the most promising response action identified.

The preliminary proposal is submitted to the EPA, Ecology, and RL. They review the proposal and jointly decide if the site warrants further consideration as an ERA activity. These parties will then prioritize the sites depending upon the urgency of the situation, cost and schedule of implementation, and the availability of resources for conducting the activity.

Project Plan/Site Characterization

Once a site is selected as a candidate for conducting an ERA and approval to proceed is obtained, a project plan is prepared describing each of the tasks needed to complete the ERA Proposal. Information provided in the project plan includes the following:

- A brief description of site characteristics
- Identification and preliminary screening of response alternatives
- Identification of any focused characterization tasks needed in selecting the appropriate response alternative
- Sampling and analysis plans
- Tasks necessary in evaluating and selecting the appropriate response alternative
- A project schedule for implementing these activities.

ERA Proposal/Action Memorandum

An ERA Proposal is prepared based on the information obtained as a result of the site characterization activities and engineering development of the cleanup alternatives. This plan contains an engineering evaluation/cost analysis which recommends the preferred response alternative to be taken at the waste site in question. This alternative could include the no action alternative if the evaluation indicated that no significant benefit would result from performing the ERA. The proposal also contains information on implementing the preferred alternative, including design of process systems, and development of implementing procedures, as well as the schedule for implementing the preferred alternative and project costs.

The ERA Proposal is submitted to the EPA, Ecology, and RL for their review and comments. Once all comments are resolved the ERA proposal will be submitted for public review and comment. Once this comment period is concluded and all comments received have been resolved, the EPA will issue an action memorandum authorizing the initiation of the cleanup activities.

Design/Implementation/Monitoring

After the Action Memorandum has been issued, the project design and implementation phase is begun. This phase of the ERA includes system designs and/or development of operational work plans and procedures, safety analysis, and monitoring plans for assessing the effectiveness of the actions taken. During this phase, the required equipment is procured, installed, and tested as necessary. The ERA is then initiated in conjunction with the appropriate monitoring to ensure optimum efficiency of the actions taken. Information obtained during the monitoring activities may result in design changes as well as termination of activities if necessary or prudent.

EXPEDITED RESPONSE ACTIONS INITIATED AT THE HANFORD SITE

As indicated in the introduction, three ERAs have been initiated to date on the Hanford Site. Because these activities were new to the Hanford Site, innovative technical and management solutions to problems had to be pioneered. By providing the project engineer for each of these ERAs with the authority and autonomy to build a successful project team, make critical decisions, and develop new and innovative approaches for complying with existing orders and procedures, the projects proceeded on schedule and at significantly reduced costs.

In addition, all environmental cleanup activities have an intrinsic element of the unknown. Many cleanup projects evolve as site conditions change. To this end, it is essential that highly qualified individuals be placed in charge of the field activities and be given the authority to make real-time decisions to avoid delays, improve job efficiencies, and maintain the entire operation in a safe and environmentally secure manner. The following sections provide a brief summary of each of the ERA's activities conducted to date.

618-9 Burial Grounds ERA

The 618-9 Burial Ground ERA was conducted as a "time-critical" response action and consequently was initiated in February 1991. The response action involved the retrieval of organic solvents potentially contaminated with uranium disposed of in 55-gal drums during the 1950's. Since the solvent had not been detected in the groundwater and there was no significant subsidence on the ground surface, it was felt that at least a significant portion of the drums were still intact. It was the intent of the ERA to retrieve the solvent before it was released into the environment.

The retrieval process consisted of excavating the soil around the intact drums, puncturing the drums with a non-sparking opener, and pumping the material into new containers. As a result, over 1,600 gal of the organic solvent have been retrieved. A comprehensive soil sampling program was conducted to determine the extent of contamination resulting from the release of solvent from the portion of the drums which were not intact. The results of the soil sampling effort are currently being evaluated.

316-5 Process Trenches ERA

The 316-5 Process Trench ERA is being conducted as a non-time critical ERA. This consists of excavating and consolidating sediments contaminated with uranium as well as heavy metals from the bottom of the trenches to the portion of the trenches farthest away from the outfall structures where the discharge water is released into the trenches. The water currently being discharged is not considered to be hazardous but may potentially drive the contaminants farther through the soil column and into the groundwater. Due to the reduced

volume of water being discharged, the water will not enter the portions of the trench containing the contaminants.

An ERA Proposal was submitted to the regulatory agencies who approved of the action and prepared the required Action Memorandum. Field activities were initiated in July 1991. To date, contaminated sediments from one of the two trenches have been consolidated. Field screening measurements indicated that the majority of the contaminants have in fact been removed from the bottom of the trench.

200 West Area Carbon-Tetrachloride Vadose plume ERA

The 200 West Area carbon-tetrachloride vadose plume ERA is also being conducted as a non-time critical ERA. The proposed action is to utilize a vapor extraction system to pull volatilized carbon tetrachloride from the vadose zone. Focused field tests have indicated that large quantities of the carbon tetrachloride may be removed via this method. An ERA proposal has been prepared and is currently being discussed with the regulatory agencies.

FUTURE ACTIVITIES

As remedial investigation activities proceed, more waste sites warranting ERAs will be identified. As these sites are found, a preliminary proposal for each will be produced and submitted to the regulatory agencies for their decision on whether conducting an ERA at that particular site is appropriate. These agencies will also prioritize the sites warranting ERAs to ensure that the most critical or promising ones take precedence over those less critical or promising.

The endeavor of conducting ERA's has proven to be a rewarding experience for those involved with the restoration of the Hanford Site while also improving the public perception of the restoration program as a whole. With the unprecedented success of the three initial ERAs, additional sites are already being proposed. It is anticipated that many more will follow. As a result, ERAs will undoubtedly play a key role in the restoration of the Hanford Site.

REFERENCES

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4. EPA, "Corrective Action for Solid Waste Management Units (SWMUs) at Hazardous Waste Management Facilities" (55FR 30798), U.S. Environmental Protection Agency, Washington, D.C. (1990)
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STRATEGIC PLANNING OF AN INTEGRATED PROGRAM FOR STATE OVERSIGHT AGREEMENTS

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ABSTRACT

Among the barrage of agreements faced by federal facilities are the State Oversight Agreements (known as Agreements in Principle in many states). These agreements between the Department of Energy (DOE) and the states fund the states to conduct independent environmental monitoring and oversight which requires plans, studies, inventories, m els, and reports from DOE and its management and operating contractors. Many states have signed such nents, including Tennessee, Kentucky, Washington, Idaho, Colorado, California, and Florida. This typ ersight agreement originated in Colorado as a result of environmental concerns at the Rocky Flats Plant.

The 5-year State Oversight Agreements for Tennessee and Kentucky became effective on May 13, 1991, and fund these states nearly $21 million and $7 million, respectively. Implementation of these "comprehensive and integrated" agreements is particularly complex in Tennessee where the DOE Oak Ridge Reservation houses three installations with distinctly different missions. The program development and strategic planning required for coordinating and integrating a program of this magnitude is discussed. Included are the organizational structure and interfaces required to define and coordinate program elements across plants and to also effectively negotiate scope and schedules with the state. The planned Program Management Plan, which will contain implementation and procedural guidelines, and the management control system for detailed tracking of activities and costs are outlined. Additionally, issues inherent in the nature of the agreements and implementation of a program of this magnitude are discussed. Finally, a comparison of the agreements for Tennessee, Kentucky, Colorado, and Idaho is made to gain a better understanding of the similarities and differences in State Oversight Agreements to aid in implementation of these agreements.

OVERVIEW OF STATE OVERSIGHT AGREEMENTS

State Oversight Agreements have their origin in Colorado, where environmental concerns at the Rocky Flats installation in 1989 precipitated commitments by Secretary James Watkins to the state of Colorado and other states with Department of Energy (DOE) facilities. This commitment was in the form of agreements that fund the states to conduct independent environmental oversight and monitoring on DOE installations. The oversight agreement in Colorado lead the way for similar agreements, including those within the states of Tennessee, Kentucky, Washington, Idaho, California, and Florida. Although the Rocky Flats Agreement has served as a model for other states, it is obvious from review of the various agreements that each state has taken the opportunity to tailor its agreement to suit the state's particular concerns and needs.

Oversight agreements between the state and DOE provide the state funding, site access, and technical assistance to conduct independent monitoring and environmental oversight on DOE facilities. These oversight and monitoring activities are designed to ensure that each facility is in compliance with state, federal, and local laws and regulations, as well as assuring the citizens of the state that their health, safety, and environment are being protected through current programs and any new commitments by DOE. A theme that appears to prevail within the agreements is the desire for comprehensive and integrated environmental programs.

TENNESSEE AND KENTUCKY AGREEMENTS

The state of Tennessee and commonwealth of Kentucky have entered into separate oversight agreements with DOE to conduct independent environmental monitoring and oversight on the Oak Ridge Reservation (ORR) in Oak Ridge, Tennessee and the Paducah Gaseous Diffusion Plant in Kentucky. The three plants in Oak Ridge (Oak Ridge K-25 Site, Oak Ridge Y-12 Plant, and Oak Ridge National Laboratory), the Paducah plant, and the Portsmouth Gaseous Diffusion Plant are operated out of the DOE Oak Ridge Field Office, with Martin Marietta Energy Systems, Inc., as the management and operating (M&O) contractor. These 5-year agreements became effective on May 13, 1991, and provide Tennessee with about $21 million and Kentucky nearly $7 million to carry out their commitments under the agreements. Both agreements have provisions for renegotiation and extension beyond the 5-year period.

The Tennessee agreement provides funding for environmental oversight, as well as for the state's participation under the Interagency Agreement, a triparty agreement among DOE, the Environmental Protection Agency (EPA) and the state of Tennessee regarding environmental restoration activities. Under the Tennessee agreement, the state will carry out a monitoring program for surface water, fish and wildlife, groundwater, air, and radioactivity.

* Managing for the U.S. Department of Energy the Oak Ridge National Laboratory, Oak Ridge K-25 Site, Oak Ridge Y-12 Plant, and Paducah Gaseous Diffusion Plant under contract DE-AC05-84OR21400, and the Portsmouth Gaseous Diffusion Plant under contract DE-AC05-76OR00001.

DOE will be required to report transportation of radioactive materials, conduct studies in areas of waste minimization and characterization, provide decontamination and decommissioning data, and participate with the state in the evaluation and update of emergency notification systems. The state of Tennessee has set up a DOE Oversight Division to administer efforts and will employ 88 people in the areas of environmental restoration, waste management, corrective action and compliance, and radiologic monitoring and oversight. This division will manage three associated contracts with the Tennessee Emergency Management Agency (emergency response initiatives), Tennessee Wildlife Resources Agency (fish and wildlife monitoring), and the Local Oversight Committee. The Local Oversight Committee is a group composed of a full-time public information person, area county executives, public representatives, and members from local environmental groups.

Many aspects of the Kentucky agreement are similar to those of the Tennessee agreement, particularly in the areas of environmental monitoring and waste studies. However, the Kentucky agreement lacks explicit requirements in the areas of environmental restoration, decontamination and decommissioning, emergency preparedness, and radioactive-material transport. The state plans to assimilate the 14 staff members working with the agreement into existing state organizations within the cabinets of Natural Resources and Environmental Protection and Human Resources.

PLANNING AND IMPLEMENTATION

Strategic planning for implementation of the State Oversight Agreements will be essential in successfully coordinating the comprehensive and integrated programs outlined within these agreements. The magnitude of these agreements will have a substantial impact on resource requirements in the areas of both personnel and funding on the ORR and Paducah sites. This will be of greater significance in Tennessee where "comprehensive and integrated" programs will have to be developed and maintained across three installations with substantially different missions. The Y-12 Plant is a manufacturing facility, Oak Ridge National Laboratory is primarily a research facility, and the K-25 Site is a retired nuclear fuels processing site. These sites have historically operated independently and have only recently established central organizations to coordinate their environmental programs.

Detailed planning and extensive progress tracking will be needed to identify and allocate provisions for personnel and funding throughout the program. Implementation of the Tennessee agreement is expected to be particularly cumbersome because of the magnitude of the program and the complexity involved in effecting comprehensiveness across three distinctly different installations.

The first step toward implementation of this complex program is to develop a central management framework, with a manager and team members empowered with the authority to accomplish the goals of the program yet flexible enough to adjust to changing program requirements. In addition, mechanisms must be established to identify appropriate individual and organizational interfaces, delineate responsibility, and provide the necessary technical and management input to successfully negotiate detailed technical scopes and schedules with the states. Information dissemination is also important in communicating details of the program to those who will be involved with oversight activities. Also, any legal or contractual issues associated with the oversight program must be identified and resolved early in the program.

Numerous activities were conducted prior to signature of the agreements to establish a strong foundation for successfully implementing the oversight program. A program manager was named and a task team formed. The initial work of the program manager and task team involved identifying potential issues and determining which organizations would be likely to have responsibility for implementing oversight agreement requirements. This team has also worked to develop estimates for resource requirements. The task team has matured into a group that serves as an information forum and liaison between central organization staff, installations, and programs. This group will also work to develop negotiating strategies for detailed scope and schedule agreements among DOE, Tennessee, and Kentucky and to integrate implementation of these detailed scope and schedule agreements. The task-team members were chosen to represent each of the four installations and the central organizations that will be involved with major oversight work categories. These members will also serve as coordinators, provide management support, and ensure resources within their respective organizations or installations.

In addition to establishing a management framework, detailed evaluation of the agreement was conducted to gain a full understanding of the stated requirements to establish the appropriate mechanisms to meet those requirements. The Martin Marietta Energy Systems, Inc., approach was to dissect the agreement into discrete components, examine each requirement, and assign responsibility to the appropriate organization(s). The responsibility matrix, as it is called, establishes roles and responsibilities for stated agreement requirements, including designation of lead and support organizations. This responsibility matrix is in the process of being established as a self-sufficient data base; it will serve as a tool for addressing implementation of discrete tasks and identifying those responsible for contributing to negotiation of scope and implementation of tasks.

These agreements are relatively general with regard to technical scope and requirements. Because of this, it will be necessary to arrive at more detailed agreements with the state pertaining to scope, deliverables, and schedules. Major organizational interfaces have been established for negotiation, including the Tennessee Oversight Agreement Interface Group. This small group – composed of members of the state DOE Oversight Division, the DOE Oak Ridge Field Office, and Martin Marietta Energy Systems, Inc. – has been meeting on a regular basis and will be the central focus for negotiation of detailed scope and schedule agreements with the state. Several detailed scope and schedule agreements have been reached and documented by way of "side" agreements. An agreement with the state of Tennessee was reached for its 18-month deliverable of a source-reduction and zero-discharges study. In lieu of conducting a cursory study in 18 months, a long-term program for addressing source-reduction initiatives will be started and pilot process-waste-assessment studies will be conducted at each facility within 18 months. Other "side" agreements have been made with the state concerning methods of conducting business. For example, an agreement has been made concerning how the state will conduct the transition from its current Regulatory

Division to its DOE Oversight Division. As negotiations of this type proceed, the core group will remain intact and others with appropriate technical backgrounds will join the core group during activity-specific negotiations.

Because of the complexity of the oversight agreement and the numerous organizations and installations involved, policy and procedures must be established for negotiations, oversight implementation, and document submittal to the state. A detailed Program Management Plan will be developed which will be reviewed and updated regularly and serve as guidance in conducting activities under the oversight agreement. While the Program Management Plan is being developed, an implementation plan was written which provides an overview of the current knowledge of the agreement and outlines the organizational interfaces and mechanisms that need to be put in place to effectively accomplish the initiatives of the oversight agreement.

An appreciation for the necessity of establishing rules and policies for this complex and multifarious program can be gained by looking at the activities associated with determining site access requirements for state personnel. Knowing that the first big hurdle would be to efficiently and expeditiously provide the appropriate training necessary for state personnel to gain access to the sites, the task team set out to determine what these requirements would be. Although this may sound relatively easy, due to the nature and independence of the three Oak Ridge sites this turned out to be an enormous undertaking. Each site and each facility within each site has its own access requirements. This problem is being addressed by providing each facility with a generic questionnaire on which to state individual access requirements. An atlas of access requirements for all facilities on the ORR will be developed from the resulting list.

An important component of the Program Management Plan will be a project management system. This system will be required to logically delineate agreement tasks and track milestone progress and associated costs. In addition to conventional cost and schedule tracking, the system will also evaluate resource requirements. A Work Breakdown Structure has been created, and detailed schedules will be developed as the scope of the agreement components are negotiated. An integrated cost-accounting system will be established to track agreement-specific costs for all contributing organizations. The schedule-and-cost system will be integrated to allow for performance and cost to be tracked against projected goals so that program variances can be determined. In addition to developing a cost-and-schedule tracking system, a method will be developed to track the production, circulation, and distribution of all oversight agreement documents. This system is necessary because of the immense volume of documentation that will travel among DOE, the states, Martin Marietta Energy Systems, Inc., and other contractors.

OUTSTANDING AGREEMENT ISSUES

Although the agreements have been signed and implementation has proceeded, many issues have or will arise which remain to be resolved. This section addresses some of the major issues that have come to light thus far in implementating State Oversight Agreements. Although this discussion is not exhaustive, it is hoped that the reader will gain an appreciation for the vast number of issues that are inherent within these oversight agreements.

One of the more obvious issues in many of these agreements is that they extend beyond statute and regulation. Are these agreements legally enforceable, and if so, by what mechanism? How do we prioritize between these "extra" items and permits/regulations? How will DOE treat recommendations made by the states under these agreements? The agreements declare that the states will review existing programs and make recommendations; however, the document is unclear as to how these recommendations will be handled. Will they be ignored, or will they be given priority? If so, how will they be prioritized? This line of thought also raises the issue of how DOE will provide directive, funding, and reprioritization for items within the oversight agreements. And of equal importance, how will commitments under this agreement be prioritized against requirements of existing programs? In short, how will DOE deal with the myriad requirements within the oversight agreements and state and federal regulations, and how will agreements with other agencies such as EPA and the Agency for Toxic Substances Disease Registry be dealt with? Will sufficient directive and funding be made available to M&O contractors and other prime contractors for them to meet oversight agreement requirements? Provisions for prioritization, along with adequate directive and funding, will be major hurdles for successful implementation of State Oversight Agreements.

Another issue surfaced recently in dealing with the Tennessee Oversight Agreement. Tennessee has just begun to apply a fee system to permitting and inspections. Because DOE is paying the state for environmental oversight on the ORR, should state grant money be applied to fees for services conducted under the oversight agreement? This question led to an evaluation of DOE/state legal responsibilities in use of DOE monies. According to current understanding, DOE cannot fund the state to conduct activities required by regulation. This statement invokes a long series of questions. Will regulators be present on the DOE installation in addition to the state oversight personnel? Can state employees being funded by the DOE grant issue notices of deficiency or notices of violation or review or issue permits? If they cannot issue permits or perform inspections, what will their specific role be? Will it be possible to define or differentiate the role of these people versus that of the regulators, and where will this line be drawn? These questions and legal issues surrounding the use of DOE funds must be resolved lest the issue of vulnerability arise in an audit.

Other underlying issues are looming in the shadows. Many of these can be found by evaluating the wording of the agreements. These agreements declare that the states will conduct independent oversight. The states' independence could be questioned by the fact that they are being funded by the same organization that they are supposed to be monitoring. Another issue is that the agreements consistently refer to "comprehensive and integrated programs." How far does comprehensiveness and integration extend? In the case of Tennessee, it is clear that the state expects a comprehensive and integrated approach across the three installations on the ORR. However, what happens if a state enters an agreement with multiple DOE facilities operated by separate DOE Field Offices and M&O contractors? Will the state expect comprehensive and integrated programs across these installations? And to look even further, will DOE be required to

provide comprehensive and integrated programs across all facilities with State Oversight Agreements?

Other issues have arisen concerning the mechanics of operating these oversight agreements on a day-to-day basis. Site access has been an area of concern especially in the context of legal liability. Is there a need to do a medical baseline for state oversight personnel prior to site entry? Can the state personnel be given unrestricted (unescorted) access to the site? If so, are their health and safety being endangered (is liability involved)? How can it be ensured that the state employees have had the proper training for each and every site that they may want to visit on the facility? Another issue is how to deal with state employees who get trained, acquire clearances, and then seek employment with the M&O contractor or DOE. There are potential conflict-of-interest issues with state employees who are seeking employment with the M&O contractor or DOE. It is clear from this discussion that the mechanics of day-to-day implementation of the oversight agreements will take considerable thought and effort to minimize legal, technical, and ethical problems.

It is also obvious that although this section outlines some prevalent issues of the oversight agreements, numerous additional issues will arise which require resolution. Much could be gained by evaluating these agreements from state to state to determine how best to implement a program and resolve outstanding issues.

SELECTED COMPARISON OF STATE OVERSIGHT AGREEMENTS

A relatively thorough review of oversight agreements from Colorado, Idaho, Kentucky, and Tennessee was conducted to provide insight into agreements from other states.

The DOE oversight agreement with Colorado is considered to serve as the model for all others. The documents reviewed, all developed and signed since the Colorado agreement, seem to support that statement. The oversight agreements require DOE to provide technical and financial support for independent state oversight and monitoring activities designed to assure the citizens that environment, safety, and health are being protected. Further, the agreements aim to promote "... a comprehensive and integrated environmental management plan ..." through required DOE action items. The oversight agreements address traditional environmental monitoring and compliance programs (air, water, waste, etc.), environmental restoration, waste management, and emergency preparedness. The agreements also address site access, local government and tribal coordination, document availability, and public relations. The documents, with a slight exception in Colorado, even have the same basic format: preamble/boilerplate, Attachment A – Environmental Monitoring, Attachment B – DOE Action Items, Attachment C – State Action Items, and Attachment D – Grant Provisions/Application.

Several specific requirements are very similar. For example, each agreement requires a source-reduction study, expedited security clearances, air-monitoring-system review, DOE support for state offices and equipment, and emergency-preparedness activities. Although there are many similar requirements, further study reveals differences among similar activities. Some of these differences are obvious; others are very subtle. Because of this, DOE and implementing contractors cannot assume that implementation of an oversight agreement in one state can be directly patterned from a different state.

There are numerous and significant differences between agreements from different states. The differences between the agreements start with the titles. Both Colorado and Kentucky signed Agreements in Principle with DOE; Idaho signed an Environmental Oversight and Monitoring Agreement. Arguing the binding legalities of an Agreement in Principle, Tennessee and DOE simply signed an agreement. Tennessee suggested that the agreement be officially referenced as the Tennessee/Department of Energy Monitoring and Oversight Agreement and be unofficially called the Tennessee Oversight Agreement.

The preamble and boilerplate portions of the agreements contain other differences, some of which are significant to implementation. The Kentucky agreement designates the Paducah Gaseous Diffusion Plant site office manager and the Kentucky Department of Environmental Protection commissioner as primary contacts for all activities required or agreed upon through the agreement. In Tennessee, the primary contacts are the Environmental Restoration Division director for the DOE Oak Ridge Field Office and the director of the newly created Tennessee DOE Oversight Division. The Idaho agreement names the Idaho Field Office and the Idaho Department of Health and Welfare as designated leads. Interestingly, however, Idaho will deal directly with the Naval Reactors manager at the Naval Reactor Facility. Neither primary contacts nor designated leads are specifically addressed in the Colorado agreement.

Last but not least, the agreements are signed differently, particularly (if one considers the relative equivalences of various state organizations) by DOE. The Kentucky agreement is the only one not signed by the secretary of DOE and the state's governor. Colorado's agreement is the only one signed solely by the secretary of DOE and the state's governor.

A detailed evaluation of the attachments from those agreements was conducted, and differences in the appendixes are outlined in Table I. Comparison of the general oversight and monitoring Activities (Attachment A in each agreement) reveals some unique and obvious differences. Among them are requirements for an environmental data base with electronic data access and transmission (Tennessee); DOE support for enhanced laboratory capacity (Kentucky); air-emissions modeling (Kentucky and Tennessee); specific quality assurance (QA)/quality control (QC) activities (Idaho and Kentucky); submission of *draft* environmental monitoring plans (Tennessee); groundwater modeling (Kentucky); background characterization studies of water, soil, and/or sediment (Colorado, Idaho, and Kentucky); and installation of continuous air-emission monitors (Colorado and Kentucky).

Requirements that appear similar can actually be very different upon closer scrutiny. For example, both the Idaho and Kentucky agreements specifically address QA/QC. However, Idaho *will review* DOE QA/QC programs and recommend any needed modifications or improvements, but Kentucky *will follow* appropriate QA/QC protocols in state sampling and analyses, submitting such protocols to DOE upon request. Further, DOE *will support* Tennessee's use of air-emissions models, yet DOE *will model* Paducah Gaseous Diffusion Plant emissions in Kentucky. Obviously, things are not always as they first appear in the world of DOE–state agreements.

TABLE I
Selected Differences in State Oversight Agreements

Activity	Addressed by			
	CO	ID	KY	TN
Environmental data base with electronic access*				X
DOE support for enhanced laboratory support			X	
Air emissions modeling			X	X
Specific quality assurance/quality control activities		X	X	
Submit draft environmental monitoring plans				X
Groundwater modeling			X	
Background characterization studies of water, soil, and/or sediment	X	X	X	
Continuous air emission monitors	X		X	
National Environmental Policy Act compliance		X		
Decontamination and decomissioning				X
Radiation protection program review				X
Radioactive material/waste shipment		X		X
Operational change notification	X	X		X
Expansion of regulatory and safety staff	X		X	
DOE organizational changes	X			
"Need to know"	X	X		X
DOE provides medical and safety training to state				X

The differences between agreements become even more manifest with respect to DOE action items (Attachment C for Colorado and Attachment B for Idaho, Kentucky, and Tennessee). Among the more obvious differences are requirements for addressing the National Environmental Policy Act compliance (Idaho), decontamination and decommissioning (Tennessee), radiation-protection programs (Tennessee), shipments of radioactive materials or waste (Idaho and Tennessee), notification of operational changes (Colorado, Idaho, and Tennessee), expansion of regulatory and safety staff (Colorado and Kentucky), and even changes in the DOE organization (Colorado).

Each of the agreements addresses certain state actions (Attachment C in Idaho, Kentucky, and Tennessee; no specific attachment in Colorado), and each has similar requirements. However, the Tennessee agreement elaborates considerably upon other state requirements to participate with DOE and local or tribal governments in emergency-preparedness planning and training and emergency response. Such elaboration specifies the development of an enhanced state and local emergency response organization, increased state staff, and establishment of a Field Coordination Center among other activities.

Perhaps one of the first significant implementation challenges that DOE and the implementing contractors have faced deals with state access to sites, facilities, and information. Each agreement addresses similar requirements but in different terms and degrees – usually in the attachment that outlines DOE action items.

All of the agreements studied require DOE to expedite, or at least use its best efforts to expedite, security clearances for state personnel. Each agreement requires DOE to provide, or at least make available, various documents – from DOE orders to "contractor-produced" procedures and reports – regarding environment, safety, and health activities and programs. The Colorado agreement even requires that such documents be provided to organizations other than the state. The Idaho agreement requires that DOE make certain contracts available to the state.

The Colorado, Idaho, and Tennessee agreements require submission of an explanation of the DOE need-to-know policy; the Kentucky agreement doesn't mention a need to know. It appears that need-to-know criteria will apply to state personnel access in Colorado, Idaho, and Tennessee; however, in Colorado ". . . selected Q-cleared employees of the State will not be barred by the need-to-know policy from access . . ." to certain information.

In the realm of health-and-safety training and medical/radiological surveillance, only the Tennessee agreement requires that DOE directly provide such services.

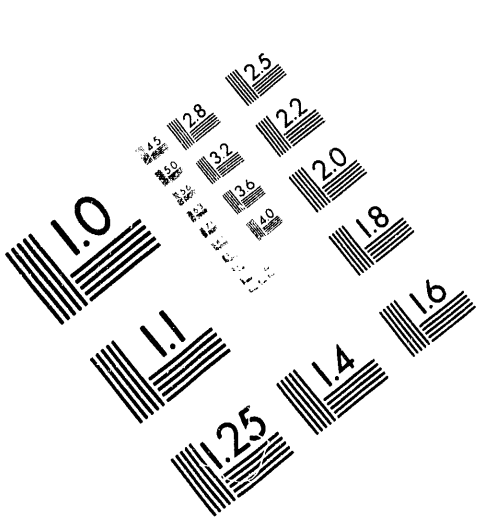
More subtle, yet probably no less significant, are the differences in use of terms, phrases, and even titles related to regulatory compliance. Words like "inspection" and "oversight" may tend to be used interchangeably on a day-to-day basis during agreement implementation by the states, DOE, and contractors. But it is highly likely that such words will be used with considerably greater discretion in legal and audit situations. To illustrate, each of the agreements is captioned under the phrase "oversight and monitoring," and each agreement generally aims to ensure compliance with statutes and regulation. However, the Colorado agreement never specifically references an environmental, safety, or health statute or regulation, nor does it restrict DOE requirements to that level of performance. Likewise, the Tennessee agreement rarely mentions any given statute, regulation, or other possible performance objective. Both the Colorado and Tennessee agreements either refrain from words or terms like "inspection" or hide them very well. Both of these agreements hold the possibility for state-established performance objectives that are unrestricted by existing statutes. On the other hand, the Idaho agreement contains numerous "yardstick" phrases such as ". . . improvements needed to meet applicable laws and regulations," and ". . . assessing compliance with applicable environmental laws and regulations." The Kentucky agreement

generally avoids phrases similar to these. However, in certain areas it specifically requires DOE to conduct activities in accordance with the Resource Conservation and Recovery Act (RCRA); the Comprehensive Environmental Response, Compensation, and Liability Act; and Kentucky statutes. It even uses the term "Kentucky Inspectors" in addressing site access, and it states that Kentucky "will inspect, review and issue applicable permits needed to comply with . . . RCRA."

What relevance does the study of similarities and differences among the agreements have to implementation by various DOE Field Offices and their respective implementing contractors? In this age of increasing cost constraints, performance-award incentives, and total quality management (or your favorite term for the quality improvement movement), it could prove to be very costly to neglect such information. Why should DOE not strive for "comprehensive and integrated" environmental management on a national basis? Implementing contractors can help themselves individually and collectively by learning from others' successes and failures. It could be very cost effective to pattern other programs that implement similar activities. Moreover, as the states compare notes, it may be found that currently unique requirements become more common. Becoming aware of such differences now can enhance proactivity, effectiveness, comprehensiveness, and future negotiating position.

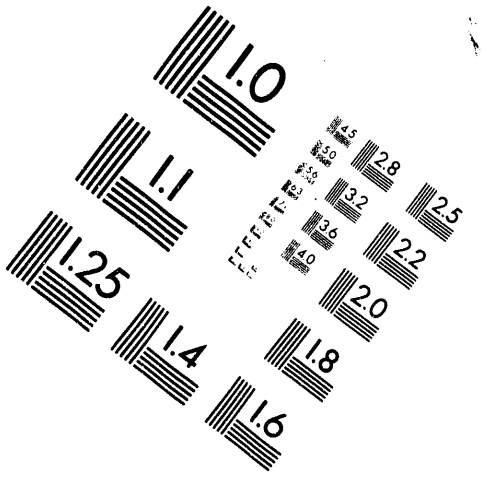
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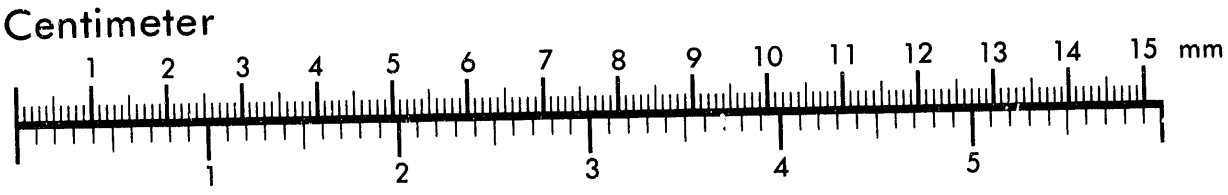
Implementation of State Oversight Agreements presents some unique and interesting challenges. The basic framework for implementation, including a manager, an implementation team, and procedures and management systems, must be established to effectively implement these agreements. In addition to establishing the basic program-management framework, efforts should be made to identify potential obstacles and to benefit from the experience of others. A careful evaluation of the outstanding issues must be conducted so that these issues can be identified and resolved early in the program. Another valuable exercise in implementation of these agreements is an evaluation of other agreements. Not only will this evaluation foster a better understanding of State Oversight Agreements, it will hopefully initiate an exercise in lessons learned that will help all DOE Field Offices and M&O contractors in implementating their respective State Oversight Programs.

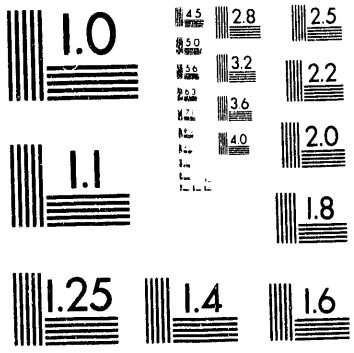


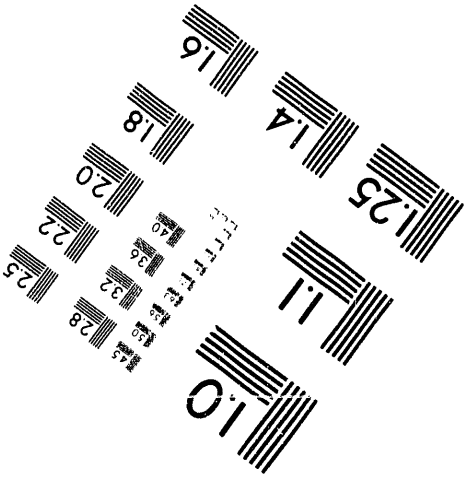


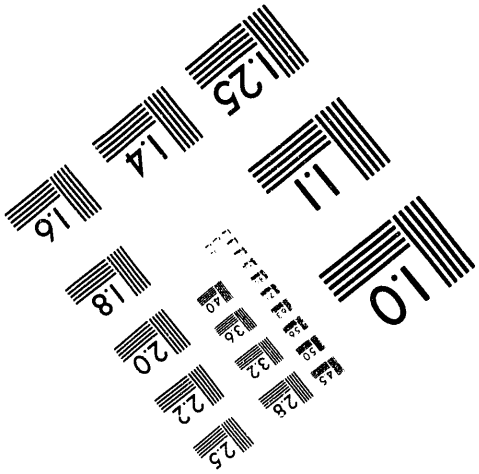
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2 of 10

APPROACH AND STRATEGY FOR SETTING REMEDIAL ACTION GOALS FOR MULTIPLE SITES WITH MULTIPLE CONTAMINANTS

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ABSTRACT

In the 1980's most of the decisions to remediate Superfund sites were based on the mere existence of contamination rather than the degree of actual public health risk. Cost appeared to be the most significant factor in the selection of the remedial action alternative (1). However, the final version of the National Contingency Plan (NCP) (2), which implements the requirements established under CERCLA, specifies that one of the two threshold criteria which the final remedy must meet is overall protection of human health and the environment. But what do we mean by protection? What level of risk are we willing to accept? Goals and priorities need to be more clearly defined in the decision-making process. Remedial Action Goals must be established early on in the Remedial Investigation/Feasibility Study (RI/FS) so that 1) the baseline risk assessment can determine whether the risks posed by the site are acceptable, and 2) remedial action alternatives that can achieve the goals can be identified. Here we present approaches that we are developing for setting Remedial Action Goals that are both consistent with EPA regulations and guidance, and that are sufficiently flexible to address the diversity of environmental concerns posed by the multiple hazardous waste sites under the auspices of the Department of Energy Field Office, Oak Ridge - Environmental Restoration Division (DOE-OR/ERD). Such approaches are likely to be particularly relevant for other large facilities with multiple sites and multiple contaminants.

SCOPE

This paper describes the approaches developed for soils/sediments, surface water and groundwater contaminated by hazardous chemicals. It does not address radionuclide standards or issues related to contaminated air. Even though approaches for setting Remedial Action Goals that are protective of ecological health are being developed by the DOE-OR/ERD, the emphasis here will be on human health issues rather than environmental issues. The goals will reflect 1) the regulatory requirements established under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), implemented by the National Oil and Hazardous Substances Pollution Contingency Plan (NCP) (2), and 2) the Section 3004(u) provision of the Hazardous and Solid Waste Amendments (HSWA) to the Resource Conservation and Recovery Act [RCRA, §3004(u)] (3).

INTRODUCTION

Site risks assessments are iterative and evolving. Their purpose is to screen out early trivial, insignificant risks, identify immediate response risks, and focus further risk assessment activities and refinements on the real constituents of potential concern. Consequently, the development of Remedial Action Goals should be an iterative process. Although the general approaches for determining Remedial Action Goals will be consistent across sites, particularly during the initial phases of the RI/FS, various site specific factors will be considered when final Remedial Action Goals are set at individual sites as more information becomes available.

Under CERCLA the process of setting Remedial Action Goals is essentially a two-step process. During Project Scoping, Preliminary Remedial Action Goals are based on readily available health-based information and generic exposure assumptions and parameters. Goals for each exposure route should be set at health-based ARARs such as Maximum Contaminant Levels (MCLs), promulgated under the Safe Drinking Water Act (SDWA) or Water Quality Criteria (WQC), established under the Clean Water Act (CWA). If these are not available, or if the aggregate risks from multiple contaminants make the ARARs not protective of human health then Cancer Slope Factors (q_i*s), and/or Reference Doses (RfDs) should be used to set Preliminary Remedial Action Goals for contaminants having carcinogenic effects and noncarcinogenic toxic effects, respectively. For carcinogens, the goal is based on an excess lifetime cancer risk of 10^{-6}. The NCP also specifies that ARARs are not deemed to be protective of human health if they would result in an aggregate risk from multiple contaminants and exposure pathways of 10^{-4} or more (55 FR 8718). For noncarcinogenicity, the goal is set at levels that do not result in adverse health effects, based on comparisons with RfDs or RfCs.

If, during the Remedial Investigation/Feasibility Study (RI/FS), it is determined that these Preliminary Remedial Action Goals are not exceeded, then a decision of no further action may be reached. Otherwise, as more information becomes available during the RI/FS, the above Preliminary Remedial Action Goals may be modified based on the consideration of various site-specific factors including exposure factors, uncertainty factors, and technical factors. For carcinogens, excess lifetime cancer risks within the range of 10^{-4} - 10^{-6} are considered acceptable. The EPA's preference is to set goals at the more protective end of the range, (i.e., towards 10^{-6}). As risks increase from 10^{-6} to 10^{-4} they become less desirable. Setting Remedial Action Goals within the risk range depends on a number of factors. The following factors will tend to push the Remedial Action Goals toward more stringent levels:

a. There are multiple contaminants at a site and/or there is a possibility of exposure via multiple exposure pathways at a site. For example, these cumulative effects

may mean that Remedial Action Goals for individual contaminants may be set at more stringent levels than 10^{-6}.

b. Sensitive populations, such as children and pregnant women, may be exposed to contamination at the site.

c. Potential impacts on environmental receptors are greater than human health impacts.

d. Remedial Action Alternatives have cross-media impacts.

e. There is a potential for human exposures from non-site-related sources.

Less stringent Remedial Action Goals may apply if:

a. A contaminant cannot be analytically detected at levels that represent a risk.

b. Background concentrations of a contaminant represent a risk.

DETERMINING PRELIMINARY REMEDIAL ACTION GOALS

For each contaminant of concern and for each medium of concern, the Preliminary Remedial Action Goal is set at whichever of the following values is the lowest:

a. Health-based criterion for carcinogenic effects.

b. Health-based criterion for systemic effects.

c. The lowest chemical-specific ARAR.

d. Ecologically-based criteria.

We will present methods used to derive health-based criteria. ARARs and various To Be Considered guidance values have been compiled for the DOE-OR/ER (4) and a discussion of these is beyond the scope of this paper. Ecologically-based criteria are currently under development.

The RCRA Facility Investigation (RFI) Guidance Volume I manual (5) provides tables of health-based criteria for determining the need for a Corrective Measures Study. Since these criteria are continually under review and are frequently updated it would not be appropriate to simply use these values as Preliminary Remedial Action Goals for hazardous waste sites. However, the methodology provided by the RFI guidance manual is consistent with the approach outlined in *Risk Assessment Guidance for Superfund: Volume I* (RAGs)(6) and in the NCP, and may be used for deriving the Preliminary Remedial Action Goals for each contaminant of concern. Since the criteria are based on generic, readily available information, the values for a given contaminant will be applicable across multiple sites.

Health-based criteria are based on carcinogenic effects and noncarcinogenic toxic effects. A conservative approach is used, assuming a combination of upper-bound and average intake variables. The criterion values are associated with an acceptable risk level of 10^{-6} for class A and B carcinogens, a risk level of 10^{-5} for class C chemicals, and a Hazard Index (H.I., the estimated dose divided by the reference dose) of 1 for noncarcinogenic toxic effects.

Health-based criteria are based on the ingestion of soils, surface water, and groundwater, and inhalation of fugitive dust particles. For sites with surface water bodies that are used for fishing, health based criteria should also be based on the ingestion of aquatic organisms. Table I shows the intake and exposure assumptions to be applied when calculating criterion values. They are based on the default values provided by RAGs (6) and by recent supplemental guidance to RAGs provided by the EPA (7).

Criteria Based on Carcinogenic Effects

The following equation is used for calculating criteria based on carcinogenic effects:

$$C_i = (R/q_i^*) \times (W/I) \qquad \text{(Eq. 1)}$$

where:

C_i = criterion concentration for the constituent of interest (water: mg/liter; soil: mg/kg; fish: mg/g; dust: mg/m^3)

R = the specified risk level; 10^{-6} for class A and B carcinogens; 10^{-5} for class C chemicals

q_i^* = Cancer Slope Factor for the constituent of interest $(mg/kg/day)^{-1}$, available on the Integrated Risk Information System (IRIS) and/or the Health Effects Assessment Summary Tables (HEAST)

W = body weight (kg)

I = intake rate (water: liters/day; soil: kg/day; fish: g/day; dust: m^3 of air/day)

Criteria Based on Noncarcinogenic Effects

For noncarcinogenic toxic effects, the following equation is used:

$$C_i = RfD_i \times (W/I) \qquad \text{(Eq. 2)}$$

where:

RfD_i = Chronic reference dose for the constituent of interest (mg/kg/day), available from IRIS and/or HEAST

Determination of Whether Preliminary Remedial Action Goals Are Exceeded

Further action will be required at a site (i.e., the RI/FS will be continued) if Preliminary Remedial Action Goals for individual contaminants are exceeded in any medium. Even if none of the individual contaminants exceed the Preliminary Remedial Action Goals for any medium, the cumulative effects of multiple contaminants and exposure pathways must be considered.

The *Guidelines for the Health Risk Assessment of Chemical Mixtures* (8) describe the recommended approach for evaluating the cumulative effects of multiple contaminants. These guidelines assume an additivity of effects for multiple carcinogens and for noncarcinogens with the same toxicological endpoint. Carcinogenic and noncarcinogenic toxic effects must be considered separately. We use the following approach for evaluating the cumulative effects of multiple contaminants.

For both carcinogenic and noncarcinogenic toxic effects, a Hazard Value (HV) is calculated according to the following equation:

$$HV = \sum_{i=1}^{n} AC_i/C_i \qquad \text{(Eq. 3)}$$

where,

AC_i = actual concentration of contaminant i in the media of concern

C_i = health-based criterion concentration for contaminant i in the media of concern, calculated using the methodology described in Eq. 1 and 2, above, and the intake and exposure assumptions shown in Table I

n = total number of carcinogens of concern or the total number of systemic toxicants of concern causing similar toxic effects

TABLE I
Exposure Parameters Used to Set Preliminary Remedial Action Goals

Exposure Pathway	Exposure Parameter
Ingestion of potable water	2 liters/day 70 kg body weight 350 days/yr 30 yrs
Ingestion of soil and dust	200mg/day for 16 kg child (noncarcinogens) 100mg/day for 70 kg adult (carcinogens) 350 days/yr 6 yrs as a child (noncarcinogens) 6 yrs + 24 yrs (carcinogens)
Inhalation of fugitive dust particles	20 m^3/day 70 kg body weight 350 days/yr 30 years
Consumption of aquatic organisms	54g/day 70 kg body weight 48 days/yr 30 years

If, for a given carcinogen or noncarcinogenic toxic contaminant, an ARAR is set at a lower level than the health-based criterion concentration, C_i, then the ARAR or environmental criteria should be used in place of the C_i.

For carcinogens, C_i is based on a risk level of 10^{-4}. Further Remedial Investigations will be required at a site if the HV exceeds unity, (i.e., the cumulative risk caused by all the carcinogens in the medium of concern exceeds 10^{-4}). Cumulative risks exceeding the 10^{-3} level (i.e., HV exceeds 10) may indicate an immediate cause of concern. Therefore, the need for interim corrective measures/immediate removal/emergency response should be evaluated.

In calculating the HV for systemic toxicants, chemicals that induce the same toxicological endpoint, such as liver toxicity, should be grouped together. If the HV exceeds unity for any of the groups, then further action will be required.

In order to determine the cumulative effects of multiple exposure pathways, HVs are summed across media; if the total exceeds unity for carcinogens or any group of noncarcinogenic toxicants, then further Remedial Investigation will be warranted.

The above approach is based on the premise that cumulative risks from multiple contaminants and exposure pathways exceeding 10^{-4} will warrant further Remedial Investigations. The 10^{-4} level was chosen for two reasons. 1) The NCP states that ARARs are deemed not protective of human health if they are associated with cumulative risk levels greater than 10^{-4} (55 FR 8718). Although the NCP also suggests that if Preliminary Remedial Action Goals are based on Cancer Slope Factors then the goals should be set at a cumulative risk level of 10^{-6}; selection of a 10^{-6} risk level would be inconsistent with the level specified for ARARs. 2) The Preliminary Remedial Action Goals are based on extremely conservative assumptions. When considering cumulative effects, the conservative effects themselves become cumulative.

If Preliminary Remedial Action Goals are not exceeded and the HV does not exceed unity, then no further action is necessary. Note that specific Preliminary Remedial Action Goals cannot be set for contaminants for which no health-based criteria, environmental criteria, or ARARs are available. These contaminants should be discussed qualitatively in the risk assessment, and best professional judgement will be used to determine whether further action is necessary.

SETTING FINAL SITE-SPECIFIC REMEDIAL ACTION GOALS

Final Remedial Action Goals are set within the acceptable risk range of 10^{-4} to 10^{-6}, based on site-specific conditions. However, cumulative risks exceeding the 10^{-3} level may be immediately unacceptable, and emergency response/interim corrective measures may be implemented as soon as possible. Final Remedial Action Goals will depend on a variety of factors, including those discussed below.

Cumulative Risks From Multiple Contaminants and Exposure Pathways

In order to determine whether cleanup will be required, it will be necessary to calculate total cumulative risks for multiple carcinogens and a cumulative hazard index for multiple noncarcinogenic toxicants (including antagonistic and synergistic effects) based on exposure concentrations estimated at the site. Chapter 8 of the *Risk Assessment Guidance for Superfund Manual* (6), outlines the procedure for calculating cumulative effects. In performing this procedure it will be necessary to consider whether ARARs or environmental criteria are exceeded. Contaminants that do exceed ARARs or environmental criteria will, at a minimum, have to be cleaned up to those levels, regardless. The question will be whether the remaining contaminants must also be remediated, and whether the contaminants exceeding ARARs or environmental criteria will need to be remediated to even more stringent levels because those ARARs or environmental criteria are not protective due to cumulative effects of multiple chemicals and pathways. Therefore, in calculating cumulative excess cancer risks and cumulative hazard indices, the ARARs and environmental criteria for contaminants exceeding ARARs or environmental criteria are used rather than the actual exposure concentrations. Of course, for the remaining chemicals that do not exceed the ARARs or environmental criteria, the actual concentrations are used. If cumulative risks exceed the Remedial Action Goals or if the Hazard Index for any group of toxicants having the same mode of action exceeds 1, then

some or all of the remaining chemicals may also need to be cleaned up.

Background Concentrations

40 CFR 264 states that groundwater in broadly contaminated areas might be remediated to specific background levels, except where remediation is part of an area-wide cleanup (55 FR 30826). If the owner/operator can demonstrate that constituent levels that are downgradient do not exceed upgradient background concentrations (even if upgradient background concentrations exceed Action Levels) and that background levels are not due to other solid waste management units (SWMUs) on the facility, cleanup may not be required. If the downgradient concentration is above the background concentration, then cleanup will be to the background level.

Therefore, Remedial Action Goals are not set for contaminants that are at levels below background. However, if those background levels themselves represent a risk for a given contaminant, then Remedial Action Goals for the remaining contaminants may be set at a cumulative risk at the most stringent level within the acceptable risk range. The more stringent risk level is used in order to add protection from the additional background risk.

Detection Limits

Both CERCLA and RCRA recognize that there are technical limitations which must be considered while establishing Remedial Action Goals. For example, 40 CFR 264 specifies that Media Cleanup Standards would not be set lower than detectable levels, unless an acceptable modeling technique to estimate contaminant concentrations is available (55 FR 30828).

Therefore, Remedial Action Goals are not set for contaminants that are at levels below detection limits, unless reliable modeling values can be applied. However, if those detection limits themselves represent a risk for a given contaminant, and site-specific information indicates that the contaminant may indeed be present at levels close to the detection limit, then Remedial Action Goals for the remaining contaminants may be set at a cumulative risk at the most stringent level within the acceptable risk range. The more stringent risk level is used in order to add protection from the possible risk associated with a high detection limit. This raises the issue of what detection levels we should strive to achieve. Risk assessors must propose acceptable detection limits for all contaminants that have been assigned toxicity values or other standards by the EPA. Such detection limits should be based on Preliminary Remedial Action Goals (regardless of whether the goals are based on human health criteria, environmental criteria, or ARARs). For contaminants that have been identified as being of concern, analytical techniques that are capable of achieving the desired detection levels need to be identified. In many cases, standard analytical procedures will be sufficient. In other cases, more sophisticated methods will be required.

ACKNOWLEDGEMENTS

The authors wish to thank Gordon Blaylock, Vicki Brumback, Venkatesh Chidambariah, Keith Eckerman, Liz Etnier, Owen Hoffman, David Kocher, Dan Land, Po-Yung Lu, Denise Miller, Bob Ross, Glenn Suter, John Trabalka, and Curtis Travis for their help in developing these approaches.

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A CO-METABOLIC APPROACH TO GROUNDWATER REMEDIATION*

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ABSTRACT

In support of the U.S. Department of Energy's (DOE) Integrated Demonstration (Cleanup of Organics in Soils and Groundwater at Non-arid Sites) at the Savannah River Site (SRS), Oak Ridge National Laboratory (ORNL) and the University of Tennessee (UT) are involved in demonstrations of the use of methanotrophs in bioreactors for remediation of contaminated groundwater. In preparation for a field demonstration at ORNL's K-25 Site in Oak Ridge, Tennessee, ORNL is conducting batch experiments, is operating a number of bench-scale bioreactors, has designed pretreatment systems, and has modified a field-scale bioreactor provided by the Air Force Engineering and Services Center for use at the site. UT is operating bench- scale bioreactors with the goal of determining the stability of a trichloroethylene-degrading methanotrophic consortia during shifts in operating conditions (e.g. pH, nutrient inputs, and contaminant mixtures). These activities are all aimed at providing the knowledge base necessary for successful treatment of contaminated groundwater at the SRS and K-25 sites as well as other DOE sites.

INTRODUCTION

Numerous chlorinated hydrocarbons pose serious threats to groundwater sources. Chlorinated hydrocarbons and organic solvents are widespread priority pollutants of groundwater, and of these trichloroethylene (TCE) is the most frequently reported contaminant at waste disposal sites on the U. S. Environmental Protection Agency (EPA) National Priority List (1). Concentrations of priority pollutants in excess of 1000 $mg \cdot l^{-1}$ have been reported beneath some U. S. Department of Energy (DOE) sites (2). TCE, a suspected carcinogen, is resistant to degradation in the subsurface environment, air stripping, carbon adsorption, and other traditional methods for removal of TCE from groundwater merely transfer TCE from one medium to another. Thus, DOE has a significant interest in developing new methodologies for the treatment of TCE contamination.

The DOE Integrated Demonstration (Cleanup of Organics in Soils and Groundwater at Non-arid Sites) at the Savannah River Site (SRS) is designed to address this type of groundwater contamination. Significant efforts under way at SRS and numerous DOE facilities, including Oak Ridge National Laboratory (ORNL), are aimed at demonstrating innovative treatment technologies for chlorinated organics at SRS. The activities at ORNL specifically focus on the remediation of a site in Oak Ridge, a seep at the K-25 Site, but also support the Integrated Demonstration by providing information on the generality of the bioremediation approaches being taken and data on operating conditions that are common to the technology not specific to the site. ORNL and the University of Tennessee (UT) are involved in demonstrations of the use of methanotrophs in bioreactors for remediation of contaminated groundwater and in determining conditions in the subsurface that will promote high rates of TCE degradation by methanotrophs.

Methanotrophs are bacteria capable of oxidizing one-carbon compounds as the sole source of carbon and energy. The first step in methane oxidation is catalyzed by methane monooxygenase (MMO). MMO has wide substrate specificity which results in fortuitous degradation of nongrowth substrates, including TCE (3–7). Transformation of compounds unable to support growth is referred to as cometabolism or cooxidation and is the basis for using methanotrophs in the degradation of TCE as well as numerous other recalcitrant organic contaminants.

The MMO of methanotrophs exists in two forms, soluble and particulate. The form of the enzyme present depends upon growth conditions (8); soluble MMO occurs under copper-limiting conditions ($< 4.8\ \mu M\ CuSO_4$), whereas the particulate enzyme is found with excess copper (9). Numerous investigators have found that production of the soluble enzyme is responsible for maximum TCE degradation (10), possibly because of its broader substrate specificity (11).

* This research was supported by the U. S. Department of Energy's Office of Environmental Restoration and Waste Management, Office of Technology Development. Oak Ridge National Laboratory is operated by Martin Marietta Energy Systems, Inc. under contract DE-AC05-84OR21400 with the U. S. Department of Energy.

The rate of methane and TCE oxidation may be limited by insufficient reducing power. It appears that both particulate and soluble MMO use NADH as the electron donor and growth yields of methanotrophs are likely to be NADH limited (12).

In addition to oxidation of methane and TCE, there is substantial evidence for methanotrophic degradation of ammonia to nitrate (9). The initial oxidation step is catalyzed by MMO. Because MMO is involved in oxidation of the three compounds, ammonia may compete for the active site on the enzyme and thus reduce both methane and TCE oxidation rates.

The effectiveness of different microbial consortia and operating conditions required for maximization of TCE degradation (nutrient levels, gas flow rates, etc.) are being evaluated in batch experiments and in bench-scale continuous-flow trickle-filter bioreactors at ORNL and in upflow expanded-bed bench-scale bioreactors at UT. The purpose of this paper is to present a summary of the results achieved to date in the determination of operating conditions for the field-scale bioreactor and a brief description of the design and anticipated use of the field-scale bioreactor.

MATERIALS AND METHODS

Characteristics of the Site Water

The seep water at K-25 contains numerous contaminants in addition to TCE, including anaerobic degradation products of TCE [e.g., dichloroethylenes (DCEs)] and compounds disposed of with the TCE, [e.g. tetrachloroethylene (PCE), toluene, other aromatics, numerous chlorinated and non-chlorinated organic compounds, and high levels of iron] (13). Pretreatment of the seep water may be necessary because of the high iron content of the water. Several pretreatment techniques designed to eliminate iron precipitation problems will be evaluated in bench-scale systems and in the field but are not discussed here.

Cultures and Culture Conditions

Cultures used at ORNL were obtained from methane enrichments of water samples from various contaminated sites, including one culture (KCMC) from a DOE site in Kansas City, Missouri, and two cultures, DT-1 and DT-2, from waste disposal areas at Oak Ridge Y-12 Plant (3). Two additional cultures were obtained from K-25 by incubating NATE mineral salts medium (7) with seep water (50% seep water, 50% mineral salts medium) containing 0.43 $mg \cdot L^{-1}$ TCE, 0.46 $mg \cdot L^{-1}$ methylene chloride, and methane, and by filtering seep water through 0.45 μM filters and incubating the filter in mineral salts medium with methane.

Cultures were prepared by transferring cells from stock plates to NATE medium, without copper and ammonia unless otherwise stated, in bottles with Teflon-lined septum caps. Sterile-filtered methane gas was injected to yield a 10% (vol/vol) methane headspace, and cultures were incubated at 22°C on a shaker table (75 RPM) for 5-7 days.

Experiments at UT used two TCE degrading consortia. The first consortium (SM) was established from an enrichment from the Savannah River Plant, Aiken, South Carolina (9,12). The second consortium (PM-M) was derived by combining the SM consortia, a methanotroph isolated from ORNL (7) and methane and propane using cultures obtained from the vicinity of Ada, Oklahoma (4). Consortia were maintained on a buffered mineral salts medium (12) containing 5% methane and 3% propane (vol/vol, headspace).

Batch Degradation Assays at ORNL

Batch experiments were run and analyzed similarly to those described previously (13). Cultures were centrifuged and the pellets suspended in NATE. Twelve mL aliquots were transferred to 40-mL vials. Water-saturated TCE and methane and/or formate were injected, and vials were inverted and incubated as described above. Hexane was injected to terminate degradation reactions and to extract TCE for quantification by gas chromatography (GC) using a Perkin-Elmer Sigma 2000 GC with an electron capture detector (ECD) and a 1% SP1000 60/80 Carbopac B column (Supleco).

Various conditions were evaluated for their effects on TCE degradation. Degradation by several consortia in mineral salts medium containing copper was compared with that in medium without copper. Ammonium chloride was omitted from the degradation medium to determine whether TCE removal would be increased. To assess the effect of additional reducing power on TCE oxidation, 20 mM sodium formate was added to the degradation media in another series of experiments. Growth of the consortia and the degradation experiments described above took place at 22°C. Because temperatures in the bioreactors may exceed 22°C, cultures were also tested for growth at 37°C. Because the bench-scale bioreactors were run at dilutions of the NATE media, a comparison was made of degradation in 1X and 0.1X NATE media. Cultures were grown in 1X media, and degradation was measured in either 0.1X or 1X media.

Bioreactors at ORNL

Six 5-cm idia glass laboratory-scale trickle-filter bioreactors are used in these experiments and are similar in concept to one described earlier (14). Five of the columns are packed with 1.6-cm polypropylene flexrings to a depth of 45 cm. One is packed with 0.48 cm idia polypropylene tubing 0.32 to 0.95 cm long. The reactors are fed 10x to 100x dilutions of the media described for the ORNL batch experiments. Ammonia has been removed from the nutrient feed to the bioreactors and replaced with nitrate.

TCE degradation is assessed by GC measurement of TCE in off-gas and liquid effluent. A Hewlett Packard model 5890A GC equipped with an ECD and a Megabore DB + 1 capillary column (J&W Scientific Corp.) was used.

Bioreactors at UT

Construction, maintenance, and operation of the total-recycle expanded-bed bioreactors operated at UT have been previously described (15). All manipulations used Teflon-plungered syringes for transferring solutions. Batch experiments used crimp-top tubes or serum vials sealed with Teflon-lined caps. All incubations were at ambient temperature (23°C). In TCE degradation experiments initial TCE concentration was 20 $mg \cdot l^{-1}$ (35 $\mu mol \cdot reactor^{-1}$). Medium was recycled for 5 days. Methane was added at 5% (vol/vol), and propane was added at 3% (vol/vol). Compounds and concentrations used in mixed-waste experiments are listed in Table I. Unless otherwise noted, data are presented as means of several bioreactors containing the SM and PM consortia.

TABLE I

Degradation of Mixed Organic Wastes by Propane/methane-fed Microbial Consortia

Organic wastes	Concentration[a] in bioreactors at day 0 ($mg \cdot l^{-1}$)	Mean loss in bioreactors after 21 days (%)	Mean loss in cell suspensions after 20 days (%)
vinyl chloride	4.0	>99	>99.9
1,1-dichloroethane	1.1	>99	N.D.b
1,1-dichloroethylene	0.7	>99	99
1,2-dichloroethylene	3.0	>99	N.D.
1,1,1-trichloroethane	1.2	>99	>99
trichloroethylene	2.6	90	>99.9
tetrachloroethylene	2.1	60	80
benzene, xylene	0.1	99	>99.9
toluene	0.05	>90	>99.9

[a]Concentrations based upon the model of all the toxicants present in the aqueous phase with headspace to liquid volume ratios of 2.0 2.5:1.
N.D. = not determined.

Analytical procedures are described in detail elsewhere (9,12,15,16). TCE and other chlorinated hydrocarbons not mentioned below were analyzed using a Hewlett Packard 5890 GC equipped with a capillary column and an ECD. Vinyl chloride, cis- and trans-1,2-dichloroethylene (DCE) were analyzed using a Schimadzu GC-9A GC equipped with a photoionization detector (HNU Systems, Newton, MA). Methane and CO_2 were assayed using a Schimadzu GC-8A gas chromatograph with a thermal conductivity detector, and radioactive CO_2 was determined by a gas proportional counter. Propane was analyzed using a Schimadzu GC-9A GC equipped with a flame ionization detector.

RESULTS AND DISCUSSION

Batch Experiments at ORNL

Elimination of copper from mineral salts medium at 1X trace metals concentration had no effect on TCE degradation by the KCMC culture. It was not surprising that TCE degradation did not increase under these conditions since soluble MMO production reportedly occurs at copper concentrations of 0.50 μM or less. However, achievement of those levels required extensive purification and decontamination measures (10). Alternatively, it may be possible to drive the system to copper limitation with less heroic efforts if high biomass levels are achieved. This is apparently the approach taken by Oldenhuis et al. (17). Because removal of trace amounts of copper from bioreactors in field situations is not feasible, we made no similar efforts to remove trace amounts of copper from glassware or the distilled, deionized water usually used in media preparation. As a possible means of circumventing the problem of contaminating copper, concentrations of trace metals other than copper were increased. This would, in effect, reduce the relative amount of copper available in the media. Doubling the trace metal concentration in the absence of copper had no effect on TCE degradation by KCMC (data not shown). Thus, simply removing the copper did not result in the high rates of degradation noted by other investigators (10) when copper is limited to very low levels.

KCMC cells cultured in 1X NATE exhibited the same level of TCE degradation when transferred into 0.1X medium as that occurring in 1X medium (Fig. 1). Similar results were obtained with the DT-1 culture (data not shown). No significant growth occurred when cells were cultured in 0.1X NATE. Thus, media concentration had no direct effect on TCE degradation but may have an indirect effect by limiting growth of the consortia. Limitation of growth in the bioreactors must be considered since nutrients are present at lower concentrations.

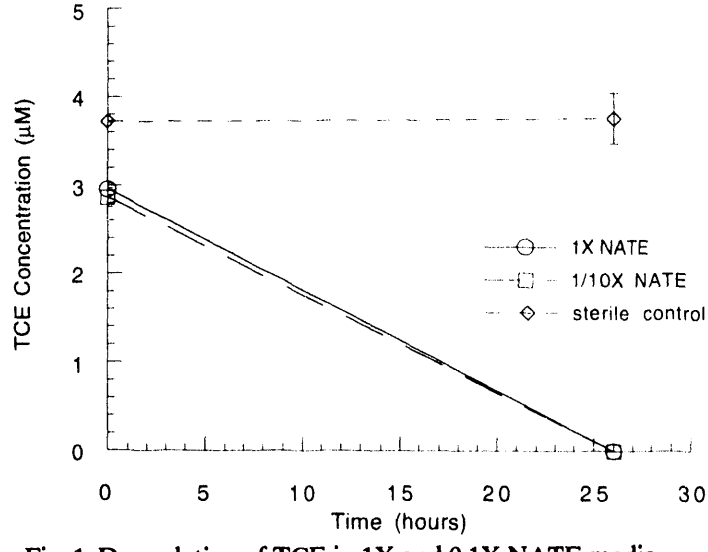


Fig. 1. Degradation of TCE in 1X and 0.1X NATE media, both without copper or ammonia, by methane using consortia in batch culture. Consortia were grown in 1X trace metals and transferred to fresh 1X or 0.1X media for the degradation assays.

As in previous experiments with a pure culture (18), the elimination of ammonium chloride from the medium resulted in significantly increased degradation of TCE by several consortia (data not shown). In experiments with 5X trace metals and without ammonia we saw increased TCE degradation by the K-25 culture. When ammonium chloride was omitted from

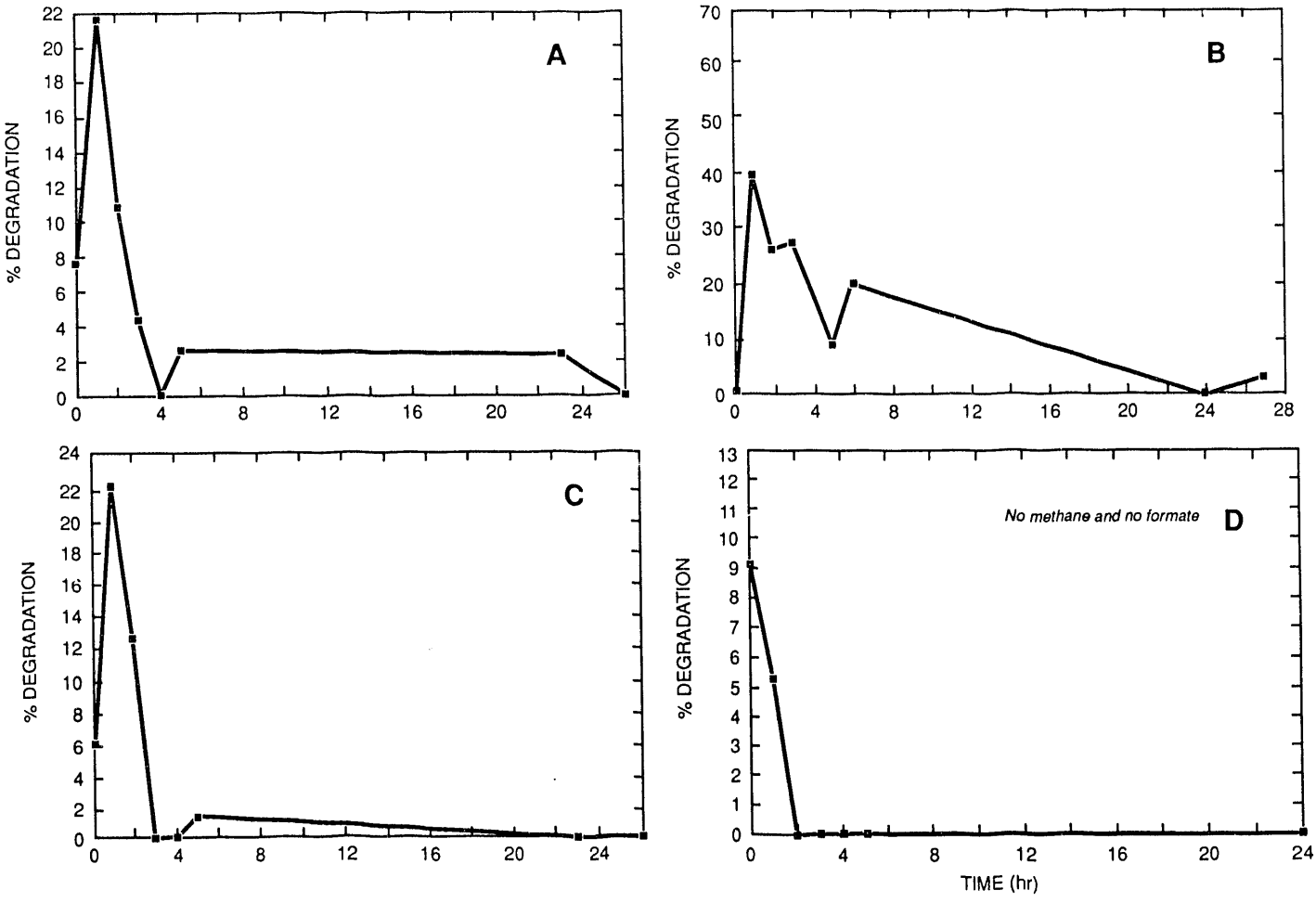


Fig. 2. TCE degradation response of continuous trickle-filter methanotrophic bioreactor to withdrawal of methane from the gas phase and simultaneous addition of 20 mM formate to the liquid phase. Panels (a), (b), and (c) are replicates; panel (d) is a control experiment in which methane was removed, but formate was not added.

the degradation mixture with the DT-2 culture degradation was doubled. The data strongly suggest that alleviating competitive inhibition of the MMO will substantially increase TCE degradation. After completion of these experiments, ammonium chloride was omitted from the plates used to isolate and maintain bacterial stocks and from the growth and degradation media.

Formate increased TCE degradation by KCMC over that occurring in the absence of both formate and methane (13), but in the batch experiments the effect was not generalizable over cultures (data not shown). For example, degradation by DT-2 was similar under all substrate conditions tested. Addition of both methane and formate decreased degradation by the K-25 and KCMC cultures. Other investigators have previously shown that under some conditions formate can increase TCE degradation (e.g. 19).

At an elevated growth temperature of 37°C, only the DT-1 culture exhibited vigorous growth. No visible turbidity was evident in either the DT-2 culture or the KCMC cultures after >7 days. DT-1 grows poorly at 22°C, often exhibiting no growth at this temperature. Preliminary results indicate that DT-1 does not degrade TCE as well as either DT-2 or KCMC.

ORNL Bench-Scale Bioreactors

Formate experiments with the ORNL bioreactors indicate a general short-term stimulation of TCE degradation with the addition of formate to the bioreactors (Fig. 2). In the absence of methane and formate the degradation rate dropped rapidly and did not show the short-term increase evident with the formate addition. Alternate pulsing of methane and formate may serve to maintain MMO production and provide sufficient reducing power for maximum TCE degradation.

UT Bench-Scale Bioreactors

The UT bioreactors (both the PM and SM consortia) removed 87±5% of the initial TCE added to reactors within 5 days. An mean of 2.1 mmol propane plus 1.5 mmol methane were oxidized for a substrate/TCE loss ratio of 123±16 (μmol/μmol). When substrate was added to the reactors only at Day 0 (pulsed-fed), twice as much TCE was consumed per mmol substrate oxidized. If reactors were replenished with respect to TCE and further starved, the TCE degradation rates dropped an order of magnitude, demonstrating that brief starvation resulted in increased TCE degradation efficiencies but frequent pulsed-feedings were required to maintain stable TCE degradation. Reactors fed either methane or propane alone degraded TCE but less effectively.

A variety of other toxic compounds were degraded, many to detection limits, in the total-recycle bioreactors (Table I). TCE degradation ceased at 0.3 mg·l^{-1}, resulting in a loss of only 90% of the initial TCE concentration while

dichloroethylenes and vinyl chloride, suspected intermediates of anaerobic TCE degradation, were degraded to the detection limits. Benzene, toluene, and xylene were degraded to detectable limits.

The bioreactor stability studies at UT have also demonstrated that pH is a critical factor in the TCE degradation by the PM and SM consortia. Elevation of the pH to >7.3 reduced TCE degradation by the two consortia from >80% to <20% indicating low resistance to pH disturbance. The resilience was also low; on these systems TCE degradation activity took days to weeks to recover. Examination of the effects of low pH excursions, as well as altered nutrient inputs and contaminant mixtures on the metabolism and physiology of the microbial community on these bioreactors, are in progress.

Progress on Field-Scale Bioreactors

The field-scale Air Force bioreactor has been modified to maximize the flexibility of the operational modes and has been moved to the K-25 site. The bioreactor consists of two 7-ft columns which are 16 in. in diameter. The modifications will allow the columns to be operated in series or in parallel and could allow treatments such as pulsing of formate. Operation of the field unit is scheduled to begin in the fall of 1991 under operating conditions established in the batch and bench-scale tests. In the fall of 1992 the operation of this system with methanotrophs will be compared with a bioreactor system that uses aromatic degraders that also can degrade TCE.

SUMMARY

The collaboration between ORNL and UT and the stepwise progression from batch tests to bench-scale bioreactors to a pilot-scale bioreactor in the field provides for testing of several types of cultures and conditions and will lead to improved rates of degradation during the demonstration. Results to date include the determination of the appropriate pH range for improved TCE degradation, the unsuitability of ammonia as a nitrogen source, the potential for a short-term positive result of formate addition (to at least some cultures), and the detrimental effect of elevated temperature on growth of most of the cultures. Continuation of this approach should also lead to greater applicability of the results to conditions at a range of DOE sites.

ACKNOWLEDGMENTS

We thank Dr. Terry Hazen and other members of the SRL Integrated Demonstration Team for their support in this project. We thank Dr. Janet Strong-Gunderson and Dr. Robert S. Burlage for their reviews of the manuscript. Thanks also to C. Deane Little and William Eng for their research efforts leading up to this project. Our appreciation also goes to the Air Force and the staff, especially Captain C. Vogel, of the Air Force Engineering and Services Center, Tyndall Air Force Base, for allowing us to modify and use their bioreactor. This is Publication No. 3766 of the Environmental Sciences Division, Oak Ridge National Laboratory.

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BIOREMEDIATION OF HANFORD GROUNDWATER

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ABSTRACT

Liquid wastes containing radioactive, hazardous, and regulated chemicals have been generated throughout the 40 years of operations at the U.S. Department of Energy's (DOE) Hanford Site. Some of these wastes were discharged to the soil column and many of the waste components, including nitrate (NO_3-), carbon tetrachloride (CCl_4), and several radionuclides, have been detected in the Hanford groundwater. A research and development program is presently underway to develop bioremediation technologies for treating contaminated Hanford groundwaters. The program includes development of both ex situ and in situ treatment methods, with primary emphasis on developing an in situ treatment process. The goal of the in situ process is to stimulate the native microorganisms and accelerate the natural degradation of NO_3- and CCl_4. A demonstration site at Hanford for in situ biological treatment was selected in 1990, and extensive hydrological, chemical, and biological characterization of the site is underway. Current research and development activities are focusing on developing methods for supplying nutrients to the subsurface, evaluating the effect of in situ bioremediation on the long-term mobility of metal and radionuclide co-contaminants, and modeling the bioremediation process using three-dimensional visualization tools to help design the field-scale demonstration site and predict performance.

INTRODUCTION

The Hanford Site, located in southeastern Washington State, is an area of approximately 600 square miles that was selected in 1943 for producing nuclear materials, primarily plutonium, in support of the United States' effort in World War II. Hanford's operations over the last 40 + years have been dedicated to nuclear materials production, electrical generation, diverse types of research, and waste management. Some of these operations have produced aqueous and organic wastes that were subsequently discharged to the soil column. In the 200 West area of the Hanford Site (Fig. 1), plutonium recovery processes at Z-Plant discharged CCl_4-bearing solutions to three liquid waste disposal facilities: a trench, tile field, and crib. A minimum of 637 t of CCl_4 was disposed to the subsurface, primarily between 1955 and 1973, along with co-contaminants and/or degradation products such as tributyl phosphate; lard oil; cadmium; nitrates; hydroxides; fluorides; sulfates; chloroform; and various radionuclides, including plutonium (1). The subsurface in the vicinity of Z-Plant consists of approximately 58 to 65 m of unsaturated sediments and approximately 70 m of saturated soil overlying low permeability silts and clays and basalt bedrock. Carbon tetrachloride vapors have been encountered in the vadose zone during well drilling operations, and groundwater contamination from CCl_4 is extensive in the 200 West Area, covering more than 5 km^2. The highest concentrations of CCl_4 in the groundwater plume were measured approximately 450 m downgradient of the three disposal facilities at levels exceeding 1000 times the U.S. Environmental Protection Agency's (EPA) drinking water standard of 5 ppb. However, groundwater monitoring activities have been able to account for only less than 1% of the CCl_4 discharged to the subsurface (1).

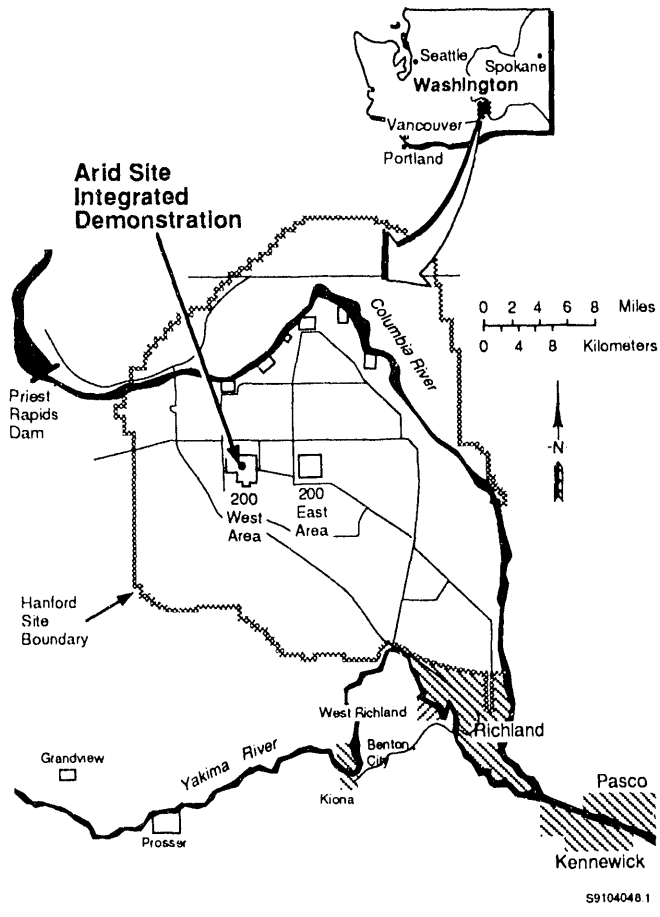


Fig. 1. Location of 200 West Area on the Hanford Site in Washington State.

* Pacific Northwest Laboratory is operated for the U.S. Department of Energy under Contract DE-AC06-76RLO 1830.

The DOE and its operating contractor at Hanford, Westinghouse Hanford Company, are currently pursuing an Expedited Response Action (ERA) to remove volatile CCl_4 from the vadose zone using soil vapor extraction (vacuum extraction) technology (2). In collaboration with the ERA, DOE's Office of Technology Development has selected the 200 West Area CCl_4 site as the host site for the Integrated Demonstration for Cleanup of Volatile Organic Compounds at Arid Sites (VOC-Arid Integrated Demonstration). The objective of the integrated demonstration is to develop, demonstrate, evaluate, and transfer for deployment new technologies for all phases of cleanup of VOCs and associated contaminants in the subsurface. The goal is to bring new technology forward to provide more effective, cheaper, and safer methods for cleanup. Bioremediation is one technology being developed as part of the VOC-Arid Integrated Demonstration to meet the need for cost effective technologies to clean groundwater contaminated with CCl_4 and other organic and inorganic contaminants.

BACKGROUND

The current understanding of the microbial degradation of carbon tetrachloride (CCl_4) is limited, particularly in comparison to other chlorinated aliphatic compounds such as trichloroethylene (TCE) that are common groundwater contaminants. However, progress has been made in recent years in identifying microorganisms and understanding mechanisms of CCl_4 biodegradation. Bouwer and McCarty (3) made some of the initial observations on the microbial transformation of CCl_4 in groundwater in batch microcosms under denitrifying conditions. Degradation of CCl_4 to CO_2 and chloroform in the microcosms was observed after 3 weeks of incubation. Bouwer and McCarty (4) also observed that CCl_4 was completely degraded to CO_2 under methanogenic conditions. In another microcosm study, Wilson, et al (5) observed the biodegradation of CCl_4 in unamended aquifer sediments. In this study there were considerable differences in the capacity of samples from different depths to degrade CCl_4, even samples that were identical in appearance. This observation demonstrates that, in addition to physical and chemical heterogeneities in the subsurface, microbial populations and their associated activities can also be heterogeneous. Therefore, precautions need to be taken when interpreting microbial characterization and biotransformation feasibility results from one or a few samples, as a small number of samples may not be representative of the complete zone because of natural heterogeneities in the subsurface. Multiple samples need to be taken to fully assess the capacity of the in situ microflora for CCl_4 degradation.

Carbon tetrachloride biodegradation has been demonstrated with a number of different bacteria. The conditions that favor biodegradation of CCl_4 are predominantly anaerobic. Carbon tetrachloride biodegradation to CO_2 and other metabolites has been demonstrated in pure cultures and consortium of denitrifying *Pseudomonas* sp. (6,7), the acetogen *Acetobacterium woodii* (8), *Clostridium* sp. (9), and under anaerobic and microaerophilic conditions by *E. coli* (10). Biodegradation of CCl_4 under denitrifying conditions is of particular interest because of the occurrence of both nitrates and CCl_4 in the unconfined aquifer on the Hanford site. Both Hansen (7) and Criddle et al. (6) identified *Pseudomonas* species capable of degrading CCl_4, with acetate as the electron donor and nitrate as the terminal electron acceptor. However, strain KC isolated by Criddle et al. (6) degraded CCl_4 more rapidly and completely than did the *P. stutzeri* strains studied by Hansen (7), but was sensitive to the presence of metals, particularly Fe(II) and Co(II). This sensitivity could have implications on the application of this organism for bioremediation of CCl_4-contaminated groundwater if there are metal co-contaminants or if the pH of the groundwater is acidic.

In addition to direct bacterial degradation, abiotic reductive dechlorination of CCl_4 has been shown to be catalyzed by the corrinoid cobalamin (vitamin B12) (11) and other metal-containing co-enzymes, including F430 and hematin (12). The reductive dechlorination of CCl_4 by co-enzymes is rapid, although the rate decreases with a decreasing number of Cl substituents. Interestingly, metal-containing proteins such as ferredoxin and azurin that carry out electron transfer reactions were unable to reductively dechlorinate polychlorinated ethylenes, CCl_4, or benzenes. The rapid reductive dechlorination of CCl_4 by co-enzymes suggests that this is the mechanism of biodegradation of CCl_4 by bacteria, although this mechanism has yet to be demonstrated. If co-enzymes are involved in the bacterial degradation of CCl_4, then this mechanism provides a strategy for isolating or developing strains that have an enhanced capacity for CCl_4 degradation and for designing ex situ and in situ approaches for bioremediation of CCl_4 in groundwater.

Efforts to evaluate the potential for bioremediation of Hanford's CCl_4-contaminated groundwater were initiated in 1987. Evidence of CCl_4 degradation by microorganisms indigenous to the Hanford Site was first obtained with a denitrifying consortium from groundwater samples (13). Additional studies conducted at laboratory-, bench-, and pilot-scales confirmed that NO_3- and CCl_4 were degraded by the bacterial consortium (14). The CCl_4-degrading *P. stutzeri* strain identified by Hansen (7) was isolated from the Hanford groundwater consortium in 1989.

To apply the degradative capability of these microorganisms, an ex situ process that uses the native microorganisms to destroy both NO_3- and CCl_4 was developed based on laboratory- and bench-scale studies. A pilot-scale treatment process was demonstrated with a simulated groundwater feed in 1989 (14). In these demonstration tests, greater than 99% of the NO_3- and 93% of the CCl_4 was destroyed at influent concentrations of 400 ppm and 200 ppb, respectively. Analysis of all product streams indicated that the concentrations of NO_3- and CCl_4 were below the drinking water standards of 44 ppm and 5 ppb, respectively. This process is continuing to be developed and tested to support remediation of contaminated groundwater. However, the primary focus of the bioremediation program is to evaluate the potential for in situ remediation. A location within the 200 West Area was selected in FY 1990 for development of a bioremediation test site. Characterization and preparation of the test site was initiated in FY 1991 as part of DOE's VOC-Arid Integrated Demonstration.

SITE CHARACTERIZATION AND SEDIMENT ANALYSIS

The primary objectives of the drilling and site characterization activities at the test site are to 1) confirm that the desired contaminant types and concentrations are present for bioremediation testing; 2) determine the microbial

populations present in groundwater and the feasibility of CCl_4 degradation by the indigenous population; 3) determine the aquifer's hydraulic, transport, and chemical characteristics for remediation system design; and 4) provide a well network to be used for testing and demonstrating groundwater bioremediation.

Sediment Sampling

During FY 1991, a borehole for site characterization was drilled using cable tool-percussion drilling to a total depth of approximately 85 m (279 ft). The depth to groundwater at the site is approximately 74 m (244 ft). Samples were collected and analyzed for physical, chemical, and microbiological characterization according to requirements provided in a written work plan. Deionized, sterilized water was used for drilling from approximately 6 m (20 ft) above the water table to the bottom of the borehole to prevent contamination from nonindigenous microorganisms. Tools used for sampling were cleaned at the site with a high-pressure hot-water cleaner prior to sample collection.

Sediment samples were collected; described for textural, general mineralogy, and color characteristics; and archived for the entire drill depth. Three sediment samples were collected below the water table. Sub-samples were taken from these split-barrel sediment samples, collected in amber glass vials containing methanol, and kept cool until analysis for volatile organics. The depth of the samples and the respective results are given in Table I.

Water samples were collected at four depths in the saturated zone and were analyzed for volatile organics, metals, anions, and gross beta concentrations. One sample was analyzed for alkalinity, total organic carbon, and gross alpha in addition to the analytes previously identified. The sampling interval was opened by driving the casing to the bottom or near the bottom of the borehole then drilling an open hole below the bottom of the casing. The borehole was open from as little as 0.15 m (0.5 ft) to as much as 0.76 m (2.5 ft) when the sample was collected. The samples were collected from the well by bailer and transferred into containers. Samples were kept cool until they were analyzed. The open intervals from which samples were collected, and the respective results from their analyses, are given in Table II for volatile organics and anions.

Samples were collected from eight depth intervals, one above and seven within the saturated zone, for studies to determine indigenous microbial populations and contamination degradation by indigenous microorganisms. For the sampling intervals during which sediments were collected for microbiological analyses, cores were collected using a split spoon sampling tool containing a Lexan liner (Fig. 2). Numerous precautions were taken to ensure the microbiological integrity of the core samples. The precautions included steam cleaning and ethanol flame disinfection of the split spoon, shoe, and core catcher prior to each sampling interval. In addition, the Lexan liners were autoclaved and aseptically placed into the disinfected split-spoon tool immediately before the trip down the borehole. Following coring and transport to the surface, the shoe was removed and the split spoon disassembled. The Lexan-encased core was immediately capped and placed into a polyethylene bag that was then flushed repeatedly with Ar, sealed, and transported to the laboratory. In contrast to in situ bioremediation of petroleum hydrocarbons in groundwater, the approach described herein requires the development and maintenance of anaerobic conditions. Therefore, sampling procedures for site characterization were designed to minimize the introduction of air into subsurface samples. In the laboratory, the cores in the polyethylene bags were placed inside an anaerobic (N_2) glovebox. Upon removal from the polyethylene bag, the Lexan core liners were wiped clean and cut longitudinally with a cordless power saw. Depending on the nature of the core material, the core was either split and the interior portions sampled for use in microbiological analyses, or one-half of the Lexan liner was removed and the outer core material pared to avoid sampling sediment that may have come in direct contact with surfaces of the drilling tools. Table III lists the intervals from which samples were collected.

Samples were collected from two depth intervals in the saturated zone for hydraulic characterization analyses. The analyses, for which the results are not yet available, include water retention characteristics, bulk and particle density, and hydraulic conductivity. These samples were collected in Lexan liners in a manner similar to those collected for microorganism studies. The intervals from which samples were collected are 78.8 - 79.3 m (258.4 - 260.3 ft) and 81.7 - 82.0 m (268 - 269.1 ft).

Microbiological Analyses

Microbiological analyses included sediment microcosm studies to determine the potential for denitrification and biodegradation of CCl_4. Nitrate disappearance from the solution phase of anaerobic microcosms upon addition of acetate was determined by colorimetric analysis for nitrate and nitrite.

TABLE I

Sediment Sample Analysis Results from Groundwater Biological Treatment Well

Sample Depth, m (ft)	Date	Methylene Chloride, ng/gm	Chloroform, ng/gm	Carbon Tetrachloride, ng/gm	Trichloroethylene, ng/gm
75.6 (247.9)	7/01/91	962	29	10	1
78.3 (257.0)	7/03/91	4505	103	287	7
79.9 (262.0)	7/09/91	< 1677*	< 8	25	< 2

*The high "less than" value (<) for this sample is caused partly by methylene chloride impurity in the purge-and-trap grade methanol and the small amount of sediment in the sample vial.

TABLE II

Water Sample Analysis Results for Volatile Organics and Anions from Groundwater Biological Treatment Well

Sampling Date	7/2/91	7/10/91	7/16/91
Sample Depth Interval (m)	75.3-76.0	79.2-80.0	81.7-82.1
(ft)	247.0-249.4	260.0-262.5	268.0-269.5
Methylene Chloride (ppb)	<5	3.2**	<5
Chloroform (ppb)	37	171	13
Carbon Tetrachloride (ppb)	1885	1736	2107
Trichloroethylene (ppb)	31	31	4
Tetrachloroethylene (ppb)	0.8	1	0.5
Acetone (ppb)	7.5*	20*	<5*
Fluoride (ppm)	0.6	0.93	0.61
Chloride (ppm)	19.2	20	21.4
Nitrate (ppm)	232	231	228
Phosphate (ppm)	<0.20	<0.20	<0.20
Sulfate (ppm)	58.4	53.1	56.8

*Noncalibrated estimates.
**Observed, but below linear detection limits.



Fig. 2. Sterile sediment sample collected for microbiological analyses using a split spoon sampling tool containing a Lexan Liner.

Carbon tetrachloride biodegradation is degraded primarily under anaerobic conditions, although recently its degradation by *Escherichia coli* was reported under aerobic conditions, albeit at low (1%) O_2 tensions (10). Ideally, the in situ degradation of CCl_4 under denitrifying conditions is preferable as, in theory, the main requirement to drive both denitrification and CCl_4 degradation would be the addition of an electron donor since NO_3^- would serve as the electron acceptor. Experiments with core sediment microcosms were initiated using several different electron donors and alternative electron acceptors to identify the conditions that will promote the degradation of CCl_4 by the indigenous subsurface microflora in the Hanford unconfined aquifer. The electron donors being evaluated include acetate, glucose/fructose mix, and glycerol.

TABLE III

Sample Depth Intervals from Which Sterile Samples Were Collected For Microbiological Characterization

Core No.	Depth Interval, m	(Depth Interval, ft)
1	71.9-72.3	(235.8-237.3)
2	75.6-76.0	(247.9-249.4)
3	78.3-78.6	(257.0-258.0)
4	79.3-79.9	(260.3-262.0)
5	80.2-80.7	(263.2-264.7)
6	81.3-81.7	(266.6-268.1)
7	82.7-83.3	(271.2-273.2)
8	83.3-83.5	(273.2-274.0)

In addition to nitrate, fumarate is also being evaluated as a potential electron acceptor for the degradation of CCl_4. In addition to biological degradation, an experiment was performed to determine if CCl_4 could be reductively dechlorinated in sediments by the addition of exogenous corrinoids. To this end cobalamin (vitamin B12) was added to sediment samples with dithiothreitol as a reductant. All microcosm experiments were conducted in 150-ml serum bottles containing 20-30 g of sediment, groundwater or mineral salts solution (15), and the various electron donors and acceptors. The serum bottles were sealed with Mini-Nert valves to permit repeated sampling and were incubated at 15°C. All treatments were replicated three times and included one autoclaved (sterile) control. Carbon tetrachloride solution concentrations were determined by gas chromatography (Hewlett-Packard).

Specific microbial populations were also quantified to gain information on the size of bacterial populations that could potentially be manipulated for bioremediation. Aerobic and anaerobic heterotrophic bacteria were measured using

direct agar plate contact methods. Populations of denitrifying bacteria were estimated using a most probable number method with nitrate-tryptic soy broth and in Hanford groundwater amended with acetate and nitrate.

Bacteria capable of reducing nitrate were present in all sediment samples as determined by microbial growth in TSA + nitrate enrichments coupled with complete loss of nitrate after 20 days. In all core samples there was greater than 10^4 MPN denitrifiers/g sediment. In sediment samples amended with groundwater, nitrate, and acetate, nitrate and nitrite were present after 20 days, indicating only a partial removal of nitrate. It is likely that microbial growth in the groundwater treatments was much less than in the tryptic soy treatments, accounting for the slower rate of nitrate removal. These results indicate that in situ biodenitrification is feasible in the unconfined aquifer on the Hanford site, as the bacteria capable of reducing nitrate are present and can be stimulated by the addition of an electron donor such as acetate.

Experiments to determine CCl_4 biodegradation are currently incomplete, but preliminary results indicate there was considerable growth in sediment enrichments with mineral medium (a defined salts solution) containing nitrate + acetate or glycerol + fumarate, and there was some growth in enrichments receiving the sugar mix (glucose + fructose). These results indicate that bacteria are present in the Hanford unconfined aquifer that are able to metabolize and grow on electron acceptors and donors that have been demonstrated to promote the degradation of CCl_4. After 20 days of incubation there was no significant biodegradation of CCl_4 in any of the microbiological enrichments. However, the presence of $CHCl_3$ has been detected in several of the sediment samples amended with glucose + fructose mix, fumarate/glycerol, and acetate/nitrate, but not in the sterile controls. This indicates that there has been some transformation of CCl_4 by indigenous microbial populations and, with additional time, the degradation of CCl_4 may increase as the microbial populations grow and adapt. Previous research indicates a strong kinetic relationship between electron donor (acetate) concentration and CCl_4 metabolism (14, 7). Therefore, additional laboratory studies will be conducted to determine whether depletion of the electron donor may be affecting the biodegradation of CCl_4.

To date, the most dramatic removal of CCl_4 from core aquifer sediment samples has occurred with B12 and dithiothreitol amendments. In all core samples, including the autoclaved control, CCl_4 could not be detected after 4 days, although trace amounts of $CHCl_3$ were detected. These later results indicate that CCl_4 can be reductively dechlorinated in the presence of aquifer sediments. Although it would not be practical to add corrinoids to the subsurface for purposes of remediation, some bacteria are capable of biosynthesizing B12 and may be candidates for use for in situ and ex situ reductive dechlorination of CCl_4.

ON-GOING RESEARCH

Engineering research activities are developing methods for supplying nutrients to the subsurface and modeling the bioremediation process using three-dimensional visualization tools to help design the field-scale demonstration site. Several experiments are planned to develop an accurate foundation for designing the in situ remediation system. First, bench-scale batch reactors will be used to rigorously study the kinetics of contaminant degradation and the growth of the microorganisms. The effects of important environmental conditions such as pH, temperature, redox potential, and the concentrations of substrate, electron acceptor, and contaminants will be included in this study. Concurrently, field studies will be conducted to characterize the test site for spatial differences in hydrologic, chemical, and microbiological parameters. The results of these bench- and field-scale studies will be incorporated into an existing three-dimensional model for subsurface transport (16) to provide a complete description of the in situ remediation process. Next, one-dimensional bench-scale as well as three-dimensional intermediate-scale flow cell experiments will be conducted to provide remediation and transport data under well-defined conditions. These experiments will be used to calibrate the bioremediation model and help minimize the error associated with applying a simulation based on laboratory-scale data to field remediation.

A conceptual design of the in situ bioremediation system that may be used in the field test has been developed. Both surface treatment of extracted water and subsurface recycle will be evaluated. Methods for bioremediation of extracted groundwater have previously been developed at PNL (14), and other chemical and physical technologies for treating contaminated groundwater will be available for testing through the VOC-Arid Integrated Demonstration. Subsurface recycle techniques will be evaluated to determine the advantages and disadvantages of enhanced hydraulic gradients within the test zone. In the conceptual design, nutrient solutions introduced at the injection well will inevitably displace some percentage of the contaminants. Subsurface recycle may enhance contact between the injected solution and contaminants by establishing a mixing region between the injection and extraction wells. Reduced well clogging from excessive bacteria growth near the injection well is another potential advantage of subsurface recycle. This can be realized by injecting nutrients at concentrations that will inhibit growth, and relying on mixing of the injected solution with the subsurface fluid to dilute the nutrients to a level that will enhance degradation. Thus, near the injection well cell growth will be inhibited, but in the bulk of the soil conditions suitable for degradation will prevail. In addition to evaluating the technical feasibility of microbial stimulation and biodegradation techniques, efforts will focus on evaluating the regulatory feasibility of the remediation strategy. Techniques that minimize the need for nutrient, microorganism, or recycled water injection will certainly have a higher likelihood of regulatory acceptability.

Through laboratory study, intermediate-scale flow-cell experiments, and three-dimensional computer simulations, a field test site will be designed and installed in FY 1992 and FY 1993. The in situ bioremediation field testing in FY 1994 and FY 1995 will be integrated with other characterization, remediation, and monitoring demonstrations that comprise the VOC-Arid Integrated Demonstration, and with ongoing environmental restoration efforts within Hanford's 200 West Area.

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IN SITU GROUTING OF LOW-LEVEL BURIAL TRENCHES WITH A CEMENT-BASED GROUT

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ABSTRACT

A restoration technology being evaluated for use in the closure of one of the low-level radwaste burial grounds at Oak Ridge National Laboratory (ORNL) is trench stabilization using a cement-based grout. To demonstrate the applicability and effectiveness of this technology, two interconnecting trenches in Solid Waste Storage Area 6 (SWSA 6) were selected as candidates for in situ grouting with a particulate grout. The primary objective was to demonstrate the increased trench stability and decreased potential for leachate migration following in situ injection of a particulate grout into the waste trenches. Stability against trench subsidence is a critical issue. For example, construction of impermeable covers over the trenches will be ineffective unless subsequent trench subsidence is permanently prevented.

After grouting, soil-penetration tests disclosed that stability had been improved greatly. For example, refusal (defined as >100 blows to penetrate 1 ft) was encountered in 17 of the 22 tests conducted within the trench area. Mean refusal depths for the two trenches were 3.5 and 2.6 m. Stability of the trench was significantly better than pregrout conditions, and at depths >2.4 m, the stability was very near that observed in the native soil formation outside the trench. The major differences between postgrout tests and tests conducted in native soil formations outside the trench were at soil depths of 1.8, 2.1, and 2.4 m. Tests within the trench showed lower stability within this range probably because of the presence of intermediate-sized soil voids (formed during backfilling) that were too small to be penetrated and filled by the conventional cement grout formulation. Hydraulic conductivity within the trench remained very high (>0.1 cm/s) and significantly greater than outside the trench. Postgrout air pressurization tests also revealed a large degree of intervoid linkage within and between the two trenches. To effectively reduce hydraulic conductivity and to develop stability within the upper level of the trench, injection of a clay/microfine cement grout into the upper level of the grouted trench is planned.

INTRODUCTION

Oak Ridge National Laboratory (ORNL) has recently finished placing an interim covering over ~4 ha Solid Waste Storage Area 6 (SWSA 6), where low-level radioactive wastes (LLW) have been buried in shallow trenches. The final closure of SWSA 6 awaits the completion of a remedial investigation into the nature and extent of contamination as well as the development of effective and safe techniques to stabilize the burial trenches. To select trench stabilization and closure alternatives, a group of 19 burial trenches in SWSA 6 was identified as a demonstration and test area to (a) identify promising trench stabilization and closure techniques applicable to the ORNL setting, (b) carry out these techniques on a field scale in actual LLW trenches, and (c) collect the necessary data to evaluate each technique relative to its feasibility, effectiveness, and cost. Several demonstrations involving dynamic compaction and grouting with a chemical grout have been conducted in this area (1).

This demonstration was conducted on a small hillock in the northeastern corner of SWSA 6. The site selection was based primarily on two criteria: (a) the site is away from daily waste management activities and (b) most important it is located entirely on high ground and is isolated hydrologically from any peripheral recharge areas that would complicate the formulation of a site water budget and the conducting of performance monitoring as part of the stabilization/closure evaluations. The water table at the site is at least 6 m below the bottoms of the trenches, and the trenches in the area are, therefore, unsaturated throughout the majority of the year. Two trenches, Nos. 151 and 170 were selected as candidates for in situ grouting with a particulate grout. Each of the trenches is ~4.6 m deep. Trench 151 measures 11.5 by 4.3 m, and trench 170 measures ~14.3 m by 4.3 m. The trenches are interconnected, such that the south end of trench 170 overlaps into the north side of trench 151 (Fig. 1).

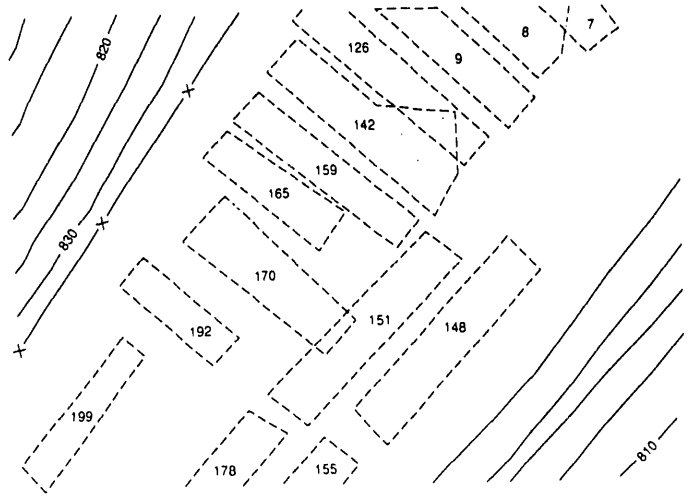


Fig. 1. Trench 151 and 170 boundaries.

* Managed by Martin Marietta Energy Systems, Inc. under contract DE-AC05-84OR21400 with the U.S. Department of Energy. Research sponsored by Office of Technology Development, USDOE.

The primary objective of this demonstration was to determine if in situ grouting with a particulate based grout is a technology that will provide long-term burial trench stability and decreased potential for leachate migration. Stability against trench subsidence is a critical issue. For example, construction of impermeable covers over the trenches will be ineffective unless subsequent trench subsidence is permanently prevented. Trench stability (characterized by soil-penetration tests) and decreased potential for leachate migration (characterized by hydraulic conductivity tests) were measured before and after grouting.

METHODS AND MATERIALS

Soil-Penetration Tests

A nonstandard penetration test has been developed for use over trenches to avoid augering contaminated waste to the surface, as would be expected with the standard ASTM (D 1586-84) soil-penetration test. The nonstandard test uses a 64-kg drill-rig-mounted drop hammer to drive a 5-cm-diam 60° cone point attached to a 4.5-cm-diam drill rod into the ground. The drill rod is marked at 0.3-m lengths, and penetration is measured by the number of blows required to move the device 0.3 m (1 ft) into the ground. In January 1990, 12 penetration tests were conducted in trench 170, and 10 tests were conducted in trench 151. Holes from the penetration tests were used to insert slotted casings, which in turn were used to conduct hydraulic conductivity tests and as injection wells for pumping grout into the trench. Because of the large pore volumes and high permeability within the trenches, boundaries for trench hydraulic conductivity could only be estimated by recording the time required for a known volume of water to permeate into the trench via the soil-penetration holes. In addition to the penetration tests within trenches 170 and 151, penetration tests were conducted outside the perimeter of the two trenches.

Installation of Injection Wells

A previous particulate grouting demonstration in SWSA 6 (2) used lances made of 5-cm-diam Schedule 80 steel pipe as injection wells. These were placed at ~1.5-m centers over the surface of the trench (total of 36). The lances were driven by a 54-kg portable air-driven hammer either to the bottom of the trench or until an obstruction was encountered. Once in place, the lance was pulled up 15 cm and the drive point knocked out of the end for grout injection. When pressures >20 psi or flow rates <23 L/min were encountered, the lance was then pulled up another 15 cm for additional grout injection. It was observed that five injection wells accounted for ~80% of the grout injected, and it was recommended that future demonstrations use fewer injection wells (e.g., injection wells be based on 6- to 7.6-m centers rather than the 1.5-m center that was used). It was also recommended that smaller-diameter pipe be used because of the difficultly in reaching the bottom of the trench. For example, in most instances the lances could not be driven as much as 2.1 m. The trench bottom was reached in only 4 out of the 36 injection wells installed. Several other operational problems were encountered. For example, because of the closeness of the 1.5-m centers, grout was often pumped directly into one well and out an adjacent well. The poor seal between the lance and surface soil (as a result of moving the lance upward in 15-cm increments during grout injection) often resulted in breakthrough of grout around the injection wells, even at a relatively low grout injection pressure of 15 to 20 psi.

Several changes were made in the installation of injection wells for this demonstration. The major changes included the use of (a) slotted pipe as injection wells and (b) considerably fewer injection wells [10 to 12 per trench compared with the 36 in the 1987 grouting study (2)]. Slotted polyvinylchloride (PVC) pipe (threaded and flush-jointed, Schedule 80, 3.2-cm diam) constructed with three rows of 0.25-cm-wide slots (138 slots/m-row, for an effective filter area of 243 cm^2/m) were placed into the holes made during the penetration tests. Solid sections of similar pipe were installed to at least 0.6 m below the soil surface. To ensure that injected grout did not return to the surface along the pipe/soil interface, a 0.3-m section of 5-cm-diam pipe was placed over the 3.2-cm-diam pipe and driven into the ground to ~8 cm below the soil surface. A cement-based grout collar was then molded around the surface of the pipe/soil interface.

Void-Volume Measurements

The combined void volume of trenches 151 and 170 had previously been determined by filling with water and taking into account losses resulting from seepage into the surrounding soil. This practice may result in serious leaching of radionuclides and/or hazardous wastes into groundwater and may induce premature settling of soil overburden into the trench. It also leaves soil within the trench near saturation levels for a significant period of time, which could have an effect on solidification of grout introduced into the trench. Consequently, flooding trenches with water is no longer an acceptable practice for determining trench void volume. Thus, an alternative nondestructive method was needed for determining trench void volume.

A potential nondestructive method for determining trench void volume is based on pressurization of the trench (treating it as a closed but leaky vessel) and calculation of void volume from the ideal gas law. The trench is obviously not a closed vessel, but experience during grouting exercises has revealed that pressures on the order of 10 to 15 psi can be achieved. After taking into consideration leak rates (similar to those used in determining trench void volume by flooding with water), void volume can be calculated from the ideal gas law. Validation of such a simple technique to determine trench void volume would be a significant accomplishment. For example, one of the most important criterion in determining the effectiveness of in situ grouting is the extent to which the available void space is filled with grout. To do this, it is important that the total void volume of the trench be known. Trenches 151 and 170 were selected for grouting because trench volumes had previously been determined by flooding with water, a technique that may no longer be practiced. Thus, these trenches offered an opportunity to compare the use of alternative methods to determine trench void volume.

This technique is based on the principle that small pressure differentials (<0.5 psi) can be monitored within the trench as a known rate of gas is pumped into the trench. The technique assumes that the void volume of the trench remains constant and that air leaking from the trench occurs across a constant resistance to air flow. The measurement is based on the ideal gas law, where

$$V_0 = \frac{n_0 RT}{P_0}. \quad \text{(Eq. 1)}$$

describes conditions in the trench before pressurization,

$$V_0 = \frac{n_x RT}{P_c} \quad \text{(Eq. 2)}$$

describes conditions in the trench after pressurization to a constant pressure, and

- V_0 = void volume of trench,
- n_0 = moles of gases initially present in trench,
- R = ideal gas constant,
- T = ambient absolute temperature in trench,
- P_0 = pressure initially present in trench (assumed to be 1 atm),
- P_c = pressure in trench after pressurization to constant pressure,
- n_x = $n_0 + n_1$, or moles of gases after pressurization, where n_0 is equal to the moles of gas initially present and n_1 is equal to the net moles of gases added to cause increased pressure to P_c.

Thus, the volume of gas added V_1 to result in P_c is equal to

$$V_1 = \frac{n_1 RT}{P_c}. \quad \text{(Eq. 3)}$$

Combining Eqs. (1) and (2) and assuming no difference in temperature on pressurization,

$$N_0 = \frac{n_1 P_0}{P_c - P_0}, \quad \text{(Eq. 4)}$$

and substituting Eqs. (1) and (3) respectively for n_0 and n_1 results in

$$V_0 = \frac{V_1 P_c}{P_c - P_0}. \quad \text{(Eq. 5)}$$

To implement this technique, air was pumped into each of the trenches using at least three injection wells for each trench. Pressure as a function of time was also monitored in each of the trenches by using pressure gauges installed in at least three monitoring wells for each trench. These data provided estimates for V_1 from which V_0 can be calculated. A detail description of the procedure is being prepared (3).

Grout Formulation and Testing

The performance criteria established for grout formulation was the same as that used by Tallent et al. (4); namely,

Apparent viscosity	< 50 cP
10-min gel strength	< 5 kgf/m^2
28-d phase separation	0 volume %
28-d compressive strength	> 60 psi

Other tests included penetration resistance and consistency.

The dry solid materials used to develop the grout formulation included the following: two cements (a Type 1 Portland cement obtained from Dixie Cement Company, Knoxville, Tennessee, and a microfine grade of cement produced from finely ground blast-furnace slag which is merchandized as MC-100 by Geochemical Corporation, Ridgewood, New Jersey), two coal-fired utility fly ashes (an ASTM Class F ash from Owensboro, Kentucky, and a ASTM Class C fly ash from Rockport, Illinois), and a cement-grade Wyoming bentonite. Three blends were tested: one for each of the fly ashes mixed at 39 wt % Type I Portland cement, 55 wt % fly ash, and 5.5 wt % Wyoming bentonite and one using 100%$_w$ MC-100 cement. Blends 1 and 2 contained class C and F, respectively, and blend 3 contained the MC-100 cement. The weight of dry solids added to a given volume of liquid (the mix ratio) for grouts containing the fly ashes was 1.4 to 1.5 kg/L, and a mix ratio of 0.90 to 0.96 kg/L was used for the grouts made with the MC-100 microfine cement. The test procedures (phase separation, compressive strength, penetration resistance, apparent viscosity, gel strength, and consistency) were all performed in triplicate.

Field Grout Mixing and Injection

Grout solids were dry-blended and then mixed with water in a concrete mixing truck. Each truckload contained 5754 kg of dry blend (2245, 3200, and 319 kg of cement, fly ash, and clay, respectively) and 3780 L of water containing 454 g of delta gluconolactone (used as a dispersant and set retarder for the grout). The density of the grout was 1.6 kg/L; thus, each truckload contained ~5.9 m^3. Grout from the concrete-mixing truck was transferred to the grouting module using a grout pump. The grouting module was designed and constructed at ORNL in 1982. The module contains two 1890-L mixing tanks (each with single-propeller lighting mixers) and two progressive cavity pumps capable of pumping 113 L/min of grout at pressures up to 200 psi. One of the two pumps was used to pump grout from the grouting module via a 2.5-cm-diam high-pressure hose to a single injection well. Pressure at the grouting module was maintained manually at levels ranging from 50 to 100 psi. Grouting pressure at the injection well was usually < 10 psi; however, as the available void space became full of grout, pressures up to 50 and 75 psi were observed, making it necessary to move to another injection well.

RESULTS AND DISCUSSION

Selection of Grout Formulation

Grouts made from each of the three blends met or exceeded established criteria (Table I). Along with the criteria listed in Table I, two additional criteria, penetration resistance and fluid consistency, were tested. If one assumes that penetration resistance readings in excess of 4000 psi reflect complete setting of cements, then all three blends set in < 3 d. Results from the consistometer tests revealed that grouts made from the Class F fly ash possessed a considerably longer field time before setting began. For example, the data indicated that grouts made from Class F fly ash could be pumped for periods up to 7 to 8 h whereas grouts made of the Class C fly ash may display considerable thickening that would inhibit pumping at periods longer than 5 to 6 h. Grouts made from the microfine cement displayed substantially less consistency (bearden units < 5) during the first 6 h compared with grouts made of fly ash (bearden units > 10). The addition of 0.02% δ gluconolactone to the water used to make the microfine cement grouts extended pumping times from 4 to 10 h. Because of the longer pumping times of grouts made from Class F fly ash compared with the Class C fly ash, it was recommended that the grout formulation made from the Class F fly ash be used for grouting trenches 151 and 170. The grout made from the microfine cement appeared to be technically acceptable; however, there was concern that it may be difficult to develop sufficient shear to adequately mix this grout formulation in the field using a cement-mixer truck. This factor, plus the fact that material costs for the microfine cement grout

TABLE I

Results of Laboratory Grout Studies

Parameter	Criteria	Blend[a] 1	2	3
Apparent viscosity	< 50 cP	35±1	37±1	10±1
10-min gel strength	< 5 kg/m^2	1.5±0.1	1.4±0.3	0.35±0.05
28-d phase separation	0 vol%	0	0	0
28-d compressive strength	> 60 psi	1601±17	908±28	2000±253

[a] Blend 1 contained 39% Type 1 Portland cement, 39% Class C fly ash, and 5.5% bentonite mixed at 1.5 kg/L of water. Blend 2 contained 39% Type 1 Portland cement, 39% Class F fly ash, and 5.5% bentonite mixed at 1.5 kg/L of water. Blend 3 contained 100% MC-100 microfine cement mixed at 0.9 kg/L of water.

were on the order of ten times higher than conventional cement/fly-ash grouts, made the choice of microfine cement less attractive.

Soil-Penetration Tests

Pregrouting soil-penetration tests within the trench area revealed that as the depth of penetration increased an increasing number of blows was required to drive the cone further into the ground. Mean blows per foot inside the trench area were significantly less than mean blows per foot into soils outside the 151 and 170 trenches (Fig. 2). Generally speaking, at soil depths > 1.5 and < 4.6 m, mean blows per foot within the trench averaged on the order of ten blows per foot below that outside the trench, implying considerable uncompacted soil or void space within the trench area.

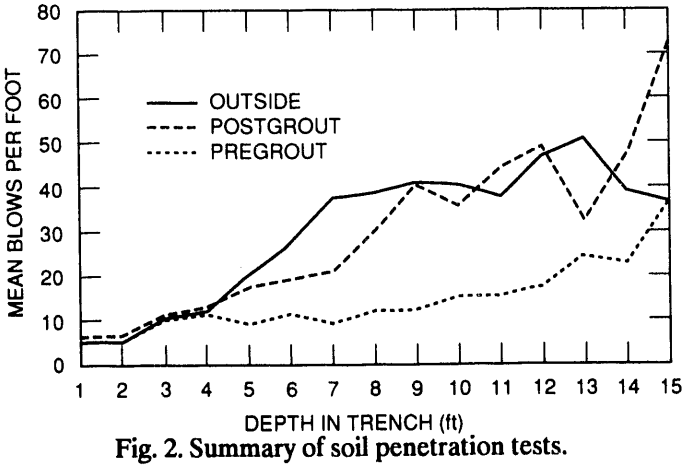


Fig. 2. Summary of soil penetration tests.

In January 1991, ~6 months following grouting, soil-penetration tests were conducted within and to adjacent to trenches 151 and 170. These tests, to soil depths of 4.6 m, included 10 tests within trench 170 and 12 tests within trench 151 (4 were also conducted outside of but adjacent to the trenches). Refusal (i.e., > 100 blows to penetrate one foot) was encountered in 17 of the 22 tests conducted within the trench area, resulting in mean refusal depths of 10.4 and 2.6 m in trenches 151 and 170, respectively. Results from the postgrouting soil-penetration tests revealed that the stability of the trench after grouting was significantly better than before grouting (Fig. 2), and at depths > 2.4 m, the stability (measured in terms of soil penetration) was very near that observed outside the trench. For example, soil penetration in mean blows per foot at depths > 2.4 m within the trench was very similar to that measured outside the trench. Pregrouting tests ranged from 10 to 20 mean blows per foot, whereas postgrouting tests ranged from 20 to 40 mean blows per foot. Only at soil depths of 1.8, 2.1, and 2.4 m were there major differences between postgrout tests and tests conducted outside the trench. The lower stability exhibited in this range (1.8 to 2.4 m) probably reflects the presence of intermediate-size soil voids (formed during backfilling) that were not penetrated by the conventional cement grout formulation.

Hydraulic Conductivity Measurements

Hydraulic conductivity within the trench area before as well as after grouting was greater than 0.1 cm/s and appreciably greater than that measured in undisturbed soil outside the trench. For example, mean hydraulic conductivity of undisturbed soil formation in "driven" wells using the above soil-penetration procedure was 1.2×10^{-5} cm/s. Previous measurements in SWSA 6 have resulted in mean hydraulic conductivities of 3.5×10^{-5} and 2.0×10^{-5} cm/s, Luxmoore et al. (5) and Davis et al. (6), respectively. Thus, these data indicate that in situ grouting with a conventional cement grout made of Portland Type 1 cement does not offer a great deal of protection against subsurface leaching of contaminants if periodical inundation by groundwater occurs.

Void Volume Measurements

As an alternative to water pump-in tests, an air-pressurization technique was used to compare accuracy and operational features of the two techniques. Preliminary pressurization tests included a series of tests to determine the extent of intervoid connection between trenches 151 and 170. For example, air was injected at one end of trench 151 to determine if pressure differences could be detected in wells at the further end of trenches 151 and 170. Other tests included air injection in a single well in trench 170 and multiple injections at six wells within the two trenches. Three flow rates were used in each test to confirm that pressure measured at the monitoring wells was a function of airflow into the trenches. The pressurization data measured at the other wells verified that a direct linkage occurred between the underground void volumes of the two trenches and that changes in flow rates in the range of 1 to 1.4 m^3/s would be adequate to detect significant changes in pressure at the well head.

To determine trench void volume using the pressurization technique, it was necessary to determine the pressure change with time as a constant flow of air was pumped into the

trenches. To do this, air was pumped into six injection wells, three in each of the two trenches. Pressure was monitored at eight wells, four in each of the two trenches. The gage pressures in trenches 151 and 170 for pressurization at 1.1, 2.0, 2.8, and 3.7 m^3/min were recorded with respect to time (Fig. 3). These data were fitted using a nonlinear least-squares regression technique (7). The calculated trench void volumes determined by this procedure ranged from 175 to 228 m^3 and were all considerably higher than the 88 m^3 determined by the water pump-in tests. Air pressurization at 2.8 and 3.7 m^3/min gave very similar void volumes, 176 and 175 m^3, respectively. In both of these data sets (at 2.8- and 3.7-m^3/min flow rates), the data appeared to fit better with the regression equation than it did for 1.1- and 2.0-m^3/min tests. Also, the coefficients of variance (%) for the estimates of the regression coefficient in the 1.1- and 2.8-m^3/min pressurization tests were 23 and 14%, respectively, compared with 9.4 and 8.8% for the 2.8- and 3.7-m^3/min tests. The simple fact that the range in pressure readings at the 2.8- and 3.7-m^3/min tests (0.22 to 0.27 psi) were so much larger than the 1.1- to 2.8-m^3/min tests (< 0.12 psi) made it easier to record the pressures as a function to time for the higher flow rates. Thus, the 2.8- and 3.7-m^3/min tests probably represent better estimates of the trenches' void volume than do the 1.1- and 2.8-m^3/min tests. It is not clear why the void volume for trenches 151 and 170 determined by the pressurization technique is on the order of 100% higher than that determined by water pump-in tests. However, if one keeps in mind that both methods involve considerable experimental error and that both are subject to a variety of boundary conditions governed by the conditions of the soil and distribution of pore volumes, the agreement between the two methods may not be so poor.

Trench Grouting

Grouting of trench 170 was started on June 26, 1990, and finished on June 29, 1990. Grouting of trench 151 occurred ~1 week later, July 7 through July 12, 1990. Grout solids were dry-blended, mixed with water in a redi-mix-concrete truck, and transported to SWSA 6. Each truckload contained 5.9 m^3. A total volume of 61 m^3 of grout (37 and 24 m^3 in trenches 151 and 170, respectively) was injected. If one assumes the void volume to be 176 m^3 (as determined by air pressurization tests), 34% of the available void volume was filled with grout. (If volume of 88 m^3 as determined from the water-pump test is taken as available void volume, then 89% of the void volume was filled with grout.) Trench 170 is the larger of the two trenches, but more grout was injected into trench 151. Assuming the trenches to be 4.6 m deep and covered with 0.9 m of soil, the volumes of the trenches are 223 and 180 m^3, respectively. In this respect, ~15% of the total volume was filled with grout (20% for trench 151 and 11% for trench 170). In the 1987 grouting study (2) 31 m^3 of the same type of grout was injected into a much smaller trench (trench 150, measuring 17 x 2.8 x 3.6 m) whose volume, assuming a 0.9 m soil cover, was 116 m^3. Based on these measurements, the volume of grout injected would constitute 26% of the total trench volume. However, the final disposition of some of this grout was outside the trench because breakthrough of grout to the surface was recorded at 6 to 8 areas outside the trench. Also, the quantity of injected grout represented 109% of the measured void volume, indicating the estimated volume of grout injected to be high. Most important

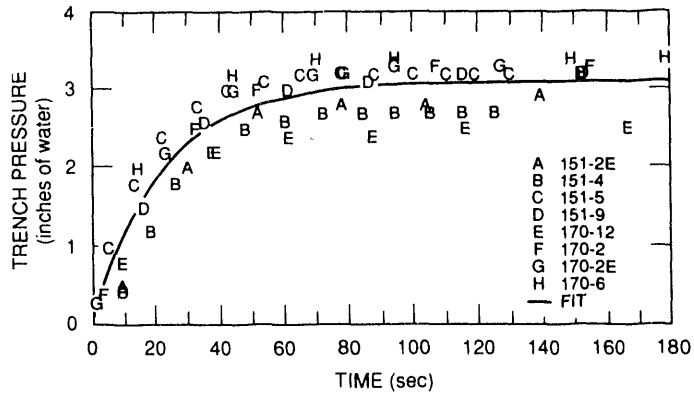


Fig. 3. Pressurization tests on trenches 151 and 170 at 3.7 m^3/min.

to recognize is that the void volume available for grouting is dependent on the waste disposed of in the trench, which is quite variable from trench to trench within SWSA 6.

Groundwater Monitoring

Sampling of groundwater was very limited because of the site's elevated position above groundwater. The only wells found to contain water were wells 165-NW and 165-SW; however, a routine monitoring program (i.e., weekly or monthly sampling) was not instigated. Water sampled (February 1991) from 165-NW and 165-SW wells outside the trench area contained higher levels of radioactivity (gross alpha, gross beta, and ^{90}Sr) after grouting than did that sampled before grouting (June 1990). The greatest difference was in the concentrations of gross beta activity, levels between 1 and 2 Bq/L before grouting compared with 7 and 10 Bq/L after grouting. Strontium-90 concentrations were also higher in water sampled after grouting (1.2 Bq/L compared with 0.6 Bq/L), but levels of gross alpha remained unchanged. If the character of groundwater were to be significantly changed as a result of grouting with a cement-based grout, levels of sodium would expected to be elevated as the bleed water or leachate from the alkali-based grout came in contact with the groundwater. However, concentrations of sodium in water sampled from these wells after grouting were similar to those found in water before grouting. Also, unlike ^{90}Sr concentrations, the levels of Ca, Mg, and Sr were similar in water sampled before vs after grouting. The major difference in water quality before vs after grouting appears to be in levels of Al, Fe, Ni, and Zn. Concentrations of all of these metals were elevated in water sampled after grouting. Elevated concentrations of these metals are probably the result of increased reducing conditions in the groundwater during February (cool and wet) compared with conditions in the groundwater during June rather than any influence of grouting per se.

SUMMARY AND CONCLUSIONS

Trench stabilization using a cement-based grout is being evaluated for use in the closure of one of the low-level radwaste burial grounds at ORNL. To demonstrate the applicability and effectiveness of this technology, two interconnecting trenches in SWSA 6 were selected as candidates for in situ grouting with a particulate grout. The trenches are ~4.5 m deep and measure 11.5 by 4.3 m and 14.3 by 4.3 m. The primary objective was to demonstrate the increased trench stability (characterized by soil penetration tests) and the

decreased potential for leachate migration (characterized by hydraulic conductivity tests) following in situ injection of a particulate grout into the waste trenches. Stability against trench subsidence is a critical issue. For example, construction of impermeable covers to seal the trenches will be ineffectual unless subsequent trench subsidence is permanently suspended.

A grout composed of 39% Type 1 Portland cement, 55.5% Class F fly ash, and 5.5% bentonite mixed at 1.5 kg/L of water was selected after laboratory testing of several grout formulations. Results of laboratory studies revealed that this formulation exhibited no liquid-to-solid phase separation and a compressive strength of >900 psi after 28 d. Penetration resistance after 2 d was >8000 psi. Most important, the viscosity of the freshly made grout was <50 cP, allowing it to penetrate and fill intermediate-size trench voids, and the suspension was stable for pumping and injection for up to 8 h.

Before the trenches were grouted, the primary characteristics relating to physical stability, hydraulic conductivity, and void volume of the trenches were determined. Their physical stability was evaluated using soil-penetration tests. Pregrout soil-penetration tests revealed that at depths >1.5 and <4.6 m mean blows per foot within the trench averaged approximately ten blows per foot fewer than that outside the trench. These data imply that considerable uncompacted soil and/or void space exists within the trench area which over time will lead to significant subsidence of the upper soil layers. Hydraulic conductivity tests within the trench area also revealed a high potential for the infiltration of water (hydraulic conductivities >0.1 cm/s).

Void volume within the trenches was determined by two techniques: (1) water-pump tests and (2) a newly developed air pressurization technique. Estimates of void volume using the air pressurization technique were ~100% higher than that determined by the water-pump test (176 m^3 compared with 88 m^3). It is not clear which of the two techniques is the most accurate because each has theoretical and operational constraints. The development of the air pressurization technique was pursued because the water-pump test could result in serious leaching of radionuclides and/or hazardous wastes into groundwater and may induce premature settling of soil overburden into the trench. The water-pump test also leaves soil within the trench near saturation levels for a significant time, which could have an influence on solidification of grout introduced into the trench. Consequently, the flooding of trenches with water is no longer an acceptable practice for determining trench void volume. The air pressurization method is fast and can be repeated under a variety of pressures and air flows. It is environmentally superior to the water-pump test in that it does not promote the leaching of contaminants to groundwater. The major concern in the use of the air-pressurization technique is that its accuracy has not been validated. More research is needed to demonstrate its accuracy and precision, as well as its theoretical and operating limitations under controlled conditions.

Soil-penetration tests before grouting revealed considerable uncompacted soil or void space within the trench area. For example, at depths >1.5 and <4.6 m, mean blows per foot within the trench averaged on the order of ten blows per foot fewer than that outside the trench. After grouting, soil-penetration tests disclosed that stability had been improved greatly. For example, refusal (defined as >100 blows to penetrate 1 ft) was encountered in 17 of the 22 tests conducted within the trench area. Mean refusal depths for trenches 151 and 170 were 3.2 and 2.6 m, respectively. The postgrouting soil-penetration tests revealed that the stability of the trench after grouting was significantly better than before grouting, and at depths >2.4 m, the stability (as measured in terms of soil penetration) was very near that observed in the native soil formation outside the trench. The major differences in results between postgrouting tests and tests conducted in native soil formations outside the trench were found at soil depths of 1.8, 2.1, and 2.4 m. Tests within the trench showed lower stability within this range (1.8 to 2.4 m), probably because of the presence of intermediate-size soil voids (formed during backfilling) that were too small to be penetrated and filled by the conventional cement grout formulation. Hydraulic conductivity within the trench remained very high (>0.1 cm/s) and significantly greater than that outside the trench. Postgrouting air pressurization tests also revealed a large degree of intervoid linkage within and between the two trenches. Even after grouting, the combined void volume of the two trenches by this test procedure was 61 m^3 (compared with 176 m^3 for the ungrouted trenches). Only 60 m^3 of grout were injected, leaving 55 m^3 unaccounted for [i.e., total void volume measured (176 m^3) minus the sum of the grout injected (60 m^3) plus the void volume measured after grouting (61 m^3)]. Thus, it appears that to effectively reduce hydraulic conductivity and to develop stability within the upper level of the trench, it may be necessary to implement additional stabilization steps. One possibility is the injection into the upper level of the grouted trench a chemical or microfine cement grout which may fill voids too small for the conventional grout.

FUTURE NEEDS

Grouting of trenches with conventional particulate grouts typically fills only 30 to 60% of the available void volume, allowing the trenches to remain vulnerable to a certain degree of leaching. On the other hand, chemical grouts typically fill all of the void volume but generally tend to be considerably more costly. Certain chemical grouting materials (e.g., acrylamide) are also toxic and present a risk to those who prepare and inject it and are potential contaminants to drinking water supplies. For these reasons, considerable testing is required to demonstrate that the chemical's use will not present unacceptable risks. Recently, microfine-size cements have become readily available. These cements, most often made from finely ground blast-furnace slag, can be used to form slurries capable of attaining permeabilities on the order of 10^{-5} to 10^{-9} cm/s when injected into fine sands. These highly permeable microfine grout formulations are attractive from the standpoint of being superior to conventional Portland cement grouts in providing hydrologic isolation. However, their costs are approximately ten times that of conventional Portland cements, and in certain instances, their costs are similar to chemical grouts.

Recent experience with microfine cement indicated that low ratios (1:1) of water to cement would have to be used unless special equipment were purchased to suspend suspensions containing high (3:1) water:cement ratios. For example, formulations based on high (3:1) water:cement ratios would require high-energy mixers (those that generate sufficient shear to fully disperse the microfine cement) to avoid significant liquid/solid phase separation. An alternative grout

formulation was investigated by using blends of bentonite clay and microfine cement with varying ratios of water. One formulation that was found to be stable and pumpable through a 30-cm column of coarse sand was made using a 8:2:1 ratio of water, bentonite, and microfine cement. The formulation was much less expensive than chemical grouts or microfine cement grouts formulated on a 1:1 basis. Because of its lower permeability, such a formulation should offer significantly better hydrologic isolation of waste trenches than conventional particulate grouts. One approach is to use a combination of conventional particulate grout to fill the large void spaces often present at the bottom of the trench and a microfine grout to fill the intermediate and small void spaces in the upper levels of the trench. This would be economical and probably feasible technically. To demonstrate the utility of this approach, it is proposed that a clay/microfine cement grout be injected into the upper sections of trenches 151 and 170 via the remaining slotted injection wells. After injection of the clay/microfine cement grout, additional soil-penetration tests will also be conducted to examine if the stability in the 1.8- to 2.4-m depth range has improved as a consequence of grouting with the clay/microfine cement grout. Hydraulic conductivity tests will also be conducted to evaluate the performance of the clay/microfine cement grout in reducing leaching of radionuclides and other potential contaminants into groundwater.

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A THERMODYNAMIC ANALYSIS OF MELT IMMISCIBILITY AND ITS IMPLICATIONS DURING VITRIFICATION

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ABSTRACT

This paper examines and defines the thermodynamic conditions conducive to the spontaneous separation of an initially homogeneous silicate melt generated during vitrification of contaminated soil or other wastes into immiscible phases. Immiscible phase development will be shown to have potentially important implications regarding melter operation and contaminant immobilization. Development of a molten immiscible iron phase will be shown to be dependent upon the oxidation/reduction chemistry of iron and the presence of electrochemically reducing constituents, specifically organic carbon. Immiscible molten iron can concentrate other selected native phase metallic contaminants drastically impacting their long-term immobilization and impact optimal melter selection.

Depending upon melt redox conditions, an immiscible sulfate or sulfide melt may also develop during vitrification of sulfur-rich wastes. Although potentially minimal melter operational impacts result from immiscible sulfur phase formation, contaminants partitioned into the immiscible sulfur phase may be very poorly attenuated, potentially resulting in failure for various leach test criteria. Potential mitigative measures are discussed.

INTRODUCTION

Thermochemical reactions occurring during vitrification of contaminated soils or other wastes can induce an initially homogeneous silicate melt to spontaneously unmix, forming multiple chemically and physically discrete liquid phases. For example, a uniform, silicate-dominated melt which would be formed during vitrification of a soil may separate into distinct immiscible silicate, metallic, and nonmetallic-dominated liquid phases, depending on soil composition and operational parameters. The frequency of immiscible phase development in nature suggests relatively common thermodynamic conditions lead to this phenomenon: conditions that can exist during thermal processing of radioactive and hazardous wastes. Immiscible liquid phase development during vitrification of silica-rich wastes has important implications regarding sequestering and fate of contaminants, optimal melter selection, and operation.

Past research has largely emphasized a phenomenological approach to this event. Alternatively, this paper presents a mechanistic and predictive analysis, utilizing thermodynamics, to assess immiscible molten phase formation potential. Morrison Knudsen is presently utilizing this technique to evaluate the feasibility of different vitrification technologies at a NPL site. This paper demonstrates that the proper application of thermodynamics can predictively discern the potential development of liquid immiscibility in silicate melt systems. This foresight can help identify preventative measures enhancing vitrification operations and generation of an optimally vitrified product.

This paper will focus on the development of immiscible iron and sulfur-dominated melt phases and assess the implications regarding contaminant sequestering and immobilization and melter operational impacts.

IMMISCIBLE IRON MELTS

Immiscible iron melts form due to the production of native valance state iron. Oxidized iron, in the ferrous or ferric valance states, is readily soluble in silicate melts often composing up to 20%, by weight, of iron-rich igneous rocks, such as basalts. By contrast, native valance state iron is totally insoluble in silicate melts (1). Molten native valance state iron can be produced by two processes during vitrification: by melting of native iron debris (i.e. barrels, metal equipment, nails, etc.); and by the electrochemical reduction of ferrous and ferric phases. Vitrification, at temperatures exceeding the melting point of native iron-bearing material, without rapid and total oxidation of the native metal, will result in the development of an immiscible molten iron phase (2). For example, vitrification of soils, particularly by in situ methods, typically yields an electrochemically reducing melt, probably due to the consumption of oxygen during oxidation of organic carbon (3). Moreover, reducing conditions, with respect to iron, have been shown to develop and be maintained during joule heated ceramic melter (JHCM) processing of relatively pure borosilicate glass (4). Thermodynamic calculations suggest organic carbon should be an important reductant for ferrous and ferric phases as shown in the following reactions:

$$2\,FeO + C \rightarrow 2\,Fe + CO_2 \qquad \Delta G^{\circ}(1700K) \; -77KJ$$

$$Fe_2O_3 + 1.5C \rightarrow 2\,Fe + 1.5\,CO_2 \qquad -206KJ$$

The large negative Gibb's Free Energy changes predict the production of native valance state iron. It is important to note that the thermodynamic prediction of the generation of native valance state iron from the reaction of oxidized iron and organic carbon is confirmed in nature. Battey (5) reported a "considerable" mass of native iron occurs where basalt contacts coal on Disco Island, Greenland and also native iron occurring in basalts, where lava flows have engulfed and carbonized tree trunks. The above reactions do not obviously indicate the quantity of native iron potentially formed by reaction with organic carbon. Organic carbon mediated iron reduction can generate significant amounts of native iron as demonstrated in the following reactions: (These reactions are

identical to the above reactions except these show mass units (in grams) rather than molar quantities.)

$$144g\ FeO + 12g\ C \rightarrow 112g\ Fe + 44g\ CO_2$$

$$160g\ Fe_2O_3 + 18g\ C \rightarrow 112g\ Fe + 66g\ CO_2$$

Note that a soil containing 14.4% FeO could have the ferrous phases quantitatively reduced to native iron by only 1.2% organic carbon. Also note that carbon oxidation by ferrous iron yields approximately nine times more native iron mass than the weight of carbon consumed. Considine (6) reports that native iron can absorb carbon and begin melting at 1575 K (1300°C). Although native iron can form below its melting point, it will exist as discrete solid metallic grains. In the solid state, iron will be unable to easily alloy with other metals and will not form continuous metallic pools at the base of the silicate melt mass. Consequently, vitrification processes operating below 1575 K (1300°C) will not be plagued with molten immiscible iron phase development. Vitrification at temperatures in excess of 1575 K (1300°C) may cause a molten native valance state iron melt to separate from the silicate melt as a relatively denser phase and likely settle to the floor of the melt chamber. The high electrical conductivity of the immiscible iron layer may result in extensive refractory corrosion and/or electrode damage. Operationally, only high temperature joule heated ceramic melters or in situ vitrification units are impacted by formation of an immiscible molten iron phase. Fossil fuel heated ceramic melters and plasma arc torch units which do not use corrosion-sensitive electrodes are unaffected by this phenomenon. In fact, fossil fuel heated ceramic melters and plasma arc torch system processing are enhanced by the presence of native iron due to more efficient heat transferral to the melt.

Organic carbon and native iron can reduce silver, cadmium, cobalt, copper, lead, and nickel to their native valance states. In a liquid state, these trace contaminants, as native metals, can easily alloy with molten iron which often occurs in volumetrically greater amounts during vitrification of soils. Robie and others (7) report melting temperatures for these native valance state metals in Table I.

TABLE I
Melting Temperatures of Selected Metals

Native Metal	Melting Point (K)
Cadmium	594
Lead	600
Silver	1,234
Copper	1,356
Nickel	1,726
Cobalt	1,768

Molten iron can act as an efficient collector and concentrator of the above native metals creating a contaminant enriched iron mass. The cooled contaminant enriched iron solid could potentially fail leach test criteria. Although Buelt and Farnsworth (2) have found immiscible iron alloys formed during in situ vitrification to pass Toxicity Characteristic Leaching Procedure (TCLP) criteria, without total encapsulation of the immiscible iron phase in silica glass, long-term contaminant immobilization is unlikely. Whereas contaminants sequestered within a silica glass matrix are likely immobilized for thousands to perhaps millions of years, cooled iron masses, exposed to oxygenated groundwater, would be expected to deteriorate within a few years resulting in concomitant contaminant release.

Removal of immiscible native valance state iron will result in a significant and potentially abrupt change in the viscosity of the silicate melt. As discussed by Bottinga and Weill (8) the addition of metallic oxides to a SiO_2 liquid results in a breakdown in the continuous Si - O - Si linkage, due to the ionic nature of the metallic atoms, and a relative decrease in viscosity. Conversely, the removal of iron will result in a profound viscosity increase in the silicate melt. The large viscosity increase can seriously disrupt joule heated ceramic melter performance which can not tolerate significant viscosity changes.

Analysis of the conditions conducive to immiscible iron formation suggest several potential mitigative measures. Specifically, native valance state iron existing as metallic debris can be removed by tramp metal magnets or manually removed from the waste.

Organic debris can be removed by wood-picking devices, incinerated prior to vitrification, and oxidized by oxygen lanced into the melt. Although direct oxygen addition to the melt can prevent immiscible molten iron development, it can exacerbate immiscible sulfate melt formation due to sulfide oxidation and carbon electrode corrosion, and generally cause or increase melt foaming. Melt foaming can lead to refractory corrosion, conductivity, and viscosity control problems, and decrease melter throughput (9, 10). As stated earlier, molten immiscible iron can not form below 1575 K. Maintaining melter temperatures below 1575 K will prevent molten immiscible iron formation. Maintaining a turbulent melt will prevent discrete immiscible molten iron layer formation and aid in silica encapsulation of the iron phase.

IMMISCIBLE SULFUR MELTS

Molten immiscible sulfur is known to readily develop in natural systems (11, 12, 13, 14). Sulfur immiscibility is likely due to the limited solubility of sulfur in silicate-dominated melts. Skinner and Peck (11) measured only 380 parts per million (ppm), by weight, sulfide in a quenched theolitic (basaltic) glass at 1338 K. Sulfate may only have a solubility in silicate melts of about 100 ppm (15). Other researchers suggest sulfate solubility maybe much greater, perhaps up to 1%, by weight (16). The frequency of immiscible sulfate in nature argue that sulfate can readily separate from silicate melts. The solubility of sulfur in silicate liquids is dependent upon several parameters (15). Decreasing temperature, increasing oxidation state (oxygen content), and addition of silica are known to decrease sulfur solubility in silicate melts. Processes invoking these changes could induce the exsolution of an immiscible molten sulfur phase.

The predominant immiscible sulfur phase is dependent upon the electrochemical oxidation/reduction state of the silicate melt. Relatively reducing conditions, engendered by organic carbon, will tend to stabilize sulfide ion relative to sulfate ion. Conversely, an elevated oxygen fugacity will allow sulfate to predominate over sulfide.

Although there may not be melter operational impacts due to immiscible molten sulfide or sulfate, formation of these phases has very important contaminant immobilization implications.

An immiscible sulfide melt would selectively concentrate chalcophile ("sulfur loving") elements including copper, silver, zinc, cadmium, mercury, lead, arsenic, selenium, and iron (17). Efficient partitioning of these contaminants would yield an anomalously enriched sulfide fraction. Exposure of the cooled sulfide phase to oxygenated groundwater could result in the oxidation of the sulfide mass generating an acidic contaminant-rich effluent.

An immiscible calcium sulfate phase, which would form at temperatures greater than 1723K, would selectively concentrate alkaline earth metals (magnesium, calcium, strontium, barium, and radium). Uranyl ion (UO_2^{+2}), which has an ionic radius similar to Ca^{+2}, would also likely be partitioned into a sulfate melt along with lead and cadmium. Unless totally encapsulated by cooled silica, contacting water would quickly dissolve the cooled sulfate phase and mobilize the concentrated contaminants. It is likely that both cooled immiscible sulfide and sulfate phases could fail TCLP criteria and therefore be subject to land ban disposal restrictions for concentrated Resource Conservation and Recovery Act (RCRA) metals. At relatively lower temperatures of 1155 K a molten immiscible sodium sulfate phase may develop. Removal of sodium from the silicate melt into the sulfate phase could adversely effect silicate melt electrical conductivity impacting joule heated ceramic melter and in situ vitrification processing. Recent data (16) indicate molybdenum, vanadium, arsenic, and chromium are selectively partitioned into the immiscible sulfate phase, presumably as oxidized oxyanions.

Preventing immiscible sulfur phase development upon the vitrification of sulfur-rich wastes may be difficult. Increasing the silica melt oxidation state would yield an immiscible sulfate melt, whereas a reduction in redox potential would yield an immiscible sulfide melt. Pretreatment removal of sulfur prior to vitrification may be required. Maintaining a turbulent melt will assist in encapsulating isolated or immiscible sulfur blebs within the silicate glass matrix. Alternatively, the immiscible sulfur phase may be removed from the melter and treated to remove concentrated contaminants.

SUMMARY AND CONCLUSIONS

It has been shown that development of immiscible molten iron and sulfur phases can have important implications regarding contaminant immobilization and melter selection and operations. Moreover, thermodynamics can identify and predict the conditions conducive to immiscible phase formation and potential proactive mitigative measures. Such studies can help evaluate the ability of specific vitrification technologies to effectively process particular wastes and the effect upon product quality.

The authors thank the management of Morrison Knudsen Environmental Services for supporting this study. We specifically thank Janet Lloyd for her helpful review and Susan Mitchell for the typing of this manuscript.

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ENGINEERING-SCALE TESTS OF IN SITU VITRIFICATION TO PCB AND RADIOACTIVE CONTAMINATED SOILS

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ABSTRACT

In Situ Vitrification (ISV) is a thermal treatment technology applicable to the remediation of hazardous chemical and radioactive contaminated soil and sludge sites. The ISV process utilizes electricity, through joule heating, to melt contaminated soil and form an inert glass and microcrystalline residual product. Applications of ISV to polychlorinated biphenyls (PCBs) and radionuclides have been demonstrated at engineering-scale in numerous tests (1,2,3). An updated evaluation of ISV applicability to treatment of PCBs and radionuclides, and recent test results are presented herein.

INTRODUCTION

To initiate the ISV melting process, four electrodes are placed in a square array to the desired treatment depth and a conductive starter path consisting of flaked graphite and glass frit is placed on the surface of the soil between the electrodes. The starter path is required because soil is not electrically conductive in its ambient or natural state. Once power is applied to the electrodes the soil achieves a melt operating temperature in the range of 1,600 to 2,000°C, where soils are typically molten and electrically conductive. The molten mass grows downward and outward from the electrodes as power is applied to the melt. Heat is transferred to the adjacent soil by conduction from the melt, and is aided by convection currents within the melt. The rate of melting for large-scale ISV equipment is in the range of 1 to 2 inches per hour, or 4 to 6 tons per hour, yielding a large-scale treatment capacity of 100 to 125 tons per day.

Vitrification results in a volume reduction due primarily to the removal of soil pore space, removal of water, and destruction of organic and other compounds. The volume reduction ranges from 20 to 45% depending upon the conditions at the site; therefore, at the end of each melt the surface of the resultant product monolith is at a lower elevation than the original grade. The subsidence volume created by the melt volume reduction is filled with clean backfill.

Remediation is accomplished by repeating the process sequentially, fusing adjacent melts to each other until all of the contaminated material has been vitrified. The molten mass cools in place resulting in a single residual monolith with chemical and physical characteristics comparable to obsidian (natural volcanic glass).

The ISV equipment used for full-scale remediation of waste sites is mobile and mounted on three standard semi-trailers. It is designed for operational readiness within one week after arriving on-site. The melt area is covered by an off-gas collection hood for routing the gases evolving from the treatment zone to a gas treatment system. The treatment system cleans the gases by quenching, venturi scrubbing, mist elimination, heating, particulate filtration, and carbon adsorption.

The electric power required for ISV is typically supplied from a 12,500 or 13,800 volt public utility distribution service line in the area. The three-phase AC utility power is appropriately conditioned to suit the electrical resistance of the melt. Typically, soil applications require 0.8 to 1.0 kilowatt hours per kilogram of soil melted (730 to 910 kWh/ton).

The molten mass produced by ISV exists as an oxygen deficient environment which creates a strong reducing capacity within the melt. Organic materials are present in the soil to be treated are destroyed by pyrolysis. After off-gas treatment, destruction and removal efficiencies are commonly greater than 99.9999 percent (six nines). Most inorganic contaminants are retained in their oxide state and immobilized within the glass product to the limit of their solubility. Mercury, which has a low solubility and a high vapor pressure at ISV operating temperatures, is an exception. Mercury is essentially removed from the melt and collected in the off-gas treatment system.

ENGINEERING-SCALE TEST DESCRIPTION

The ISV engineering-scale test equipment, illustrated in Fig. 1, is used to demonstrate the feasibility of ISV application to a particular waste site. This is accomplished through performance of a treatability test, prior to applying the technology at full-scale. In addition to demonstrating the ISV treatment capabilities, the treatability test is used to provide data to support the permitting process on-site, provide data relative to supporting cost estimation and remedial design, and produce glass samples for public relations purposes.The engineering-scale test equipment consists of a 30 kilowatt transformer equipped with 12 voltage taps and two silicon controlled rectifiers (SCRs) for controlling power input to the melt.

The soil is staged in a 110-gallon drum in a manner which simulates actual site conditions. The drum is then placed within a steel container for maintaining a vacuum and collection of off-gases from the melt during vitrification. Prior to staging, characterization is performed on the soil to determine hazardous chemical composition, geochemical composition, and the physical properties of the soil. These analyses are performed to ensure that the soil will conduct electricity in the range of the operating equipment, the soil will reach operating temperatures sufficient to allow destruction of organic contaminants, and that a high quality glass product can be produced that is capable of immobilizing inorganic contaminants.

The temperature of the soil surrounding the melt varies as a function of distance from the melt. During the melt and subsequent cool-down phase, these temperature zones as bounded by select isotherms, are measured by thermocouples to determine melt width and depth as well as the surrounding

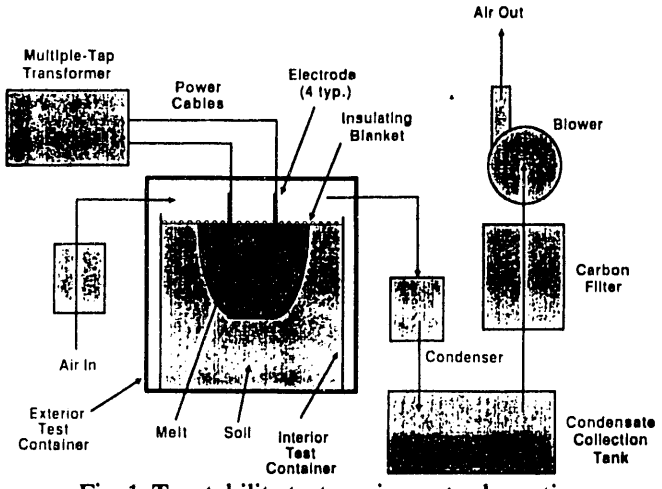


Fig. 1. Treatability test equipment schematic.

soil temperatures. Upon completion of the melt, the temperature data is then used to select soil sampling locations.

The gases evolving from the treatment zone are drawn through an off-gas line which contains sample ports available for testing the gaseous emissions from the melt. The emissions are required for the determination of destruction and/or retention efficiencies of the contaminants treated during the ISV process. Typically, every treatability test employs EPA test Methods 1 through 5 for stack gas sampling (4).

Downstream of the sample ports, the off-gases continue through a single-pass shell and tube heat exchanger to cool the gases. The condensate removed from the off-gas is collected in a tank and sampled at the completion of the treatability test. The off-gases continue through a desiccant (coarse filter) to remove any additional moisture and followed by a vapor phase carbon sorption column to remove any remaining particulate and gaseous organic emissions.

Once the target vitrification depth is achieved, power to the electrodes is shutdown and the melt is allowed to cool. Samples are obtained, according to an approved sampling plan, from locations adjacent to and beneath the melt, the glass product, the insulation blanket covering the melt, the condensate collection tank, the rinsate from pressure washing of the equipment piping, and wipe samples from the drum and steel container. These samples are determined from a statistically based sampling plan coupled with the necessary melt temperature data.

BEHAVIOR OF ORGANICS IN AND AROUND THE ISV MELT ZONE

The question of organic behavior during ISV processing has been evaluated both theoretically and empirically during the development, demonstration, and application stages of ISV. Together, these programs have involved over 130 in-depth tests/demonstrations of the technology. These tests have involved a broad range of organic, inorganic, and radioactive contaminants in various soil types. These efforts have consistently demonstrated the effectiveness of ISV for treating such contaminants.

The behavior of hazardous organic wastes during ISV processing is controlled by several interrelated mechanisms as they affect the destruction, removal, and incorporation of hazardous materials within the molten glass. These mechanisms consist of: 1) diffusion along a concentration gradient (Fick's Law); 2) capillary or wicking action; 3) reduced flow resistance in the soil column adjacent to the melt; 4) carrier gas transport; and, 5) pyrolysis.

Diffusion - Vaporization occurs at the vapor-point isotherm for each particular material; and for most organics, that isotherm is located between 100°C and the melt. It is known that vapors will distribute, by diffusion, within the available void volume and that the distribution is directed toward establishing a uniform concentration within that volume. Since vaporization occurs at the coolest boundary of this volume, and the concentration of vapors is initially a maximum at that point, the concentration-based diffusion moves down the concentration gradient, toward the melt. This diffusion is defined by Fick's Law.

Capillary Action - Liquids present in soil will move from locations of thicker to thinner films, and towards regions of lower film tension. During ISV, capillary movement is toward the dry zone and the melt. Liquids move in this direction until such time that they are vaporized.

Reduced Flow Resistance - As liquids vaporize and diffuse toward the melt, there is a resulting temperature, volume, and pressure increase. Observation of ISV melts indicate that these conditions result in the vapors moving through the dry zone adjacent to the melt and into the melt itself. In no case have vapors been observed to move away from the melt into the adjacent soil; such pathway is recognized as a path of higher flow resistance due to the soil interstitial volume being partially or fully filled with water. Vapors will flow through the past of least resistance.

Carrier Gas Transport - Water vapor is the predominant vapor present within the treatment zone during ISV processing. Water is usually present in soil in the 5 to 30 weight percent range whereas hazardous contaminants are usually present at concentrations well under 1 weight percent. It is known that water vapor (steam) will incorporate volatile organics that are soluble in water, and thus contribute directly to their movement within the treatment zone. It is also recognized that a vapor may be physically swept along by the flow of water or other vapors; this combination of vapor interactions is termed carrier gas transport.

Pyrolysis - Pyrolysis (thermal decomposition) is the predominant mechanism resulting in the destruction of hazardous organic compounds. As organic vapors distribute themselves throughout the void space adjacent to the melt, they increase in temperature to their pyrolysis temperature, where they break down into successively smaller chains of molecules and eventually reach the elemental state of diatomic gases. Upon undergoing pyrolysis, the concentration of the original compound vapor is thereby diminished, resulting in a continued concentration gradient of the original vapor toward the pyrolysis isotherm (i.e., toward the melt).

RECENT TEST RESULTS CONFIRMING COMPLETE ABSENCE OF PCB MIGRATION INTO SURROUNDING SOIL AND NO CREATION OF DIOXIN/FURAN COMPOUNDS

The most recent PCB treatability test was performed by Geosafe Corporation on soil from a Superfund Site for a private client. The primary objective of this test was to evaluate whether or not PCB concentrations in soils adjacent to and below the melt would increase, decrease, or remain unchanged as a result of ISV processing. Additionally, the possibilities of dechlorination of PCBs or formation of

dioxin/furan compounds in the adjacent soils was also evaluated. To ensure these measures were properly evaluated EPA required that the Work Plan for this test include: 1) statistical validity of the sampling and analytical methods; 2) numerous (greater than 80) soil samples obtained from all temperature zones within the soil column surrounding the melt; 3) highly precise congener specific PCB analytical methodology; and, 4) data validation by two separate independent subcontractors.

Upon completion of the engineering-scale melt, four temperature zones adjacent to the melt and three temperature zones beneath the melt were selected for sample locations and subsequent analysis. Each temperature zone was approximately two inches in width and had a minimum of three samples analyzed from random locations from within the zone. Figure 2 illustrates the post-test temperature zones.

Individual PCB congeners were analyzed by EPA Modified Method 8270/680. The congener specific analytical method was performed to conclusively demonstrate that destruction, not dechlorination of PCBs occurred. The analytical detection limits ranged from 8 to 65 part per billion (the higher the degree of chlorination the higher the detection limit) for the PCB congeners; all PCB samples analyzed were below these limits of detection (not detectable). In addition, the data validation efforts did not require any qualification of the analytical results, and the samples were well within the 80 percent confidence interval established prior to performing the test.

The absence of PCBs throughout the soil column adjacent to and beneath the melt confirmed that migration did not occur. In addition, calculations (5) demonstrated that simple dilution of the PCBs from the soil to be vitrified outward into adjacent soils during the test did not occur.

In summary, 1) all samples adjacent to and beneath the melt were non-detectable for the mono through deca chlorobiphenyls (congeners); 2) dechlorination of PCBs did not occur; 3) the sample results were statistically valid; 4) dilution, by migration, of PCBs from test soil into adjacent soils did not occur; and, 5) no data qualifiers were required as a result of the data validation efforts. This data confirms all earlier PCB test data and the theoretical basis of organic behavior during ISV processing (6). These test results conclusively demonstrate that the hypothesis of contaminant "retreat" away from the melt during ISV is a myth and has no scientific validity.

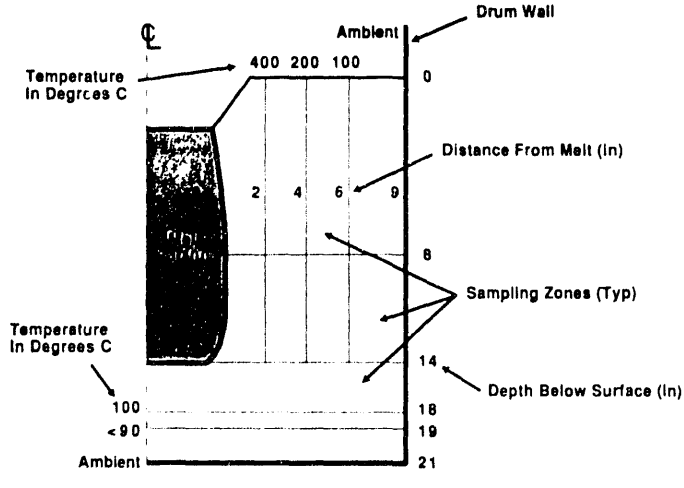


Fig. 2. PCB test temperature zones.

Dioxin/Furan compounds were also analyzed from the same sampling zones as the PCB samples. The 2,3,7,8 tetrachlorinated dibenzodioxin (TCDD) toxicity equivalencies for the individual polychlorinated dibenzodioxin/dibenzofuran (PCDD/PCDF) compounds were calculated for the pre-test soil to be vitrified, and the adjacent soil used to surround the melt.

The equivalency calculations for all the PCDD/PCDF compounds were summed together to obtain a total 2,3,7,8-TCDD toxicity equivalency concentration for each sample. Concentrations corresponding to the 80 percent confidence intervals were calculated from the means of the 2,3,7,8-TCDD toxicity equivalencies for the pre-test soils versus the post test soils. According to the confidence interval concentrations, the 2,3,7,8-TCDD toxicity equivalencies decreased in the soil samples adjacent to the melt as a result of ISV processing. This reduction was shown clearly, as the confidence intervals of the pre- and post-test soils did not overlap. In addition, within the limits of differing detection limits, each individual PCDD/PCDF isomer also decreased in concentration during the engineering-scale test as summarized below.

To simplify the dioxin/furan discussion, the soil surrounding the melt prior to ISV was known to contain trace amounts of dioxin/furan contamination, but no detectable PCBs. Upon completion of the engineering-scale test, those same soils were sampled and had a net decrease in dioxin/furan concentration, and were non-detectable for PCBs. This clearly illustrates the movement of organic contamination towards the melt, subsequent pyrolysis of the contaminant, collection and treatment by the off-gas treatment system, and no additional creation of dioxin/furans in soils adjacent to the melt.

RECENT TEST RESULTS ON SOILS CONTAMINATED WITH RADIOACTIVE COMPOUNDS

The most recent radioactive test results were performed on soils obtained from two independent Superfund Sites. The first site contained radium-226 as the primary contaminant. The objectives of the radium test were to determine: 1) the retention and distribution of radium contamination in the vitrified block; 2) the amount of radon released during vitrification; and, 3) the rate of radon emanation from the vitrified product.

The pre-test contaminated soil from the first test site had radioactive readings of approximately 2.5 mrad/hr. Upon completion of the ISV engineering-scale test, the vitrified block measured 8.5 mrad/hr. This higher contact-source radiation level measurement of the vitrified product could be occurring because vitrification concentrates the radioactive materials into a smaller volume as a result of the natural volume reduction during ISV processing. This volume reduction, or subsidence area would be covered by clean backfill limiting the radioactive readings at the surface of the clean backfill into acceptably low micro-rad/hr ranges. Backfilling the subsidence volume combined with minimizing the potential for intrusion into the vitrified block by institutional control over the processing area would eliminate the potential for exposure.

Analysis of radium release during testing was measured through sampling the off-gases. The radium that was released from the melt was very low (at or near the detection limits)

and in the form of particulate, which is easily removed during off-gas treatment. Analysis of radon release during processing indicate the projected radon release during full-scale processing could approach regulatory point-source limits. Radon release; however, can be controlled by either increasing the off-gas flow rate or lowering the rate of vitrification.

The radon emanation rate from the vitrified product was over 30,000 times lower than the radon emanation from the existing untreated soil. The radon emanation level for the treatability test was at or below the detection levels. These data are consistent with other engineering- and pilot-scale test results conducted on soils contaminated with radium (7).

The second Superfund Site, previously mentioned, contained radium-226, lead-210, natural uranium, selenium, and arsenic. The objectives of this treatability were to confirm that ISV is technically appropriate for the application to the site soils by demonstrating immobilization and/or removal of the inorganic contaminants, and absence of contaminant migration into surrounding soils.

The ISV glass product produced from the engineering-scale melt resulted in immobilization of the target contaminants. The retention efficiencies were:

Contaminant	Retention Efficiency
Arsenic	82.5%
Selenium	99.9915%
Lead-210	96.13%
Radium-226	99.9994%
Uranium (Natural)*	>60%

*Uranium retention was limited by the detection limit of the analytical method. Previous uranium results indicate uranium retention in the range of 99.99% (8,7). The target contaminants retained within the glass all passed EP Tox leach requirements 40 CFR 192.32(b)(1)(ii).

Post-test soil samples were obtained from several random locations within two different temperature zones adjacent to and beneath the vitrified product. Comparison of the mean concentration of contaminants measured in the pre-test soils to the mean concentration of contaminants measured in post-test soils illustrate a net decrease in contaminant concentration.

To summarize, the two recent ISV tests performed by Geosafe Corporation on radioactive contaminated soil supports previous test results. ISV does not destroy radioactive species, but simply incorporates the contaminants into a non-leachable glass and micro-crystalline form, which prevents mobility in the environment. The glass product, once covered with clean backfill following a melt, can bring surface dose rates below exposure concern levels in most cases. Migration of the contaminants into surrounding soils does not occur.

APPLICATION CONSIDERATIONS

ISV of both PCB contaminated and radioactive contaminated soils has been successfully demonstrated at engineering-scale in numerous tests. Allegations of migration of contaminants, particularly organic contaminants, away from the melt has been shown to be a scientifically flawed hypothesis based on the use of non-representative analogies and without scientific validity. Based upon past ISV data and recent test results, it can be concluded that one of the most significant applications for ISV, is the simultaneous treatment of both organic contaminants (such as PCBs) and inorganic contaminants (such as radionuclides, and other heavy metals) in the same melt or batch process. The resultant ISV product will have the characteristics of a high quality glass product with the properties of volcanic glass, high quality leaching characteristics, and long term geologic stability.

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POTENTIAL FOR USING A SIX-PHASE ALTERNATING CURRENT POWER SUPPLY FOR IN SITU VITRIFICATION

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ABSTRACT

In situ vitrification (ISV) has been identified as a potential treatment technology for stabilizing underground tanks at Hanford and other U.S. Department of Energy (DOE) sites. A key requirement for this application is an electrical system that can supply the power needed to vitrify a tank in a single setting. This paper describes an engineering-scale test conducted at the Pacific Northwest Laboratory (PNL) to assess the efficiency of a six-electrode, six-phase energy supply system in melting soil. The test was conducted with a 30-kW six-phase system. Based on the test results, a six-electrode, six-phase system shows potential for scaleup to larger systems.

INTRODUCTION

In situ vitrification is a thermal treatment process that converts contaminated soil into a leach-resistant material resembling obsidian. The process was developed by PNL to immobilize contaminated (e.g., radioactive) soil and isolate it from the surrounding environment. It is currently being used to demonstrate soil remediation at DOE-owned facilities at Hanford and other sites, including the Idaho National Engineering Laboratory and the Oak Ridge National Laboratory (ORNL).

In situ vitrification is based on the joule-heating principle used in electric melter technology developed by PNL for the immobilization of nuclear waste. The process is initiated by inserting an array of graphite electrodes into the ground to a nominal depth (0.2 to 1 m). An electric potential applied across the electrodes generates current through an electrically conductive starter path. The resultant power creates temperatures that are high enough (typically about 1700°C) to melt the starter path and the surrounding soil. As the soil melts, it encompasses the contaminated area and incorporates the radionuclides and nonvolatile hazardous elements, such as heavy metals. After the process is complete, the melted soil slowly cools, producing a vitreous mass of relatively high strength and chemical durability.

Work is currently under way to adapt the ISV technology for treatment of previously emptied and other underground tanks at Hanford and other DOE sites. For this application, a key requirement is an electrical system that can supply the power needed to vitrify a tank in a single setting. In November 1990, PNL conducted an engineering-scale test to assess the efficiency of a six-electrode, six-phase energy supply system in melting soil. Data from this test will be applied in the development of an electrical system for underground tank vitrification. A six-phase system was chosen for the initial evaluation for the following reasons: the circular layout of the electrodes is more compatible with the geometry of the circular tanks; the energy supply system can be scaled up to 30 MW with ease; the electrode voltage is controlled by fixed taps on transformer windings or by changing the taps under load, thus avoiding the power factor and harmonic generation associated with the Scott-Tee method of power supply; the possibility of extending the electrode system to 12 phases is high; and the six-phase system may yield a more rapid heating technique than has been observed with single-phase or T-connected electrical supplies.

TEST DESCRIPTION

Equipment Configuration

The system consisted of an alternating current (ac) power supply and a cylindrical tank (8 ft high by 6 ft in diameter) containing soil and six graphite electrodes arranged hexagonally. The electrodes were placed in insulated brackets so they would drop by gravity as the test progressed. Thermocouples were installed at various locations within the tank to monitor melt rate and melt temperature. The tank was covered and vented to the building vacuum system through a HEPA filter. The soil used in this test was uncontaminated sand from the Hanford Site. Radioactive or hazardous materials were not used in this test. The test plan called for a starter path as shown in Fig. 1, with current flow allowed radially between the electrodes. The starter path consisted of a mixture of 65% by volume of graphite and 35% glass powder placed in trenches that were 2-in. deep and 2-in. wide. To provide contact, each electrode was surrounded by a 1-in.-wide, 2-in.-deep band of graphite. The starter path was covered with 6 in. of soil followed by an insulating barrier of 4 in. of fiberglass wool. The delta power supply of 480 volts ac (Fig. 2) does not allow neutral current in the source winding, thus yielding complete electrical isolation between the source and the electrodes. Currents can, however, flow in a variety of paths that do not involve neutral conductors, thereby generating a hotter central region due to I^2R losses in the soil. There are 15 options for paths between two electrodes in the six-phase electrode system. This arrangement provides a wider variety of paths for current flow than that provided by the six paths in the T-connected, four-electrode system.

Power Supply System

The power supply consisted of six four-winding transformers (240, 480/120, 240 Vac) connected two in series per phase to provide 480/480 Vac, three-phase isolated secondary voltage. Each secondary winding was center tapped, with the

* Pacific Northwest Laboratory is operated by Battelle Memorial Institute for the U.S. Department of Energy under Contract DE-AC06-76RLO 1830.

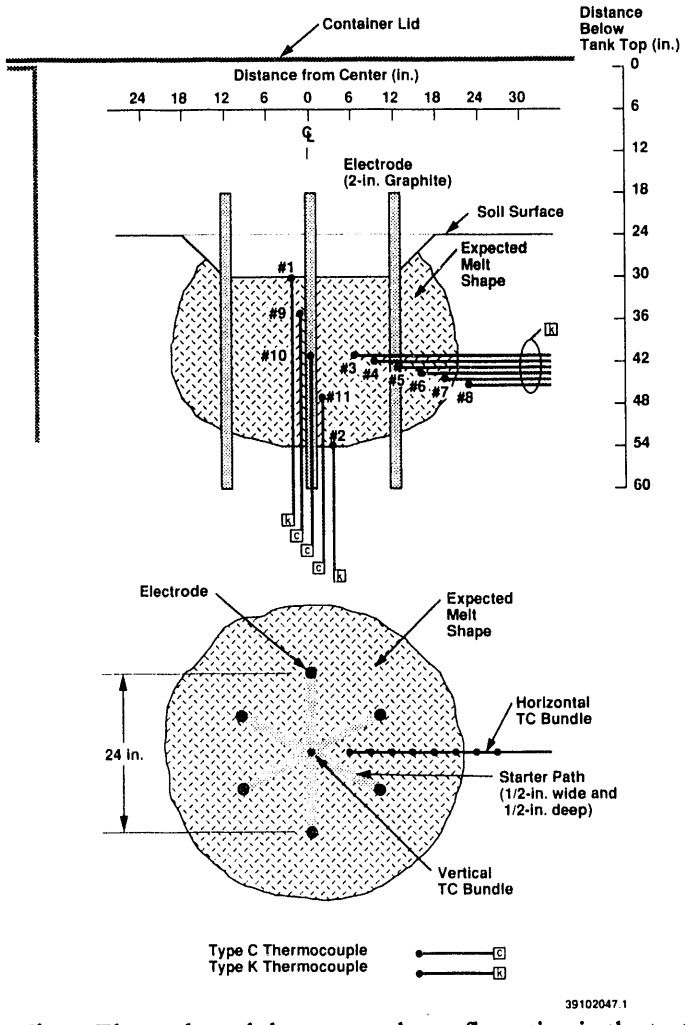


Fig. 1. Electrode and thermocouple configuration in the test tank.

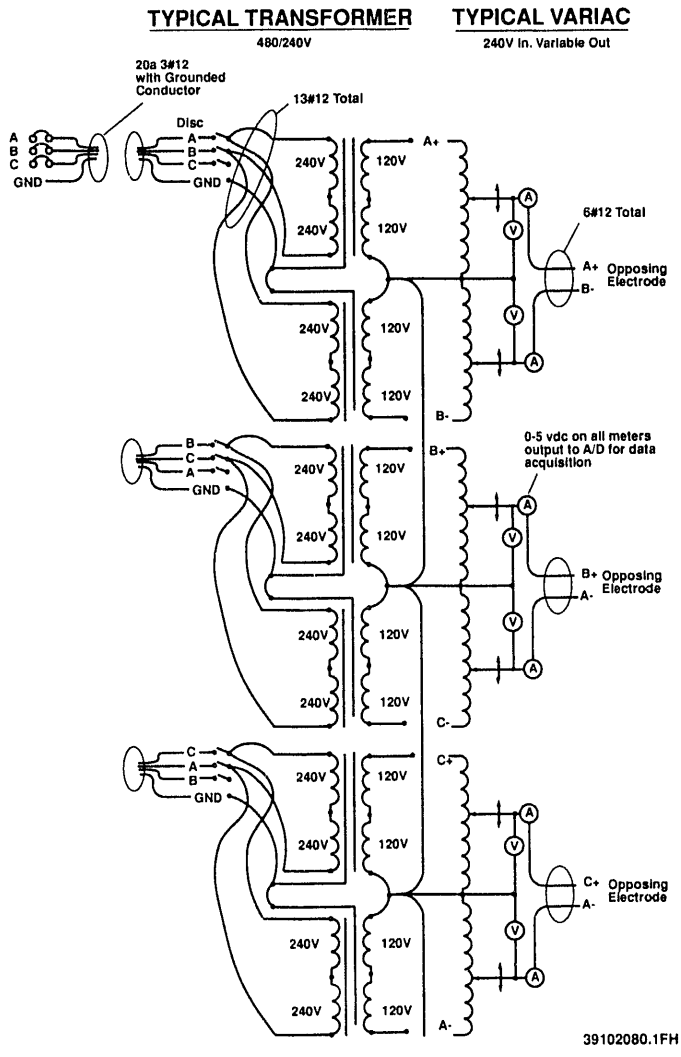


Fig. 2. Phase connections for the electrical configuration.

centertaps made common. These connections yielded six conductors, each having 240 Vac to neutral, each differing in phase by 60 electrical degrees, and labeled (A+, B-) (B+, C-) and (C+, A-) for each of the six phases. These six conductors were connected to the 240-volt terminals of independently adjustable variacs, each rated 16 kVA. (Each variable voltage source consisted of two variacs connected in parallel with a series-equalizing transformer.) The variac neutrals were electrically connected to the secondary centertaps of the transformer to provide a ground for the variac and electrode assembly. The output voltage terminal of each variac was connected to an electrode in the tank.

Figure 2 shows the method used to control electrode voltage (wipers are indicated by arrows). The electrode voltages are adjusted by adjusting the variac wipers independently. This electrical interconnection of transformers and variacs provides a means of supplying electrical energy to each electrode. In contrast, the Scott-Tee connection can permit voltage differences to pairs (A-phase and B-phase) of electrodes only, and the A-phase voltage must be equal to the B-phase voltage to avoid severe power factor penalties.

In addition to avoiding the power factor problem that arises with Scott-Tee transformers, the problems of voltage waveform distortion associated with harmonic generation caused by rectifier or saturable reactor control are avoided when using the variable voltages provided by the variacs. For this test, each variac was initially set to zero.

Test Startup and Operation

To begin the test, the electrodes were inserted to 6 in. below the soil surface. Calibration marks on each electrode showed penetration depth from the soil surface. The test plan called for ramping electrode power over 3 hours from an initial value of 1 kW to 20 kW. However, this plan had to be altered after 2 hours when the starter path developed sporadic open circuits. To keep the test going, we increased selected electrode-to-neutral voltages up to 290 volts to re-establish melt paths after the open circuits appeared. Subsequent short circuits caused excessive currents (94 amps) to flow temporarily until we could adjust the variacs. Occasionally, circuit breaker operations required that the test be halted, but restarting within seconds had little adverse effect. Melted soil paths were established primarily electrode-by-electrode by increasing the voltage of the selected electrode and then controlling the current while attempting another path. After about 30 minutes, all electrode paths through melted soil were established. The problems described above may be eliminated by using a more reliable starter path.

After establishing the melt path, we ramped the electrode power to 20 kW and maintained it in the range of 20 to 25 kW.

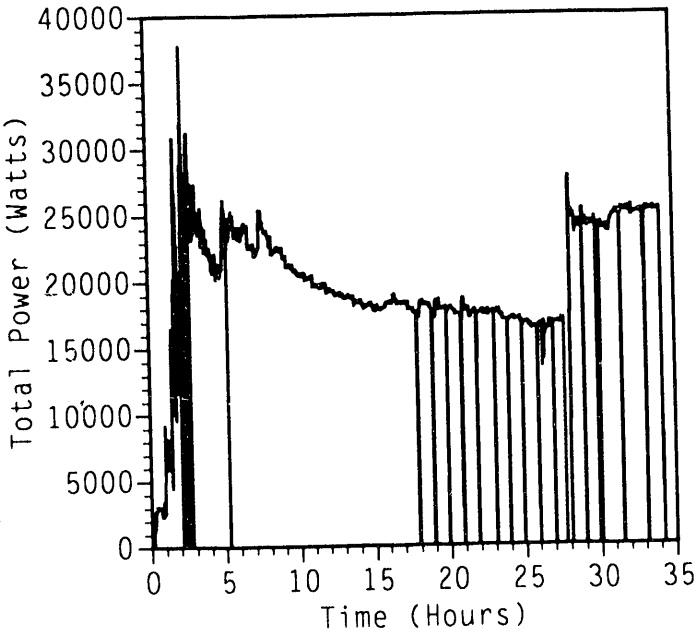


Fig. 3. Total power input as a function of time.

The starter path was covered with a 6-in. layer of soil and a 4-in. blanket of fiberglass wool. This insulation formed a solid cap on the melt that, although not bonded to the electrodes, held them as the melted soil subsided below the cold cap, forming a void space similar to a volcanic caldera prior to collapse. We had to tap the electrodes with a rubber mallet to free them from the cold cap so they could follow the advancing melt front. As the melt depth increased, the resistance decreased, requiring that we establish a current limit of 40 amperes per phase for the electrode conductors (#10 wire). The resistance continued to decline and, at about 15 hours into the test, the melt was inadequately powered because of the current limit. At about 28 hours, we provided a double circuit supply of #10 wire to the electrodes. This adaptation successfully increased the electrode power. At about 34 hours into the operation, the target depth of 30 in. was achieved and, as shown in Fig. 3, the energy supply was shut off.

ANALYSIS OF TEST RESULTS

Basis for Using Six-phase Electrode Resistance

The approximation of interelectrode resistance is based on an elementary two-electrode formula found in Stanek (1). Although this analysis is defective, an analytically sound method yields an equation identical with equation 3.125 from page 257 of Stanek. The analytical method is the solution of problem 1 from page 79 of Panofsky and Phillips (2). The same solution is more elegantly derived in Kreyszig (3), page 740 in example 5. The two-electrode formula is derived by Koegler and Kindle (4).

$$*R_i = (\rho/\pi\ell)\ln\left\{\frac{D_i}{d} + \sqrt{\left(\frac{D_i}{d}\right)^2 - 1}\right\} \quad \text{(Eq. 1)}$$

$$\approx (\rho/\pi\ell)\ln(2D_i/d),\ i = 1,2,3,$$

where

ρ = melt resistivity (estimated to be 1.2 mΩ at 1600°C)

ℓ = melt depth (initially 6 in. and increasing with time to 36 in.)

D_i = electrode separation (12 in. on the edge of the hexagon for i = 1)
(2 x 12 cos 30° on alternate electrodes for i = 2)
(24 in. on diagonal electrodes for i = 3)

d = electrode diameter (2 in.)

The interelectrode currents follow paths delineated by R_i, i = 1, 2 and 3 in Fig. 4. The composite resistance between electrodes is evaluated using balanced current approximations to be

$$R_{a+b-} = 1/(1/R_1 + 1/R_2 + 1/R_3) \quad \text{(Eq. 2)}$$

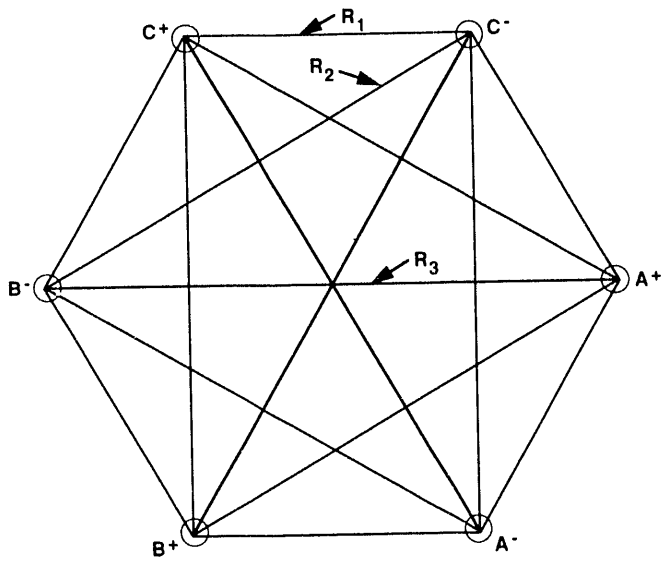


Fig. 4. Current paths in the six-phase electrode system.

The initial resistance R_{a+b-} was estimated to be 2.395Ω for the 6 in. of melted Hanford soil. Assuming 25 kW of power into the melt, the three paths would require $3(V_{a+b-})^2/R_{a+b-}$ = 25 kW, which implies V_{a+b-} = 141.3 volts, or approximately 71 volts electrode to neutral. The current is evaluated using $3(I_{a+b-})^2 R_{a+b-}$ = 25 kW, which implies I_{a+b-} = 58.99 amps. These calculations were not observable because of the limited current-carrying capacity of the electrode conductors. Consequently, reduced currents and reduced voltages prevailed until the latter part of the test. During the latter part of the test, the 28 kW circuit breaker limited the magnitude of electrode current because it would automatically trip at 28 kW. These data points, together with estimates of the melt size, yield additional approximations of the melt resistivity, an elusive parameter not well documented in the literature. The model for interelectrode resistance assumes an infinite slab approximated by a slice of melt having a finite radius. Subsidence and thermal variation contribute to increase the uncertainty in the estimate of melted soil resistivity.

Study of Resistivity

The Stanek formula is an approximation for D > > d taken from the following more accurate representation shown in Eq. 1 above. Here, we have chosen ρ as an unknown variable to be evaluated during the analysis. Using Eqs. 1 and 2 above,

$R_1 = 5.175\rho\Omega$, $R_2 = 6.333\rho\Omega$, $R_3 = 6.634\rho\Omega$, $R_{a+b-} = 1.993\rho\Omega$.

These are intermediate results that depend on our observed value of ρ to provide data for transformer design in the specification of ISV equipment.

The choice of ρ is motivated through the most demanding part of this engineering-scale ISV test. Ohm's Law dictates the following:

$$I_0 = (V_0-V_1)/R_1 + (V_0-V_5)/R_1 + (V_0-V_2)/R_2 + (V_0-V_4)/R_2 + (V_0-V_3)/R_3$$
$$= (2V_0-V_1-V_5)/R_1 + (2V_0-V_2-V_4)/R_2 + (V_0-V_3)/R_3 \quad \text{(Eq. 3)}$$

Equation 3 is derived by inspecting Fig. 4, which exhibits the paths for current flow between electrodes. I_0 is the sum of the currents leaving electrode (0). Values of I_0, V_0, V_1, V_2, V_3, V_4 and V_5 were recorded during the test. Data line 7547 was chosen to be used to evaluate the resistivity for the (0) electrode labeled A^+ in the test.

Data: V_0(labeled A^+) = $70.36\angle 0°$ volts, V_1(labeled A^-) = $74.40\angle 60°$ volts,

V_2(labeled B^+) = $75.11\angle 120°$ volts, V_3(labeled B^-) = $71.62\angle 180°$ volts,

V_4(labeled C^+) = $74.77\angle 240°$ volts, V_5(labeled C^-) = $75.22\angle 300°$ volts,

$2V_0-V_1-V_5 = 65.91\angle 0.617°$ volts, $2V_0-V_2-V_4 = 215.7\angle -0.078°$ volts,

$V_0-V_3 = 141.98$ volts. Using $I_0 = 57.71$ amps yields $\rho = 1.1816 + j0.0015\ m\Omega$.

The other five currents yield similar values. It is interesting to note that this result could be tuned for $\rho = 1.2$ by jittering ℓ.

For this value of ρ, the viscosity is such that the melted material must be a solid, a contradiction that has been resolved by Koegler in a subsequent study that assumes electrode surface resistances.

Interelectrode resistance is calculated using * with ℓ increasing with melt depth. This relation yields monotone decreasing parabolic behavior of the interelectrode resistance with melt depth. Since uniform energy input per unit of melt is desired, the required current/voltage relation that yields uniform energy per unit volume can be determined. Here we assume the melt is cylindrical and increases in depth linearly with time, which implies that the melt accumulates at a constant rate. The total weight of the vitrified material was 1640 lb. The total energy input was 650 kWh. The ratio gives 0.3936 kWh/lb. We melted a cylindrical volume of soil of diameter 2 ft and depth 40 in. in ≈33 hours using the power curve shown in Fig. 3. Using 156 lb/ft^3, we have ≈10.51 ft^3 with a cylindrical volume of $\pi\ell D^2/4$ where ℓ = 40 in. and D becomes the equivalent diameter = 2.004 ft, which is well within experimental accuracy. Assuming a volume of πD^2 x /4 was swept out in each increment of time, in 33 hours x = 40 in. would be melted ⇒ x = 40/12/33 ft/hr = .0101 ft/hr. Using 650 kWh in 33 hours or 19.697 kWh/h implies ≈20 kW. (Initially, ℓ = 6 in. and terminally, ℓ = 40 in. Consequently, R_{a+b-} = 2.395Ω initially and 2.395 x 6/40 = .3592Ω terminally.)

Thermal Characteristics of the Test

The locations of the thermocouples in the tank were shown previously in Fig. 1. Table I provides temperature data

TABLE I

Temperature Data for this Test

Thermocouple	Type	Thermocouple Location: Depth of Thermocouple (in.)	Thermocouple Location: Horizontal Distance from Vertical Centerline (in.)	Time to Obtain 1000°C (hours after start of test)	Temperature Reached
1[a][c]		K	6	0	41000°C
2[b]	K	30	0	29	1000°C
3[c]	K	18	6	17	1000°C
4[c]	K	18	9	18	1000°C
5[c]	K	18	12	20	1000°C
6[c][d][e]	K	18	15		880°C
7[c][d]		K	18	18	480°C
8[c][d]		K	18	21	240°C
9[c]	C	12	0	13	1676°C
10[c]	C	18	0	23	1634°C
11[c]	C	24	0	32	1605°C

(a) For this thermocouple, the soil cover and fiberglass wool barrier formed a cold cap over the melt that became an air chamber as the melt subsided.

(b) This thermocouple was located in an aggregate material less capable of holding moisture; thus, data for the 100°C latent heat of vaporization are barely discernible.

(c) These thermocouples showed the plateau for the 100°C latent heat of vaporization.

(d) Thermocouple did not melt.

(e) Subsided to ambient temperature after reaching 880°C.

for the test. Thermocouple #1 melted first, followed by thermocouples 9, 10, 3, 4, 11, 5, and 2. In this test, 6 in. of cover soil was placed on top of the starter path. The soil was then covered with an insulating barrier of 4 in. of fiberglass wool. Since the fiberglass wool did not melt during the test, the heat was generally confined to the soil.

Energy Input and Melt Shape

At about 5 hours after startup, we shut off the power and tapped the electrodes to force them to the bottom of the melt. We did not make any additional attempts to position the electrodes until 18 hours into the test. From that time on we tamped the electrodes at 1-hour intervals until the end of the test. At 28 hours, we switched to the double-circuit power supply, which significantly increased the electrode power (see Fig. 3).

After the melt block cooled, we obtained measurements at 2-in. intervals along the block. As shown in Fig. 5 and listed in Table II, bulges appear at the subsidence line 24 and 16 in. from the bottom of the block, with a more narrow section 20 in. from the bottom. Although we expected that the electrodes would protrude from the bottom of the melt, they are in the melt, indicating that the assembly and the cold cap held the electrodes, allowing the underlying soil to melt. It appears that the increased electrode energy in the final hours of the test contributed to the increased depth of melt.

CONCLUSIONS

This engineering-scale test ran for 34 hours, producing a 743.9-kg (1640-lb) vitrified block with 650 kWh of energy. This product/power ratio indicates that the six-phase system provides an efficient method of heating. Additional conclusions follow:

- A six-phase, six-electrode ISV system looks feasible and should be considered for scaleup to larger systems. The melt produced a circular form, with little lateral spreading outside the electrodes.
- The six-phase system avoids the power factor and harmonic generation associated with Scott-Tee transformers.
- The test configuration provided currents and voltages that were used to calculate resistivity [(see Appendix A of Richardson 5)]. The resulting value is in agreement with values determined in other ISV tests, and corroborates the use of this parameter in scaleup calculations.

In this test, initializing the melt path presented difficulties that could be countered by using a different material (i.e., nichrome wire) to establish the path, or by providing a greater number of starter paths in parallel. Initialization of the test appeared to be limited by the available voltage. Increasing the voltage capability by 20% or more may solve this problem. The final hours of the test were affected by current limitations; however, adequate current-carrying capability was easily supplied without stopping the test.

TABLE II

Dimensions of Vitrified Block

Diameter (in.)	Distance from Bottom of Block (in.)
33.4	24
31.8	20
33.1	16

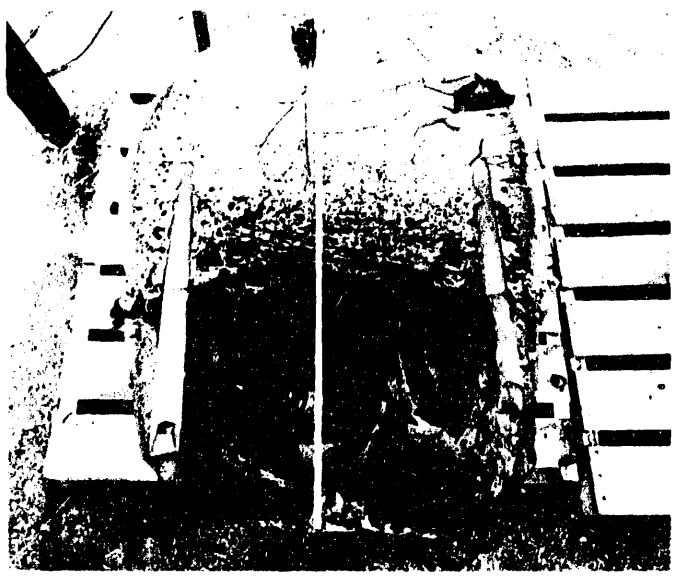


Fig. 5. Vitrified block produced by this test.

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FACILITATION TECHNIQUES FOR ENVIRONMENTAL RESTORATION PLANNING AND IMPLEMENTATION

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ABSTRACT

Successful environmental restoration requires effective coordination of efforts among many disciplines. It also must address a broad array of regulatory concerns, select suitable technical solutions, and consider various social and political concerns. Chem-Nuclear Geotech, Inc. (Geotech), uses trained facilitators who apply special planning and problem-solving techniques to help ensure success in these multifaceted efforts. Facilitated sessions, which often include representatives from regulatory agencies (e.g., the U.S. Environmental Protection Agency and state officials) as well as Geotech and U.S. Department of Energy (DOE) personnel, help clarify the direction of environmental restoration early in the planning and design phases, provide substantial savings to the DOE, reduce redesign activities, shorten schedules, and eliminate schedule delays.

This paper describes and explains how Geotech facilitators use facilitation techniques to assist technical experts in environmental restoration plan development and problem solving. The paper does not attempt to address all possible facilitated planning and problem-solving methods that may be useful, nor does it provide sufficient detail about the techniques to allow the reader to conduct such activities without further training or instruction.

FACTORS OF FACILITATED SESSIONS

Geotech facilitators apply the planning and problem-solving techniques of Systematic Development of Informed Consent (SDIC) Mission Statement Development, Nominal Group Technique (NGT), and Value Engineering (VE) to environmental restoration issues. Regardless of the technique used, certain characteristics (e.g., skills required of the facilitators, appropriate team composition, and desired team interaction) are common to all.

Facilitators' Roles

Trained facilitators provide many benefits to these processes. These benefits include improved human interaction during planning and problem-solving activities, strong team-building capabilities, efficient use of the time provided by any experts involved, clear focus on needed planning or problem resolution, team member buy-in to ideas or solutions developed, and improved cost-efficiency and schedules.

Facilitators are trained to understand facilitation processes and the philosophies of the processes. It is their responsibility to concentrate on the process while team participants concentrate on the subject under study, applying their specific and shared areas of expertise. Two facilitators are recommended for these planning and problem-solving sessions to share the responsibilities for leading team processes, maintaining group cohesiveness, and recording information.

Facilitators are also models for good group behavior. They demonstrate openness and non-evaluative behavior and ensure that participants and ideas receive equal attention and acceptance. Facilitators must also be able to quickly intervene when necessary to correct inappropriate or distracting behavior.

Because the quality of a session's output depends on the quality of input, facilitators solicit the support and participation of all team members to obtain insight and any study-related information. Facilitators do not allow team sessions to be dominated by strong personalities, inhibited by fear of possible sanctions or conflicts, or suppressed by organizational or social status differences. Sharing ideas and equalizing participation increases group synergy and creativity. Openness and frankness are important to the success of the session, and objectivity helps team members probe elements of problems and discover innovative solutions.

Up-front preparation and planning by the facilitators are crucial to the success of facilitated sessions. Facilitators must develop strong opening statements, identify and understand the scope of the planned sessions, and prepare well-defined problem statements to elicit appropriate types of responses. They must also assemble all necessary supplies and select suitable locations and times for the planned sessions.

At the beginning of each session, the facilitators cordially welcome the team members, stress the importance of the team's task, emphasize the importance of each member's contribution, and explain the usefulness and purpose of the session's output. The facilitators ensure that the team understands the objectives; discussion of the objectives in precise terms focuses team attention on the desired outcome.

Using easel-style flip charts, the facilitators record-in the team members' own words-highlights of the team discussion, ideas generated by the team, and any resulting decisions. This approach increases the members' perception of their importance, equality, and shared-ownership identification of the task. It also diminishes the perception that the facilitator is manipulating the team. Additionally, the team can separate recorded written information from the personalities or positions of individuals who contribute to the discussion because written ideas are more objective and less personal than verbal statements. Teams are more capable of handling a greater number of ideas if the ideas are presented in a written rather than an oral format.

Team Member Selection

Selection of appropriate team members is vitally important to the success of these planning and problem-solving sessions. The team process cannot substitute for appropriate team membership because the process simply facilitates the decoding of ideas by the assembled individuals. Team members should be interested in the problem, have experiences or educational backgrounds that will serve as resources to the team, and be sufficiently flexible to openly explore various points of view. Assembling a team composed of individuals from diverse disciplines and with strong experiences ensures an extensive collective body of experience and knowledge. Heterogeneous groups (i.e., multiple ages, disciplines, positions, and personalities) are generally more creative; however, it is important for team members to speak a common language to prevent communication difficulties.

The ideal team size is five to seven members, but larger teams can be facilitated if necessary to ensure appropriate team composition. Teams with fewer than five members are less capable of task-oriented discussions. In small groups, members who have difficulty withdrawing from embarrassing positions may feel overexposed, and there is a heightened personalization to the discussion. However, member satisfaction may be reduced in groups with more than seven members because there are fewer opportunities for each team member to participate in the process, more members may become inhibited in the presence of a large number of people, and large teams tend to split into subgroups or factions. Additionally, the mechanics and the process of facilitating can become more burdensome as the number of participants increases.

SYSTEMATIC DEVELOPMENT OF INFORMED CONSENT MISSION STATEMENT DEVELOPMENT

Overview

Systematic Development of Informed Consent (SDIC) is a technique used to identify potential social and political barriers to public programs and projects such as environmental restoration. This technique will assist in developing plans for informing agencies and the public about a program or project to gain public consent and ultimately to remove any barriers to successful implementation (1).

A key part of the SDIC process is careful development of a mission statement to serve as the focus for individuals who support a given program or project. The mission must be *communicated* (two way) up and down the line internally (within the organization) and externally (to and from any potentially affected interests, i.e., individuals, organizations, or other agencies). More understanding of the mission is required internally than externally.

An effective mission statement should

- Offer "why" not "what" and provide explanations that convey the central, driving, or primary "why?" It should express what contribution the mission makes or can make to the quality of life.
- Allow all employees to see how their jobs connect to the overall mission.
- Stress that the organization's goal is fulfillment of the mission.
- Positively state the need for action.
- Give guidance in a crisis.
- *Not* cite laws, regulations, etc., as the reason for action.

The team representing the organization for which the mission statement is being developed is asked to consider specific questions based on SDIC guidance. These focusing questions are

- Does the mission address a serious problem or important opportunity that must be addressed? The responses to this question are used to develop a "systems" statement within the mission statement that describes how the real world works versus quality-of-life issues.
- Is your organization the right entity to address this problem or opportunity?
- Do all potentially affected interests understand your mission?
- Do all potentially affected interests understand that, because of your mission, you would be *irresponsible* if you did not address this problem or opportunity? The responses to this and the previous two questions become the portion of the mission statement that describes your mission and responsibility to address the problem or opportunity.
- Do the potentially affected interests understand you are doing all you can, short of compromising your mission, to minimize the costs, negative effects, and hardships that your effort will cause them? The responses to this question become the portion of the mission statement that describes how you are addressing the problem or opportunity, including past considerations, current plans and considerations, and specific issues and interests.

Process

Geotech facilitated discussions among personnel who support the Department of Energy Idaho Field Office (DOE-ID), Environmental Restoration Programs Branch. These discussions were held to clearly define the branch's mission and its ties to the overall DOE-ID mission, identify major tasks to be achieved to meet the mission, and identify needed actions and follow-on activities.

During these discussions, a summary of the overall DOE-ID mission was presented to the team by DOE-ID executive management. Following this presentation, the facilitators reviewed the objectives of the session, explained the essentials of a good mission statement, and asked the team to consider the focusing questions to help develop its mission statement.

All team members were asked for input regarding their perceptions of the DOE-ID Environmental Programs Branch's mission. The facilitators recorded team members' responses but did not allow team discussion or evaluation.

Following this recording of thoughts and ideas, the facilitators conducted a review and discussion based on the SDIC guidelines for effective mission statements. The purpose of the discussion was to clarify team perceptions and thoughts; consider appropriateness; and eliminate, expand, or consolidate as necessary to reach team agreement.

The team was divided into small groups and asked to identify perceived barriers and needs to accomplish the mission that were generated during the review and discussion. During the time allotted, the facilitators compiled the

information produced during the recording and clarification activities, combined all common threads, and developed a draft mission statement. A facilitator wrote the draft mission statement on an erasable board. The small groups were reconvened, and the facilitators presented the draft mission statement. The team members discussed the mission statement, and the facilitators revised the statement to reflect team concerns as appropriate to obtain consensus.

When the team was satisfied with the content and wording of the mission statement, a representative from each discussion group presented findings relative to the barriers and needs to accomplish the mission. This information was recorded and consolidated into a summary list for assignment of follow-on actions.

Conclusions

Development of a mission statement helps individuals supporting a program, project, or organization understand the specific tasks that must be accomplished to achieve the mission, decide how to organize to accomplish these tasks, and focus on areas of specific concern requiring further planning or problem-solving actions. This activity helps unify individuals so that future planning and follow-on actions can be aligned with a mutually understood mission. In addition, the mission statement is available to help those outside the program, project, or organization understand the importance of its mission.

NOMINAL GROUP TECHNIQUE

Overview

The Nominal Group Technique (NGT) is a facilitating technique used when a decision-making situation is complex and individual judgments must be aggregated to arrive at decisions that cannot be effectively decided by one person. NGT enables a diverse group to reach a decision and establish priorities that truly reflect group preferences (2,3). It is particularly valuable in situations where there is a lack of agreement or incomplete knowledge concerning the nature of a problem or the elements that must be addressed for its successful solution.

Through use of the six-step NGT process, the elements of a problem and elements of suitable solutions can be identified and appropriate priorities can be established. The six basic steps are

1. Presentation of the focusing or nominal question.
2. Silent generation of ideas in writing.
3. Round-robin recording of ideas.
4. Discussion to clarify ideas.
5. Voting and ranking.
6. Discussion of results.

The NGT technique is very effective when it is agreed that a decision is needed, but the individuals involved in reaching the decision have conflicting or diverse opinions. Domineering personalities often inhibit "free" discussion of information within decision-making groups. In such cases, NGT provides a constructive method for dealing with conflict and often results in a clear expression of whatever degree of consensus exists. NGT also instills a strong sense of closure and a feeling of group accomplishment that members will typically support.

Process

Geotech facilitators selected NGT as the appropriate decision-making technique for discussions between Geotech and DOE personnel and representatives of the U.S. Environmental Protection Agency (EPA) and the State of Utah. The purpose of the discussions was to identify key environmental restoration issues that required focused attention to successfully complete the Monticello Remedial Action Project (MRAP), a project established to mitigate surface and groundwater contamination by relocating contaminated material from an abandoned DOE uranium millsite to a permanent repository near the original site. Key issues were chosen for further discussion to develop possible approaches for their resolution.

The facilitators followed the six basic NGT steps by posing the NGT *focusing*, or *nominal*, question to the team: "What do you consider to be the key issue(s) that must be resolved to successfully complete MRAP?" After a brief discussion to ensure that team members understood the scope of the question, the team members were asked to silently generate, in writing, short phrases that described their responses to this question. A time limit was imposed, and discussion among team members was not allowed. After the time limit elapsed, a round-robin recording step was conducted to register the team's responses. Team members presented their ideas in brief phrases, which the facilitators recorded on flip charts. Each team member was allowed one idea per pass, and team members were encouraged to add ideas to the flip-chart list even if they did not appear on individual worksheets. The facilitators did not allow discussion among the group during this recording process.

After the ideas were recorded, a facilitated team discussion of each idea clarified the meaning of the recorded ideas and eliminated disparate information, misinformation, or misunderstanding. The facilitators informed the team that judgment was not allowed during this step, and argument was unnecessary because the team's final judgment would be made during a later step of the process. Facilitation was structured and paced to avoid undue focus on any particular idea, argument, or debate among team members. Duplicate ideas were combined but not so extensively that loss of detail reduced the value of the voting and ranking step.

The voting and ranking step assembled the team members' judgments on what they considered the most important ideas on the list. During this step, team members voted by secret ballot to select the five ideas that represented the most important issues under discussion. A bracketed or polar voting process was used to rank the order of importance of each idea by alternately selecting the most important idea followed by the least important idea until all the ideas were ranked. This voting and ranking process captures individual and collective preferences and ensures anonymity of individual votes. The facilitators tabulated the voting results by recording each vote on the flip chart above the corresponding idea, the group total for each idea, and the total number of individual votes. The facilitators and the team analyzed the scoring results, identified the ideas with the highest numbers and largest numbers of votes, and then compared the results to the task statement.

The team discussed in detail the items selected and prioritized by this NGT process, and the facilitators monitored

and recorded the discussions. Team members were able to select appropriate approaches to address key issues by focusing on these specific items, and Geotech personnel were then able to develop position papers summarizing the chosen methods for resolving issues and the resultant direction for environmental restoration. These position papers received concurrence from regulatory agencies primarily because regulatory agency representatives participated as part of the NGT team. Furthermore, these early decisions resulted in more clearly defined investigative studies and efficient systematic design development. Geotech personnel estimate that use of the NGT and position-paper process reduced the schedule for these activities by at least 6 months.

Conclusions

The NGT process is an excellent tool to develop consensus regarding priorities of focus for complex environmental restoration projects. The process ensures that more aggressive or vocal participants do not drive others involved in decision-making to inappropriate conclusions. Specific follow-on activities and actions can be determined on the basis of results of the NGT process.

VALUE ENGINEERING

Overview

Value Engineering (VE) is an organized interdisciplinary team approach using a facilitated problem-solving/decision-making technique. This technique uses a structured process called the job plan and incorporates function analysis as a means to identify the functions of the subject under study (4,5,6,7). The basic steps of the Value Engineering Job Plan are

1. Preparation planning phase.
2. Information-gathering phase.
3. Brainstorming.
4. Evaluation phase.
5. Planning/presentation phase.
6. Implementation phase.

While the DOE has used VE to evaluate designs or production processes, Geotech applies VE to various aspects of environmental restoration. The VE process can assist in identifying the functions of a specific environmental restoration program and in determining the most effective means to accomplish those functions. Representatives of DOE and regulatory agencies (e.g., the EPA and state officials), as well as technical experts representing the specialized disciplines required in the environmental restoration process, served as team members. The teams developed sound, innovative decisions that addressed key issues and identified efficient and effective actions to accomplish environmental restoration.

Examples of VE studies conducted by Geotech include

- Investigation and evaluation of methods to address commingled waste discovered during remedial action on properties included in the Uranium Mill Tailings Remedial Action (UMTRA) Project. This study resulted in the development of position papers with the State of Colorado, avoidance of schedule delays, and development of a cooperative immediate response process.
- Investigation and evaluation of the Monticello Vicinity Properties (MVP) Project inclusion identification and remediation process. This study resulted in a more streamlined inclusion process that allowed the DOE to meet an increased scope of work and a $1.2 million savings.
- Identification and recommendation of design and construction elements required for the Monticello Remedial Action Project 30 percent design stage to expedite regulatory approval. This study resulted in an estimated 6-month schedule reduction and regulatory acceptance of selected design approaches.
- Investigation and evaluation of processes to decontaminate radioactively contaminated surface materials. This study resulted in better utilization of limited repository space and an estimated $0.3 million savings.

Process

When a particular problem or issue was identified, the Geotech facilitators worked with executive management to ensure that VE was the most suitable technique to address the problem. A clear, well-defined scope statement was developed to identify components of the session, including measurable objectives. The facilitators and executive management selected appropriate team members, including at least one individual with knowledge in an applicable discipline but with little knowledge of the project under study. The nonproject-related participants were assets to the team because they asked the "why?" questions that members more intimately involved in the project might overlook. The facilitators selected a suitable time, location, and agenda for each VE session and scheduled a team briefing approximately 2 weeks before the session.

During the team briefing, the facilitators and team members became acquainted with each other. The facilitators presented the team with a brief overview of the VE process, including a discussion of team logistics such as dates, times, location, and type of dress for the sessions. Review and discussion of the scope of the study were carefully facilitated to ensure team buy-in to the objectives of the session. The facilitators questioned the team members to ensure understanding of the scope, objectives, and areas in which they could and could not focus their efforts. Team member roles were explained so that all members understood their involvement with the VE study, and the facilitators emphasized that all team members were equal participants in the study regardless of their positions or work responsibilities. Materials and information needed for the study were identified to allow collection by team members.

At the beginning of the VE session, informative background presentations were made by team members, followed by a facilitated discussion of selected key word topics. This step, the *information-gathering phase* of VE, established the necessary common level of understanding among team members regarding the status of the project to date.

Function analysis, often considered the heart of VE, was completed to identify the various functions of the problem under study. A Function Analysis System Technique (FAST) diagram prepared by the team showed the specific relationship of all functions, tested the validity of the functions under

study, and deepened the team's understanding of the problem to be solved. The team then selected the functions that were most key to the scope of the study and the areas in which positive changes could be made or solutions found. The functions chosen by the team were used as the focus for brainstorming, the creative step of the process.

The *brainstorming* step afforded team members the opportunity to identify better solutions through the generation of a large quantity of ideas, many of which were innovative and of high-quality. All team members were encouraged to participate, and the facilitators ensured that no criticism, judgment, or evaluation of ideas occurred during this activity. In most cases, the team generated more than 100 ideas per function. The facilitators recorded all ideas as presented by the team members.

After all functions were brainstormed and ideas were recorded, the team evaluated the ideas. The *evaluation phase* of VE ensures that a team does not reject ideas simply because they are new. Team members used individual judgment and selected criteria to evaluate ideas by eliminating nonsense, grouping similar ideas, and developing and refining the remaining ideas until the best ideas could be selected.

The team discussed the remaining ideas and recommendations, as well as the approvals necessary to implement the ideas. Team members determined the best way to validate the promising concepts, identified follow-on action items, and developed suitable implementation plans.

As part of the *planning/presentation phase*, the team presented its findings to DOE and Geotech management. Following this presentation, the team with the assistance of the facilitators prepared a written executive summary of the VE study findings. The sponsoring managers, executive management, and team members worked together to ensure implementation of the recommendations.

Conclusions

The VE process allows regulators and technical experts to develop a common level of understanding regarding the scope required to accomplish specific environmental restoration projects or specific aspects of the projects. This interdisciplinary (and interagency) approach results in early identification of activities that should be completed, proper sequencing of environmental restoration activities, and efficient and innovative selection of methods to accomplish these activities. The VE process also ensures early "buy-in" by all participants, including regulators, which helps reduce the number of lengthy written or verbal discussions between various experts and agencies required to reach critical decisions.

BENEFITS

Geotech uses these facilitated techniques to efficiently and effectively plan and manage numerous environmental restoration projects. SDIC Mission Statement Development ensures a strong focus for initial project or program planning and identification of activities that must be accomplished throughout remedial action. The NGT process is a powerful tool that can be used to elicit decisions and establish priorities for complex situations that involve individuals with diverse opinions. The flexibility and power of VE allows for the study of broad or specific aspects of environmental restoration and can result in the development of innovative and effective solutions to problems. All these facilitating techniques can be successfully applied throughout the DOE to more expeditiously achieve the complex mission of environmental restoration. They are innovative and proven problem-solving techniques that will serve as effective tools for any environmental restoration program manager.

ACKNOWLEDGEMENT

Work supported by the U.S. Department of Energy Office of Environmental Restoration and Waste Management at the Grand Junction Projects Office under DOE Contract No. DE-AC07-86ID12584.

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LIFE CYCLE PLANNING TO FORECAST BUDGET REQUIREMENTS AND MAINTAIN EFFECTIVE COST CONTROLS

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ABSTRACT

Projecting budget requirements for performing environmental restoration activities in a manner consistent with the regulatory agencies requires long-term planning, scheduling, and budget forecasting. The Westinghouse Idaho Nuclear Company, Inc. (WINCO) Environmental Restoration Program is responsible for 14 operable units (OUs) at the Idaho Chemical Processing Plant (ICPP) located within the Idaho National Engineering Laboratory (INEL). To facilitate response to U.S. Department of Energy (DOE) requirements, a baseline document has been established, and activities for each of the 83 environmental release sites in the OUs have been developed.

The baseline document is based primarily on the activities identified in the Federal Facility Agreement and Consent Order [commonly referred to as the Interagency Agreement (IAG)] for operable unit scoping and investigation. In addition, the schedule for some sites reflects fiscal year 1991 Consent Order Compliance Agreement requirements. Planning has been conducted through completion of the Record of Decision (ROD).

The baseline document provides management with a defensible basis to project and control costs. Work that requires modification in scope, changes to applicable DOE or regulatory orders/guidance, or identification of additional release sites will normally impact costs and schedule. The impact of these changes will be evaluated and the baseline revised to reflect the changes. Management can use the baseline to evaluate potential cost impacts and assist with decision making when resources are limited to select the optimal technical strategy and minimize the impact to cost and schedule for other projects.

INTRODUCTION

The object of this paper is to describe why the uniqueness of environmental restoration projects does not lend itself easily to the standard cost/schedule control activities of construction projects and how proper life cycle planning is important to forecast budget requirements and maintain effective cost controls.

UNIQUENESS OF ENVIRONMENTAL RESTORATION PROJECTS

Applying U.S. Department of Energy (DOE) Orders 4700.1, "Project Management System" (1); 2250.1C, "Cost and Schedule Control Systems Criteria" (2); and 1332.1A, "Uniform Reporting System" (3) to environmental restoration projects has its challenges because the end result of the project does not produce a tangible product, but provides a clean environment and the documentation to prove it. The goal of the stated DOE orders is to provide standard sound management principles to assure that the scope of work is properly defined and planned, that management has the proper tools to effectively manage the work, and that DOE has a basis for evaluation of performance and project management.

Consistent with DOE requirements is a project baseline in which the scope, schedule, and cost bases are established. In developing the project baseline, the anomalies of environmental restoration projects become apparent.

Definition of scope of work assumes that the respective task or cost account manager knows what the end result is. With environmental restoration projects, the definition of work is based largely on assumptions because the source, type, and volume of contaminants to the environment or risk to human health is not always known. These assumptions are necessary to arrive at a determination of the final action to be taken (no action, interim action, final remedy selection) and, therefore, completion of the scope of work development.

Determining the longest path through the project schedule (the critical path) cannot be achieved because the project is made up of many individual environmental release sites that have individual, unrelated schedules. The only common tie among them is a single end date when all characterization work is completed prior to determining the final remedy selection.

Standard cost estimating practices do not apply to environmental restoration projects, and little cost history is available to develop cost estimates. To make the estimating process more difficult, cost history that is available from the private sector may not be applicable due to the different nature of the environmental concerns, less strict security, and different regulations.

Cost data from sites within the DOE complex may not be applicable due to differing geography, topography, operating versus nonoperating facilities, political climate, public relations, and proximity to populated areas. All of these factors combined with differing labor costs and labor laws affect the cost of characterization and remediation.

APPLYING THE BASELINE PHILOSOPHY

A project baseline serves as the basis for evaluating project performance, identifying changes to scope of work, and identifying if work costs more or less than projected. It is also a very valuable planning tool. Developing the baseline means identifying the life cycle of the project (the start and completion dates must have a basis) and defining and planning the work to complete the life cycle of the project.

Because of the unknowns and the assumptions made, the proper documentation must exist so that when more knowns become available, the proper changes to scope, cost, and schedule can be made. This process of developing the baseline information is necessary for all projects, but is handled slightly differently in the environmental world.

With any baseline, there should be a one-for-one relationship among the baseline components. Development of the environmental restoration project scope of work begins with evaluation of the existing data on environmental release sites, regulatory requirements, and contractual agreements with regulatory agencies. To compensate for the lack of up-front project definition, a "four-component" baseline is established. Instead of the standard three-component approach to developing a baseline using scope of work, schedule, and budget, a fourth component is added. This fourth component, the technical baseline, consists of all of the knowns about each environmental release site (or selected planning unit): area, contaminants, existing drilling and sampling data, etc. A controlled database consisting of this information together with a controlled drawing of environmental release site area boundaries is a useful technical baseline. This information acts as the "keystone" to developing the scope of work, schedules, and cost information.

While the one-for-one relationship must exist between the scope, schedule, and cost baselines, the technical baseline serves as a basis for the development of the other three components and, therefore, does not need to meet this criteria.

The scope of work should consist of all of the work elements required to take the project from start to finish. In detailing the scope of work element, the work should be broken into manageable pieces, such as developing a sampling analysis plan or drilling and sampling. The baseline schedules are developed from this information. It is important to determine if an end product will result from the scope of work as an end product such as a report or letter is important in assessing performance of the scope of work.

The schedule to complete the scope of work is based on the project manager's estimate of the time it will take to complete the task based on the available resources. Regulatory requirements may also drive the schedules. If resources are limited, realiocation of resources, assessment of priorities, and/or use of alternate resources can allow for completion of the activities consistent with regulatory requirements or other drivers.

Simultaneous with the development of the schedules is the development of the cost information. While estimating the number of labor hours may not seem like a surmountable task, the number of boreholes, wells, samples, cubic feet of soil to be excavated, etc., and the associated costs are difficult to identify at this early stage of the project. Making documented assumptions during the development is crucial to a useful baseline.

MAINTAINING EFFECTIVE COST CONTROLS

While the foundation for maintaining effective cost controls is set when the baseline is established, the only way to effectively control the costs is to 1) measure performance against the baseline, 2) provide/request detailed cost estimates when requesting work from others, and 3) monitor commitments against the baseline.

Measuring performance against the baseline produces variances that will allow identification of future costs that may be incurred. This comparison will allow for the analysis of whether the work being performed costs more than anticipated, and will raise the question of whether work outside the scope of the baseline is being performed. The answer to these questions should provide the explanation for the variances as well as help the task or cost account manager plan for the future.

Key to maintaining cost control is the development of cost estimates for all work to be performed by others. While the baseline is the cost estimate for the task manager, detailed cost estimates should be agreed upon by the requestor and provider of work. This again provides a basis for performance measurement and identification of where a variance to the baseline might occur.

All commitments should be evaluated against the baseline to determine if they are within the scope of the baseline. Any commitments outside of the scope of work should be scrutinized and identified for a change to the baseline documents if they are approved.

WINCO ENVIRONMENTAL RESTORATION PROJECT

At the Idaho Chemical Processing Plant (ICPP) operated by Westinghouse Idaho Nuclear Company, Inc. (WINCO), there are 83 environmental release sites. The release sites at the ICPP make up Waste Area Group (WAG) 3 of the sites at the Idaho Engineering Laboratory (INEL), which is located approximately 50 miles west of Idaho Falls, Idaho.

The 83 release sites are grouped into 14 operable units (OUs) based on contaminant or geographical location:

0) No Action
1) PCB
2) Chemicals
3) Percolation Ponds
4) Asbestos
5) Old Sewage Treatment Plant
6) Land Disposal Units (LDUs)
7) Tank Farm Area I
8) Tank Farm Area II
9) CPP-603 Area
10) Chemicals I
11) Chemicals II
12) New Units
13) Remedial Investigation/Feasibility Study.

The Federal Facility Agreement and Consent Order (4) [commonly referred to as the Interagency Agreement (IAG)] is a legally binding document between the DOE, the State of Idaho, and the U.S. Environmental Protection Agency (EPA), and outlines the minimum requirements for completion of characterization, remedial investigation/feasibility studies, record of decision (ROD), and remediation activities at the OU level for all of the 10 WAGs at the INEL. Based on the IAG, a life cycle plan encompassing the ROD date was used to develop the WAG 3 project baseline.

The baseline was developed at the release site level for ease of determining final costs for those sites at a later date, and also for the ease of moving the baseline information for each site to another OU if necessary. The work breakdown

structure (WBS) and the cost coding structure were set up so that costs and schedule information could be generated at the OU level if necessary.

The development of the cost estimates for the baseline were achieved by using two independent cost estimates. After the first estimate was developed, the second estimate was achieved by using the same technical information and assumptions (number of wells, number of samples, etc.) that were used for the first estimate. The second independent estimate was within 12 percent of the first estimate, and the two estimates were reconciled to achieve the final cost estimate basis for the project baseline.

SUMMARY

Little history exists on the scope, cost, and duration for completion of environmental restoration activities. Each site may differ significantly from others due to topography, political climate, or public relations.

Effective planning and control of environmental restoration projects rests on the bottoms-up development of the project baseline with emphasis on documenting assumptions used in planning and cost estimating. While these assumptions may not hold true, they are a basis for making changes and evaluating the effects of the changes to the other baseline components. Constant evaluation of performance, cost estimates, and commitments against the baseline will provide effective cost control and identification of problems and will be useful in future planning.

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TREATMENT OF Y-12 PLANT MIXED WASTE CONTAMINATED SOILS UTILIZING THE WESTINGHOUSE SOIL WASHING PROCESS

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ABSTRACT

A soil washing demonstration was successfully conducted for the U.S. Department of Energy to demonstrate a physical segregation and chemical extraction soil washing approach for decontaminating soils from the Oak Ridge Y-12 plant.* Uranium and PCBs were removed from an oil landfarm material containing high levels of oil and grease. Excessive levels of uranium, mercury, and PCBs were also removed from a sewer sediment material. Physical segregation and chemical extraction techniques reduced the uranium content of both soils making them non-radioactive. In addition, both soils successfully met the PCB requirement and passed the TCLP test, showing the materials to be no longer hazardous. The sewer sediment mercury level was reduced by over 90%, but was still above the desired level. Additional washing may achieve that level. All of the oil landfarm and at least 85% of the sewer sediment are recovered as non-radioactive and non-hazardous materials.

INTRODUCTION

This study was conducted for Martin Marietta Energy Systems, Inc. under contract to the U. S. Department of Energy to demonstrate technologies for treating two contaminated soils from the DOE's Y-12 Plant located in Oak Ridge, Tennessee. The two soils tested in this study were a contaminated sewer sediment, which contained excessive levels of mercury, uranium, and PCBs, and an oil landfarm soil which was contaminated with heavy metals, uranium, and PCBs. The goal of the treatment study was to remove the chemical and radiological contaminants sufficiently to allow a majority of the soil to be disposed of in an industrial landfill. The soil criteria that had to be met to successfully achieve that goal is summarized in Table I.

TABLE I

Criteria for Acceptable Treated Waste Composition

Mercury	< 12 ppm
PCBs	< 2 ppm
Metals and Organics	The treated soil must pass the EPA's Toxicity Characteristics Leachate Procedure (TCLP) test
Liquid	Must pass paint filter test

The soil decontamination technology evaluated in this study utilizes both chemical extraction and physical segregation techniques. This approach has been successfully demonstrated on copper, uranium, and PCB contaminated soils, and on lead, cadmium, and zinc contaminated ashes. The testing conducted in this study included soil and contaminant characterization tests and extractant optimization tests.

SOIL AND CONTAMINANT CHARACTERIZATION

An essential first step in the remediation process is to determine the feasibility of washing a particular soil by generating selected soil and contaminant characterization data. This may include contaminant speciation, chemical and physical soil characteristics, and contaminant distribution. Based on these data, an evaluation can be made as to whether or not soil washing is a viable approach. Additional laboratory tests can then be conducted to determine the optimum chemical extraction and physical segregation conditions.

Visual inspection of the oil landfarm material showed it to be, as expected, oily with significant fines, which results in this soil being difficult to handle and process. The sewer sediment was a granular material with significant pebbles and little fines, which indicated that it should be relatively easy to handle. While no speciation data was available on the contaminants, discussions with the contractor indicated that based on their visual observations, the mercury in the sewer sediment is present as a metal (i.e., beads of mercury). On this basis, it was assumed that this contaminant could be removed by density separation. However, no mercury was visible in the actual soil received. The absence of mercury beads thus required a more detailed examination of this soil to determine how the mercury was in fact present.

Using an electron scanning microscope with an energy dispersive x-ray detector, the mercury contamination was identified as a crystalline structure, less than 5 micrometers in size, located on the surface of the soil particles. X-ray diffraction (XRD) and electron spectroscopy for chemical analysis (ESCA) were then applied to provide more detailed information on the composition of the mercury compound(s). In addition, argon ion sputtering was combined with the ESCA to generate some depth profiling.

* Managed by Martin Marietta Energy Systems, Inc. for the U.S. Department of Energy under contract DE-AC05-84OR21400.

The data showed that the mercury level was about 1 wt% at the surface, but was absent after sputtering to a depth of 15 angstroms (1×10^{-4} μm) thus indicating that the mercury was located only on the surface. The analysis showed the mercury to be present as crystalline in nature, with probable compounds identified as mercury uranium, mercury aluminum oxide, and potassium mercury iron nitrate. None of these species are readily solubilized, and thus an aggressive extractant will be required to mobilize these compounds.

Other characterization data generated on the soils included contaminant distribution as a function of particle size. In a majority of cases, the smaller particles, due to their greater surface area and activity, contain the highest levels of contamination. Depending on the contaminant distribution, a significant reduction in the contaminant level can be achieved by removing the highly contaminated fine fraction.

The particle size analysis and contaminant distribution as a function of particle size for the sewer sediment is shown in Fig. 1. The data show that over 90 w/o of the soil is greater than 250 micrometers. Uranium and mercury analysis of the dry sieve fractions showed that the levels of contamination increased significantly with decreasing particle size. In fact, by removing the material less than 250 micrometers, which only represents about 7 w/o of the soil, over 50 w/o of the uranium and almost 40 w/o of the mercury are removed from the bulk of the soil. The uranium level is effectively reduced from 124 mg/kg to 63 mg/kg and the mercury is reduced from 842 mg/kg to 552 mg/kg, while recovering over 90 w/o of the soil. Segregation of the minus 250 micrometer fraction will be an effective first step in the soil washing process.

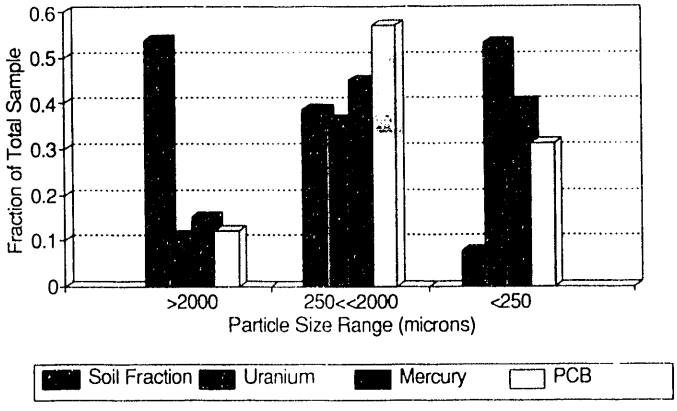


Fig. 1. Sewer sediment soil size and contaminant distribution.

Accurate and meaningful particle size data could not be obtained on the oil landfarm material. During wet or dry sieving, the oil and grease present caused the material to agglomerate, and true particle size analyses were not obtained. This thus confirmed that handling and processing of the material will be difficult. That is, segregation of particular size fractions, and contacting of individual particles with extractant will be difficult.

CHEMICAL EXTRACTION TESTS

A series of laboratory tests were conducted to identify extractants for mobilizing the contaminants from the soils. The initial characterization data had shown that the oil and grease present in the oil landfarm soil would likely prevent the required contacting between the extractant and contaminant. The initial extraction tests thus targeted the use of surfactants to remove the oil and grease, and produce a more viable product for either physical segregation or chemical extraction.

The surfactants used were a mixture of the nonionic, readily biodegradable APG-325, supplied by Henkel Corporation, and the anionic Witconate AOS (alpha olefin sulfonate), supplied by Witco Corporation. Due to analytical problems, the exact amount of oil and grease removal with this mixture could not be determined. However, the soil produced from this extraction was free flowing and no longer agglomerated. Extraction or segregation was now possible. The surfactants were effective at a concentration of 1 g/l each.

A series of extractants were then tested on the surfactant washed soils to determine their ability to remove the contaminants. The results, summarized in Table II, showed that a mixture of sodium hypochlorite, to oxidize and mobilize the contaminants, and sodium carbonate, to complex the uranium, were effective. Using 20 g/l sodium hypochlorite and between 21 and 53 g/l sodium carbonate, the uranium level was reduced by over 20% and the PCB level was reduced by up to 63%. A two-step extraction process was thus identified as the approach for soil washing this soil.

TABLE II

Extraction of Contaminants from Oil Landfarm Soil

	Uranium		PCBs	
Extractant	% Removed	Residual, mg/kg	% Removed	Residual, mg/kg
Surfactants*	3%	112	0	7.5
Surfactants* followed by 30 g/l Acetic Acid	3%	112	0	7.5
Surfactants* followed by 21 g/l Na_2CO_3 & 20 g/l NaOCl	17%	93	63%	2.7
Surfactants* followed by 53 g/l Na_2CO_3 & 20 g/l NaOCl	22%	90	50%	3.7

The initial characterization testing on the sewer sediment soil had shown that fines segregation was an effective means for greatly reducing the contaminant level in the remaining soil. The more highly contaminated, high surface area small particles were thus segregated, and the extraction tests targeted the less contaminated, lower surface area large particles which should be easier to restore. This should lead to a more efficient and effective overall process. In fact, after segregation of the fines, the uranium level in the remaining soil was acceptable (< 30 pCi/g), thus the extraction testing targeted mercury and PCBs.

As shown in Table III, oxidants were required to mobilize crystalline mercury compounds. Sodium hypochlorite was found to be the most effective. At a concentration of 20 g/l, over 80% of the remaining mercury was removed. In addition,

the PCBs, although not likely affected by the NaOCl, were reduced to less than 2 ppm. Fines segregation and aggressive scrubbing with hypochlorite were thus identified as the optimum approach for washing this soil.

TABLE III

Extraction of Contaminants from Sewer Sediment

	Mercury		PCBs	
Extractant	% Removed	Residual, mg/kg	% Removed	Residual mg/kg
38 g/l Citric Acid	1%	121	-	-
12 g/l Acetic Acid	2%	128	-	-
26 g/l NH_4Cl + 20 g/l H_2O_2	70%	395	-	-
18 g/l NaOCl pH ~6	83%	227	39%	2

PILOT-SCALE TESTS

The pilot scale testing examined attrition scrubbing and chemical extraction followed by classification. The attrition scrubber used in the tests was a 2-cell (each 1 ft^3 (0.03 m^3)) rubber lined device supplied by Denver Equipment. This scrubber provides intimate contacting between the extractant and soil and removes surface contamination from particles by causing significant particle-to-particle interaction. The effluent from the attrition scrubber was classified into two size fractions (+250 micrometers and -250 micrometers), and then the extractants were separated from the solids by filtration and rinsing. Approximately 200 kg of each soil were processed.

The pilot scale tests conducted on the sewer sediment are summarized in Table IV. The most effective conditions were two contacts with 20 g/l sodium hypochlorite followed by segregation of the size fraction less than 250 micrometers. The +250 micrometers soil produced, which represented 85 w/o of the initial soil, contained 65 ppm (22 pCi/g) uranium, 100 ppm mercury, and 1.6 ppm PCBs. This soil passed the TCLP test, showing that it was non-hazardous, and the Paint Filter test, showing that it did not contain free liquid.

The pilot scale tests conducted on the oil landform material are summarized in Table V. The most effective conditions consisted of first contacting the soil with the surfactant mixture and then contacting with the sodium hypochlorite and sodium carbonate solution. The soil produced from this process contained about 65 ppm uranium and approximately 1 ppm PCBs. Again, this soil passed the TCLP and the Paint Filter Test.

CONCLUSIONS

The testing conducted on the Oak Ridge Y-12 soils demonstrated that soil washing, utilizing both physical and chemical techniques, is an effective method for decontaminating

TABLE IV

Summary of Pilot Scale Tests on Sewer Sediment

			Contaminant Level, ppm		
Conditions	Product Streams	Wt. Fraction of soil feed	U	Hg	PCB
Attrition Scrub with Water (single 30 minute contact)	a) +250 μm	68%	50	230	-
	b) -250 μm	32%	555	2660	-
	c) Solution	-	<0.1	<0.1	-
Attrition Scrub with Water (30 minute contact followed by 5 minute contact)	a) +250 μm	61%	50	135	-
	b) -250 μm	39%	520	2480	-
	c) Solution	-	<0.1	<0.1	-
Attrition Scrub with 20 g/l NaOCl pH 6 (single 1 minute contact)	a) +250 μm	90%	90	250	-
	b) -250 μm	10%	735	1990	-
	c) Extractant	-	1.4	240	-
Attrition Srub with 20 g/l NaOCl pH 6 (1 minute contact followed by 5 minute contact)	a) +250 μm	85%	65	108	1.6
	b) -250 μm	15%	471	390	-
	c) Extractant #2	-	8	245	-

TABLE V

Summary of Pilot Scale Tests on Oil Landfarm Soil

Conditions	Product Streams	Wt. Fraction of soil feed	Contaminant Level, ppm U	PCB
Attrition Scrub with Water (single 1 minute contact)	a) +250 μm	30%	100	-
	b) -250 μm	70%	100	-
Attrition Scrub with Surfactants (Single 1 minute contact)	a) +250 μm	28%	95	-
	b) -250 μm	72%	112	-
Attrition Scrub with Surfactants (1 minute contact) followed by 5 minute contact with 21 g/l Na_2CO_3 and 20 g/l NaOCl	a) +250 μm	10%	83	1.7
	b) -250 μm	90%	60	0.4
	c) Final Extractant	-	40	-

these materials. For both soils, the acceptability criteria were met in the following areas:

- PCB < 2 ppm
- Radioactivity < 32 pCi/g
- Pass the TCLP
- Pass the Paint Filter Test

The soils produced are thus non-radioactive, non-hazardous as defined by the TCLP, and contain acceptable levels of PCB.

The only acceptability criterion not met was for total mercury level in the sewer sediment. While a 90% reduction in the mercury remaining in the sewer sediment was achieved, the final mercury level was still about 100 ppm, which is above the guideline (< 12 ppm). While exceeding that acceptability criterion, the TCLP data show that the mercury extraction requirement of 0.2 ppm is met. The remaining mercury thus does not represent an environmental hazard. In the event that lower mercury levels are required, the demonstration tests indicated that significant mercury removal was still occurring in the second attrition scrubbing step. Subsequent attrition scrubbing steps can be used to effectively lower the residual mercury level in the soil. In fact to verify this, an additional laboratory extraction scrubbing test was conducted on the soil produced in the demonstration test. The mercury level was reduced to 59 ppm, thus showing that potentially the 12 ppm could be reached with additional contacts.

ACKNOWLEDGEMENTS

This work was conducted for the U. S. Department of Energy, under contract number 43Y-JY307V. The guidance supplied by R. Kimmitt from the Oak Ridge Y-12 Facility, and the program management supplied by J. Pride and J. Harvey from the Westinghouse SEG site are gratefully acknowledged.

SOIL VAPOR EXTRACTION TEST IN A RADIOLOGICALLY CONTAMINATED SITE, HANFORD SITE

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ABSTRACT

A pilot test was conducted at the Hanford site in Washington State using soil vapor extraction technology, to test the vapor extraction technology under Hanford Site conditions, and to provide data for designing a large-scale vapor extraction system that will be used to stabilize an existing vadose zone CCl_4 vapor plume. Testing was performed at the 216-Z-1A tile field where over 5 million liters of water, 245 metric tons of CCl_4, and 58 kilograms of plutonium and americium were disposed in the 1960s. The test objectives were to determine the distribution of CCl_4 beneath the tile field, estimate soil permeabilities, observe trends in CCl_4 concentrations during soil vapor extraction, and determine the behavior of radionuclides during the extraction process. The presence of the radionuclides required the use of a high-efficiency particulate filter mounded in-line with the conventional vapor extraction equipment. Gas and filter samples were collected for laboratory analysis using a gas chromatograph/mass spectrometer. Real-time monitoring was performed using on-line flame-ionization and photo-ionization detectors for CCl_4, and continuous alpha-radiation and beta-radiation air monitors for radionuclides. The test results showed that CCl_4 concentrations generally increased with depth with significant concentrations of CCl_4 detected outside the tile field boundaries; air permeabilities were in the range of a sand; large amounts of CCl_4 were produced (over 365 lbs for the 80 hour test at concentrations up to 900 ppmv); plutonium and americium were not detected during the test or later on any of the test equipment; and unexpectedly high volumes of radon can be produced. The test demonstrated that the soil vapor technology is a viable method for removing CCl_4 at the tile field, with the ability to separate CCl_4 from the plutonium and americium soil contamination.

INTRODUCTION

Westinghouse Hanford Company (Westinghouse Hanford) performed a soil venting characterization study at the 216-Z-1A title field during April 1991 to assess the feasibility of using a soil vapor extraction system (VES) to remove carbon tetrachloride (CCl_4) vapors and other volatile organic compounds from the unsaturated soil beneath the tile field (Fig. 1) in an area radiologically contaminated with plutonium and americium. The study was completed as Task 7 of the Expedited Response Action Project Plan that was drafted by Westinghouse Hanford in response to the joint agreement between the U.S. Environmental Protection Agency, the Washington State Department of Ecology, and the U.S. Department of Energy - Richland Field Office.

The 216-Z-1A Tile Field was selected as the study site for several reasons. First, historical operations resulted in the disposal of about 5,200,000 liters of wastewater containing about 245 metric tons of CCl_4 to the tile field between 1964 and 1969. Consequently, the vadose (unsaturated) zone above the groundwater table is know to contain elevated concentrations of CCl_4 vapors. Second, many test casings already had been installed to about 150 feet below ground at the 216-Z-1A file field. Third, some of the casings were outside the fenced zone at the tile field, which allowed easy access for the venting tests.

In addition to the CCl_4, liquid waste discharged to the 216-Z-1A Tile Field in the 1960s is estimated to have contained 57 kilograms of plutonium and 1 kilogram of americium. The total volume of discharged liquid was about 6.2×10^6 liters. Most of the plutonium and americium was immobilized in fine-grained sediments (generally silt size) within 30 meters of the ground surface.

OBJECTIVES

The objectives of the Task 7 vapor extraction test were to obtain information on the following.

- Approximate vertical and lateral distribution of volatile compounds in soil strata under and near the tile field to confirm whether volatile organic compounds (VOCs) have accumulated in the expected strata.
- Soil permeability and radius of influence in strata that are potentially useful for a full scale VES.
- Trends in concentration, volumes, and types of vapors that are vented under conditions likely to be used in a full scale VES.
- As a safety consideration, measure concentrations of particulate radionuclides that might be entrained into the vented soil gas.
- Provide data for future design and permitting of a full scale VES.

EQUIPMENT

The VES apparatus, which was purchased from a subcontractor, was designed to vent 500 cubic feet per minute of soil gas. The gas was treated using high-efficiency particulate filters and canisters filled with granular activated carbon to remove radiological and organic components, respectively, before the treated air was discharged to the atmosphere.

Continuous in-line monitors were installed to measure the process-stream concentrations (Fig. 2). Instrumentation included flame-ionization detectors and photo-ionization detectors for CCl_4, alpha and beta continuous air monitors for radiation, and a lower explosion limit monitor for methane gas. The data acquisition system was programmed to automatically shut down the venting system if the measured concentrations in the process piping exceeded allowable limits for CCl_4 (5 ppmv at the compliance point), flowrate (> 500 cfm),

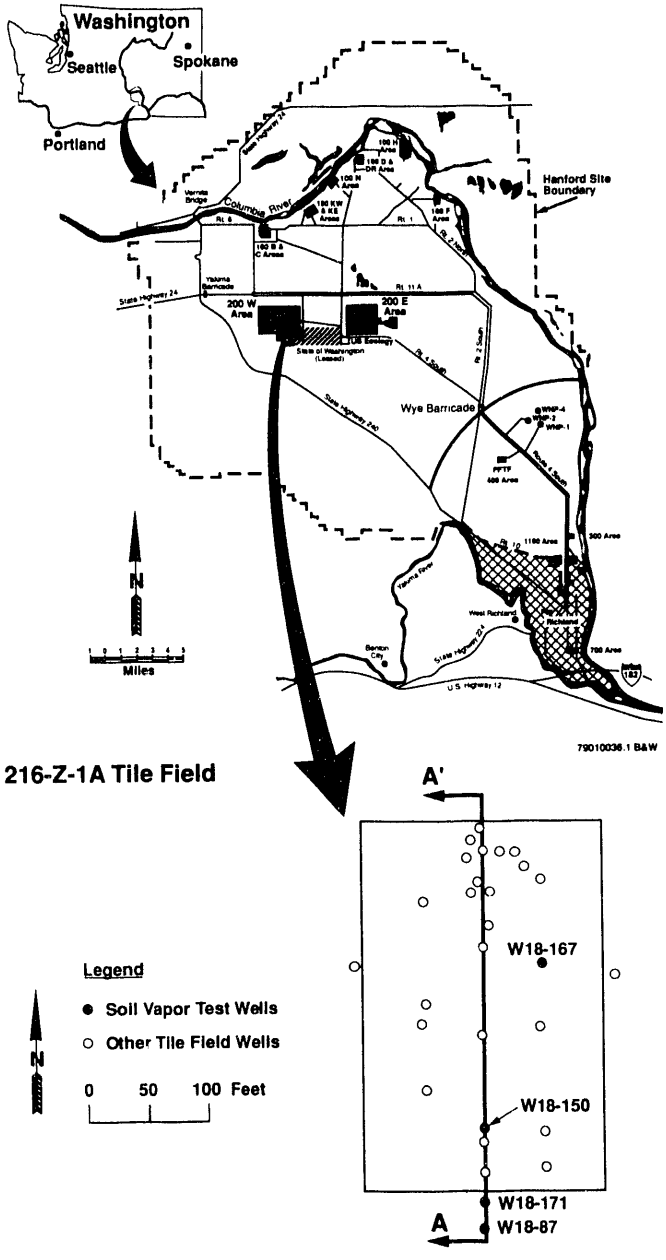


Fig. 1. Location of the 216-Z-1A tile field on the Hanford Site, Washington.

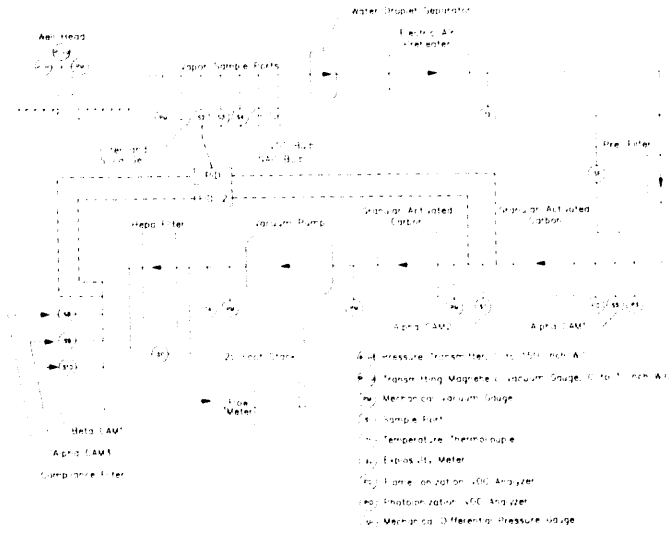


Fig. 2. Schematic diagram of the vapor extraction equipment trailer.

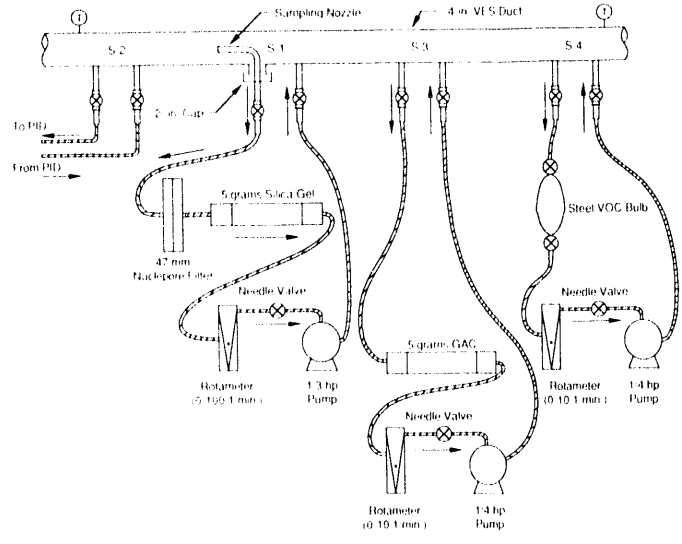


Fig. 3. Vapor Extraction sampling apparatus.

methane (18% of the LEL), alpha radiation (> 30 cpm), and beta radiation (> 4,200 cpm).

The VES apparatus was equipped with sampling ports to allow sampling of the extracted soil vapor (Fig. 3) for chemical analysis by the Westinghouse Hanford laboratory and another offsite laboratory. Sampling was performed for the following items: volatile organic compounds (primarily CCl_4); particulate radionuclides; butyl alcohol and other possible breakdown products of the disposed process chemical waste; and water vapor, which is not toxic but could affect the performance of a full-scale venting system.

WELL FIELD DESIGN

Four existing wells at the 2216-Z-1A Tile Field were used for the study. They were configured in a nearly linear relationship from north to south (Fig. 1). Two of the wells were inside a radiologically contaminated fenced area and penetrated the tile field itself; two wells were located outside the fenced area. The northernmost and southernmost wells were about 250 feet apart, with well spacings of 30 feet, 60 feet, and 210 feet from the extraction well (W18-171).

Based on inspection of historical boring logs, each of the four casings was perforated at strategic vertical intervals to provide access to the soil strata that were considered most likely to have accumulated volatile compounds. The perforated intervals in each well were isolated progressively using straddle packers to allow the different strata under the tile field to be tested.

TEST PHASES AND RESULTS

Phase One: Soil Vapor Characterization

This part of the study was devoted to assessing the lateral and vertical distributions of CCl_4 under the 216-Z-1A Tile Field. 'Puff tests' were conducted by inducing low flowrates

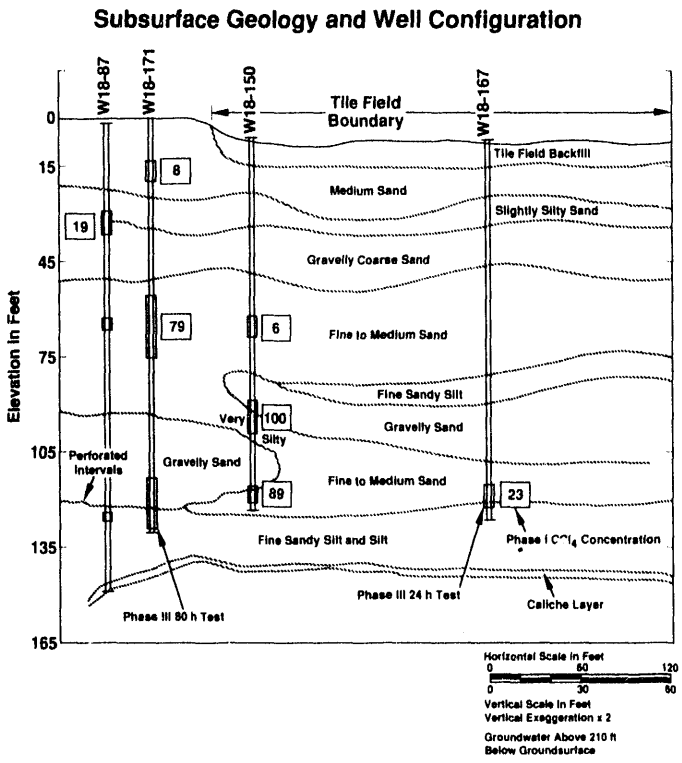


Fig. 4. Measured CCl_4 vapor concentrations from Phase One testing.

of soil gas from a perforated interval and then collecting gas samples (Fig. 4). The Phase One tests showed that the CCl_4 vapor was mainly concentrated in the lower soil zones under the tile field, and that significant CCl_4 vapor concentrations were found in subsurface soils outside the tile field boundary.

Phase Two: Hydraulic Assessment

This part of the study was devoted to assessing the air permeability of the soil within two strata at the edge of the 216-Z-1A Tile Field. The measured permeability of a sandy-soil layer situated about 60 feet below ground surface ranged from about 2 to 6 darcies (2×10^{-8} to 6×10^{-8} cm^2).

The second hydraulic venting test in a fine-sand layer about 120 feet below ground surface did not produce usable data, because the test data was masked by diurnal barometric pressure 'swings'. Permeabilities were estimated using the USGS computer model MODFLOW.

Phase Three: Long-Term Soil Venting

This part of the study involved separate long-term venting tests on two of the wells with perforations in intervals where high CCl_4 concentrations were found during Phase One. The first test was done by venting well W18-167 (about the south-center of the tile field) for 24 hours at about 55 cfm. The CCl_4 vapor concentrations quickly stabilized at about 200 ppmv, and about 7 pounds of CCl_4 were removed during the 24-hour test (Fig. 5).

The second test was performed by venting well W18-171 at the outer edge of the tile field for 80 hours at about 330 cfm. The CCl_4 vapor concentrations increased steadily to about 900 ppmv, indicating that higher concentrations (a 'plume') of CCl_4 were being drawn to the venting well probably from the interior of the tile field as the test proceeded. About 365 pounds of CCl_4 were removed during the 80-hour test (Fig. 6). The radius of influence during venting at well W18-171 was over 70 feet.

During the long-term test, significant quantities of radon gas accumulated in the canisters of granular activated carbon (GAC). Spectral gamma logging of the exterior of the GAC canisters during testing confirmed this phenomenon. Radon is a naturally occurring compound in soil, and it is believed that most of the accumulated radon originated from natural sources. About 3 weeks after the test, gamma radiation from radon daughter products could no longer be detected at the GACs. Plutonium and americium were not detected in the vapor extraction equipment during or after the testing.

SIGNIFICANT FINDINGS AND CONCLUSIONS

Several significant findings acquired from the characterization study will be beneficial for designing CCl_4 cleanup on a large scale.

- The CCl_4 vapor concentrations generally increased with depth below ground surface.
- Significant concentrations of CCl_4 vapors were detected outside the outer limit of the Z-1A tile field.
- Air permeabilities were found to fall in the range expected for a sand.
- A significant amount of CCl_4 was extracted during the test (about 365 pounds at a flow rate of 300 cfm over 80 hours) with the concentrations probably increasing at the end of the testing period.
- The GACs accumulated significant volumes of radon gas from the subsurface. Gamma radiation from the radon daughter products was not detectable about 3 weeks after the test.
- Plutonium and americium were not detected in the test equipment or in any of the samples collected during the test.

In conclusion, the soil vapor extraction technology appears to be a viable method for removing CCl_4 from the vadose zone. The technology is able to separate CCl_4 from plutonium and americium radiological contamination in the subsurface, leaving the radiological elements in situ.

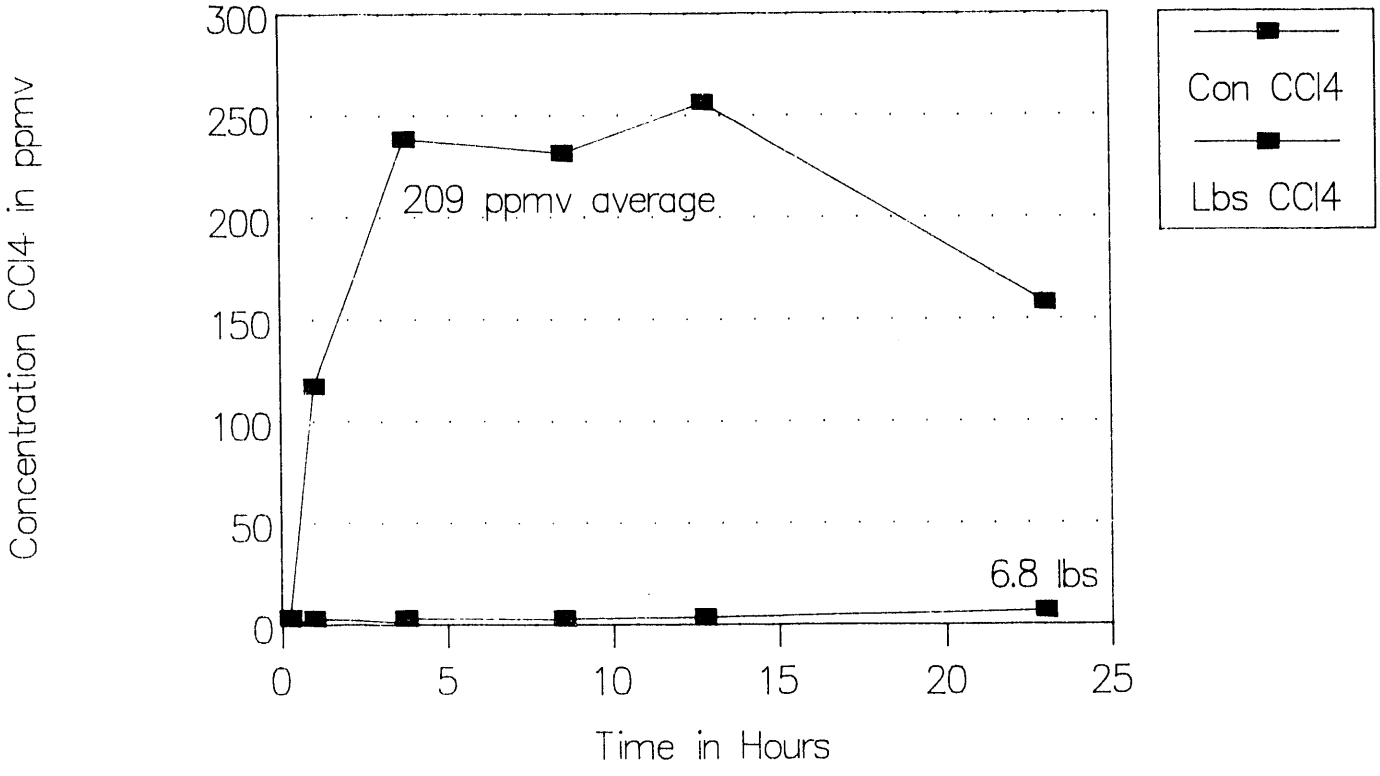


Fig. 5. Estimated CCl_4 concentrations and cumulative CCl_4 removed during the 24 hour test at Well W18-167.

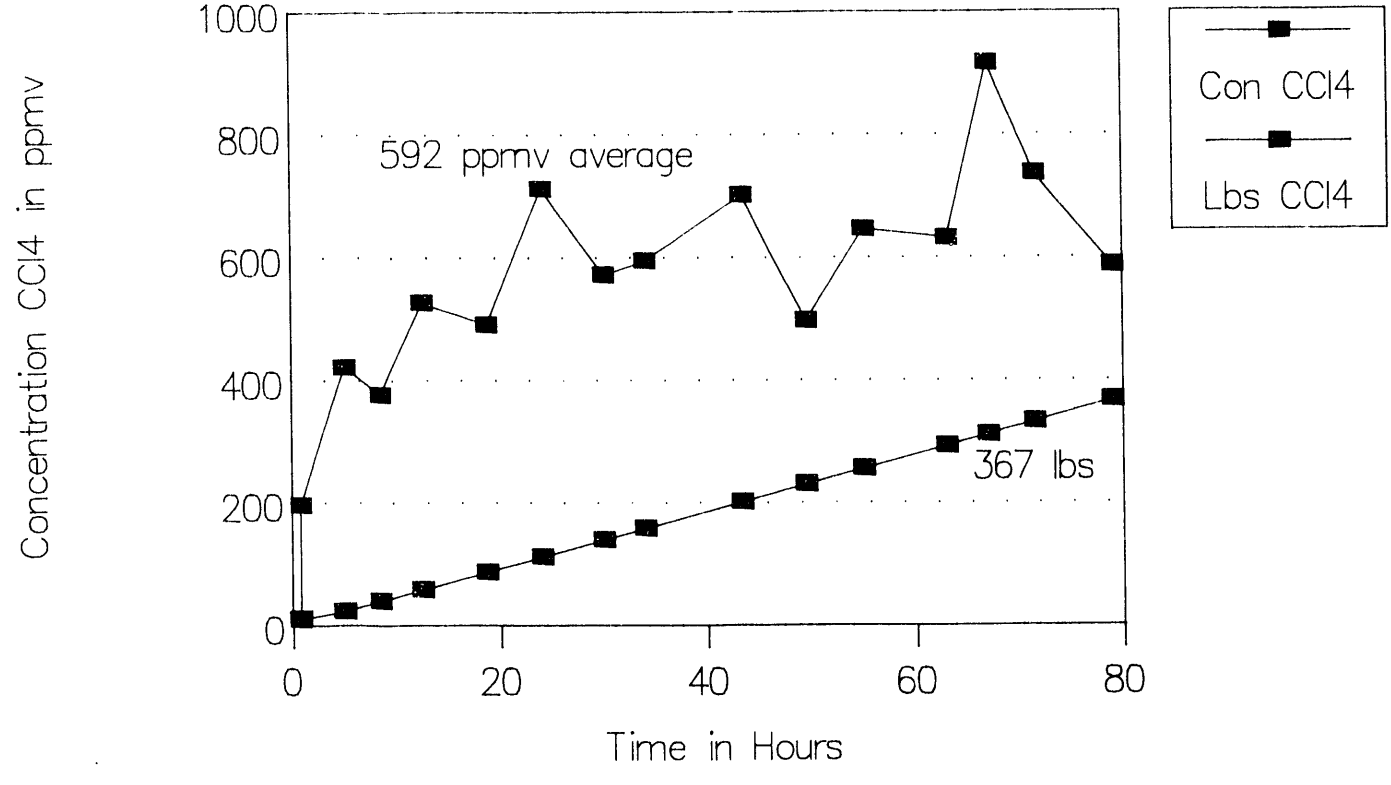


Fig. 6. Estimated CCl_4 concentrations and cumulative CCl_4 removed during the 80 hour test at Well W18-171.

EXPEDITIOUS REMEDIATION OF A LEAKING UNDERGROUND TANK

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ABSTRACT

An inactive leaking diesel fuel tank, at a TV transmitter site in Memphis, Tennessee, was removed just prior to transfer of ownership. The removal of contaminated soil resulted in an excavated to a depth of about 5.5 m (18 ft) by a contractor from Memphis. This excavation partially undermined the building, and furthermore exposed two friction pilings which supported the transmitter building.

Rogers and Associates Engineering (RAE) accepted project management. The excavation was backfilled with gravel to stabilize the site and prevent damage to the foundation of the building. Site characterization, including bore holes and groundwater monitoring wells indicated that essentially all of the remaining contamination was in the area immediately beneath where the tank had been located.

Final mitigation was performed using a 1.5-m (5-ft) diameter caisson auger to excavate the material to a depth of 11 m beneath the surface. A steel casing was driven behind the auger to the full depth to provide site stability and prevent caving. Simultaneous drilling and driving the casing resulted in essentially no mixing of material and removal of the contaminated soil, without impact on the building. Sampling from the excavation and additional groundwater monitoring verified full remediation had been accomplished. The monitoring wells were plugged according to Tennessee requirements and the area of the excavation was capped. This phase of the site characterization and remediation were completed within about one month and the State verified the closure.

INTRODUCTION

An inactive diesel fuel tank at the WHBQ-TV transmitter site in Memphis, Tennessee, was found to be leaking, just prior to transfer of ownership. The tank was removed and contaminated soil excavated to a depth of about 5.5 m (18 ft) by a contractor from Memphis. This excavation partially undermined the building, and furthermore exposed two friction pilings which supported the transmitter building. It had been raining for several days, the hole was filling with water, and the ground surface had become extremely hard to negotiate on, even with a backhoe. On June 29 Rogers and Associates Engineering was requested to provide engineering consultation and support services to assess the stability of the building, stabilize the site, and finish remediation of the site.

The excavation of contaminated material was terminated and on Friday, June 30, the excavation was backfilled to safeguard the building and improve the stability of the site. Heavy rains were scheduled for the next few days, and there was concern that the friction pilings were not stable and the building could be damaged (TV transmitter was on the air). The ground surface became so unstable, due to the heavy rains, that the front end loader could not maneuver safely, and by midday on Saturday, backfilling had to be suspended while there was still a depression. Polyethylene sheeting was placed over the depression and a sump pump was used to prevent additional infiltration of water into the contaminated area.

The unusual and unique difficulties of this project were due to a combination of factors, including:

- The leaking tank was located immediately adjoining the building. The associated excavation for removing the contamination undermined the building and exposed the friction pilings that supported the building.
- The property, in association with the TV studio and the station license, was in the process of closure for a sale when the contamination was discovered. The presence of the contamination delayed the sale and was a possible cause for terminating the sale.
- This phase of the project was started on June 30, the Friday before July 4, which was on Tuesday, for many people and businesses a 4-day weekend. This compounded obtaining support from drilling companies and supply companies.

SITE CHARACTERIZATION

Work was started on July 3, and a temporary road was built using geotextile fabric and crushed rock. After completing backfilling and capping of the excavation, a drill rig from Geotek Engineering of Nashville Tennessee was mobilized to construct bore holes and monitoring wells to assess the extent of the residual contamination. Geotek provided two drill rigs and support of a geologist. The Mark Group of Las Vegas, Nevada, also provided assistance. Site characterization was started on July 4th. Bore holes were drilled in the area of the

* Now with Tetra Tech, Inc.

excavation for the tank, and the area adjacent to where the tank was located. The bore holes were generally drilled and cased to a depth of 7.6 m (25 ft). Nine bore holes, with continuous sampling, were placed in the 6 by 6 meter (20 ft by 20 ft) area of the initial excavation, and 6 bore holes were constructed in the area around the periphery of the initial excavation. Soil samples from the bore holes and samples of the perched water associated with the initial excavation were submitted to laboratories for expedited 24-hour analyses for petroleum hydrocarbons to delineate the area of contamination. The layout of the site is illustrated in Fig. 1, and the site geology is illustrated by the cross section in Fig. 2. After the area of contamination was delineated 8 groundwater monitoring wells were installed. Various combinations of 3 of the wells were used to calculate the groundwater gradient and direction of flow. The various combinations provided compatible information and indicated five of the wells were in the down gradient direction. The gradient was about 0.006 (see Fig. 1).

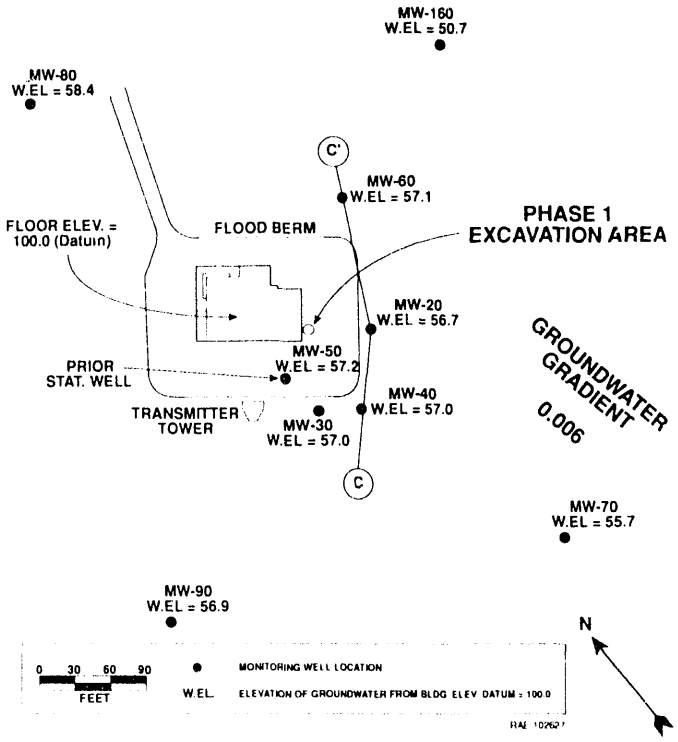


Fig. 1. Monitoring wells.

CHARACTERIZATION OF CONTAMINATION

The analysis of soil samples from bore holes and groundwater from the eight monitoring wells and a station well indicated that the remaining contamination was essentially limited to an area directly below where the tank had been located. This remaining contamination was over 100 parts per million (ppm) of total petroleum hydrocarbons (State of Tennessee limiting criteria) at depths of about 8.5 m. Extensive sampling of the area indicated that essentially the only soil samples containing over 100 ppm of total petroleum hydrocarbons (TPH) were from bore holes which were in the immediate area where the tank had been (see Fig. 1). Concentrations of TPH from these bore holes ranged over 1000 ppm to a depth of 9 m (30 ft). A single sample from the first sampling interval of BH-10, in the southwest area of the initial

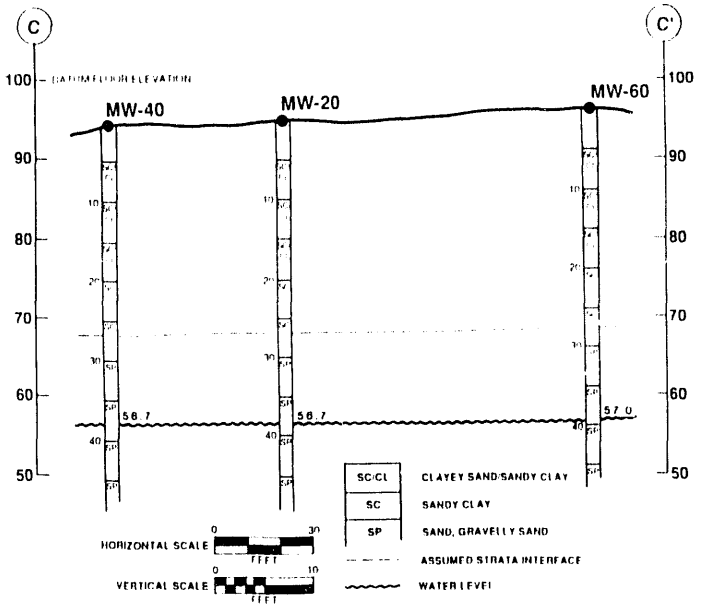


Fig. 2. Site geology.

excavation, indicated 150 ppm. But, four samples at intervals below that sample were less than 10 ppm.

Water samples from all of the monitoring wells indicated essentially no contamination in the groundwater. The only TPH concentrations detected in groundwater were for samples taken from the perched water in the initial excavation. Assessments indicated that this water was not connected with the groundwater aquifer and that it was primarily from infiltration from the recent rain. The available water from the gravel in the excavation was removed using screens in the bore holes and well points made from drilling augers and taken off-site for treatment.

REMEDIATION

The location of the contamination and the structural design of the building prevented the use of normal excavation techniques for final mitigation. After consideration of the area of contamination and alternatives for removal of contamination, final mitigation was performed using a 1.5-meter (5-ft) diameter caisson auger to excavate the material to a depth of 11 m (36 ft) beneath the surface. A steel casing was driven behind the auger to the full depth to provide site stability and prevent caving. The simultaneous drilling and driving of the casing resulted in essentially no mixing of soil and removal of the contaminated soil, without impact on the transmitter building. Sampling from the excavation and additional groundwater monitoring verified full remediation had been accomplished. The casing was removed and the 1.5-meter (5 ft) hole was backfilled partially with bentonite and cement.

The monitoring wells were re-sampled after completion of the remediation of the site. The TPH in samples was below the detectable levels (less than 0.1 ppm) and within state criteria. The monitoring wells and the station well were pressure grouted to the surface. The area that had been remediated was capped with a 0.5 m (20 inch) layer of soil cement to provide stability to the site and minimize infiltration of precipitation. The remediation was completed before the end of July and the State verified the closure.

SUMMARY

A leaking underground fuel tank was discovered just prior to completion of a property transfer. The initial remediation work by a local contractor resulted in partial undermining of the building and exposing friction pilings that supported the building.

The final phases of remediation by RAE included backfilling the initial excavation, construction of bore holes and groundwater monitoring wells to characterize the remaining contamination, and excavation of the contaminated material to a depth of 11 m (36 ft) with a 1.5-m (5 ft) caisson auger drill. Use of the caisson auger and casing the hole immediately behind the auger allowed excavating the contamination without impact on the stability of the adjoining transmitter building. The final phase was completed in about one month. The closure was accepted by the State.

ELECTROKINETIC REMEDIATION OF CONTAMINATED SOILS*

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ABSTRACT

Electrokinetic remediation of contaminated soil has been demonstrated for saturated and unsaturated sand in preliminary experiments using a novel transport visualization technique. Large anionic organic dyes were mixed with a portion of soil and the rate of electromigration of the dye in an imposed electric field was monitored photographically. One of the fastest current-normalized electromigration rates was measured in the driest sand, which contained 7% water by weight. This moisture content is typical of the moisture content in the unsaturated zone of subsurface native soils found in New Mexico.

The characteristics of the electromigration were similar in both the saturated and unsaturated sand. The leading edge of the dye migration front was diffuse while the trailing edge was sharp and concentrated. This and other observed behavior may indicate a concentration effect, where the electromigration rate of dilute dye is greater than that of concentrated dye. The soil left after the trailing edge passed seemed to contain no residual dye in both the saturated and unsaturated cases.

The success of demonstrating electromigration of large molecules in unsaturated soil is encouraging and indicates that it may be feasible to remediate *in situ* anionic heavy metals such as chromate from unsaturated soil with electrokinetic techniques.

INTRODUCTION

Heavy-metal contamination of soil and ground water is a widespread problem in the DOE weapons complex, and for the nation as a whole. For example, some soil at the old chemical waste landfill located at Sandia National Laboratories, is contaminated with chromate ions from past chromic acid disposal. One possible technique for removal of such contaminants directly from soil is the use of electrokinetics. In electrokinetic remediation, electrodes are implanted in the soil, and a direct current is imposed between the electrodes. The application of direct current leads to two effects: ionic species in the soil-water solution will migrate to the oppositely charged electrode (electromigration), and concomitant with this migration, a bulk flow of water is induced toward the cathode (electroosmosis). The combination of these two phenomena leads to a movement of contaminant ions toward one or the other of the electrodes. The direction of contaminant movement will be determined by a number of factors, among which are type and concentration of contaminant, soil type and structure, and interfacial chemistry of the soil-water system. Contaminants arriving at the electrodes may potentially be removed from the ground water by one of several methods, among them electroplating at the electrode, precipitation or co-precipitation at the electrode, pumping of water near the electrode, or complexing with ion-exchange resins. In this paper, we demonstrate the feasibility of moving anionic contaminants in unsaturated soil similar to the soil present at Sandia's chemical waste landfill.

BACKGROUND

A soil particle in contact with water will typically acquire a net excess charge at its surface that produces an electrical potential difference between the solid and aqueous phases (1). Since the overall system must maintain electrical neutrality, the excess surface charge is balanced by an equal and opposite charge in solution. The charge in solution is distributed over a finite distance from the solid surface; this excess charge in solution is the well-known electrical double layer (2).

The presence of the electrical double layer gives rise to some interesting transport phenomena in solid-liquid systems; these phenomena are collectively known as the electrokinetic phenomena. The electrokinetic phenomena pertinent to *in situ* remediation are depicted in Fig. 1 and include electroosmosis (movement of water in response to an electrical field), electrophoresis (movement of a charged particle or colloid in an electrical field), and electromigration (movement of solute ions in the electrical field).

Water transported by electroosmosis exhibits qualitatively different behavior from hydraulically driven flows. Hydraulic flow depends on the soil physical structure, i.e. the smaller the pores the lower the hydraulic conductivity. Electroosmotic flow depends on the electric current and is generally independent of the soil pore structure. When flow is

* This work funded by the Environmental Impact and Restoration Division 7723, and performed at Sandia National Laboratories which is operated for the U. S. Department of Energy under Contract No. DE-AC04-76DP00789

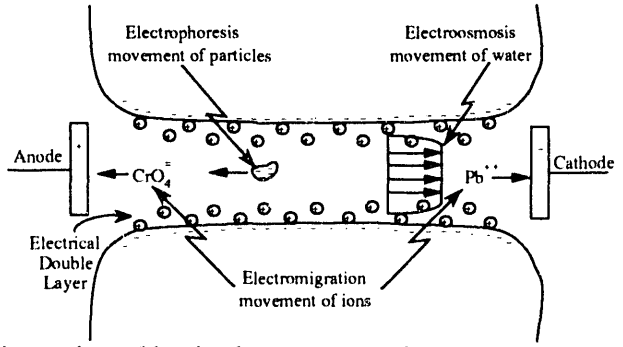


Fig. 1. Electrokinetic phenomena pertinent to *in situ* remediation.

induced electroosmotically in a closed system a hydraulic head develops which causes a flow in the opposite direction. At equilibrium, the hydraulic head difference established is known as the electroosmotic counter pressure (2). In highly permeable soils, only a small counter pressure develops to counteract he electroosmotic flow. In low permeable soils, such as clays, a large counter pressure is required to counteract the electroosmosis. In soil systems with layers of different soil types, more significant electroosmosis is expected in fine soils than in course soil because the counter pressure will produce more return flow in the course soil. Part of the current experimental study is to investigate this effect by examining layered systems of alternating fine and course soils.

Electrokinetic phenomena have been studied for a long time (3). Electrokinetic techniques have been used extensively for the stabilization of soft soils (4,5) and other dewatering operations (6,7,8,9,10). The notion that electrokinetic phenomena may be applicable to hazardous waste remediation appears to stem from the work of Segall *et al.* (11), who found that electrokinetically dewatering dredging sludges generated extracted water, rich in heavy metals. Ironically, Segall *et al.* considered this to be an inhibition to the use of electrokinetics in the field, since it produced a toxic liquid waste that required further treatment.

By the mid-1980's, numerous researchers, apparently simultaneously, realized that separations of heavy metals from soils posed a potential contamination solution rather than a potential contamination problem. Mitchell (12) and Renaud and Probstein (13) described the possibility of removing contaminants by electroosmosis from fine-grained saturated soils. Shapiro *et al.* (14) have described removing small soluble organic contaminants from columns of saturated clays in the laboratory. In similar bench-scale experiments, Acar, *et al.* (15) and Hamed *et al.* (16) describe the removal of heavy metals from clays. In each of these experiments the concept has been to convect contaminants with water using electroosmosis as the separation mechanism. Runnells and Larson (17) demonstrated the removal of cationic copper from sands in a bench-scale experiment, without considering whether electroosmosis or electromigration caused the removal. So far there have been few field demonstrations of electrokinetic remediation. Lageman (18) has described field-scale attempts to remove heavy metals from saturated soils in The Netherlands. A field-scale trial funded by EPA for the removal of chromium contamination from soils has met with partial success, but the success was limited by inadequate site characterization (19).

In this contribution, we extend electrokinetic remediation techniques to unsaturated soil. To date, virtually all electrokinetics research has been done on soil systems at or near saturation. In one recent study (20), the existence of electroosmotic flow in partially saturated clay was demonstrated experimentally. In the Soviet Union (21) and in India (22), electromigration has been used for exploration of some metals in unsaturated soil. It is not unreasonable to expect electrokinetic phenomena to occur in unsaturated soil. As the soil system dewaters, the large pores empty first, followed by the small pores. Provided there is a continuous connection of small pores filled with water, there will still be good electrical conductivity. As long as a reasonable amount of current can be passed through the soil, electrokinetic phenomena will occur and remediation of unsaturated soil may be possible.

EXPERIMENTAL

General

The experiments consisted of transport visualization of dye in sand under both saturated and unsaturated conditions. The plastic test cell used has internal nominal dimensions of 23 cm high, 23 cm wide and 1.9 cm thick (see Fig. 2). In all experiments depicted the anode is on the right hand side of the test cell and the cathode is on the left. The advantage of visualization experiments is that the dye location can be monitored *in situ* by photography and no chemical analysis is required. The camera used was a Nikon 2000 with a 50 mm lens. The camera was placed on a tripod and a timer triggered the shutter at a preset time interval.

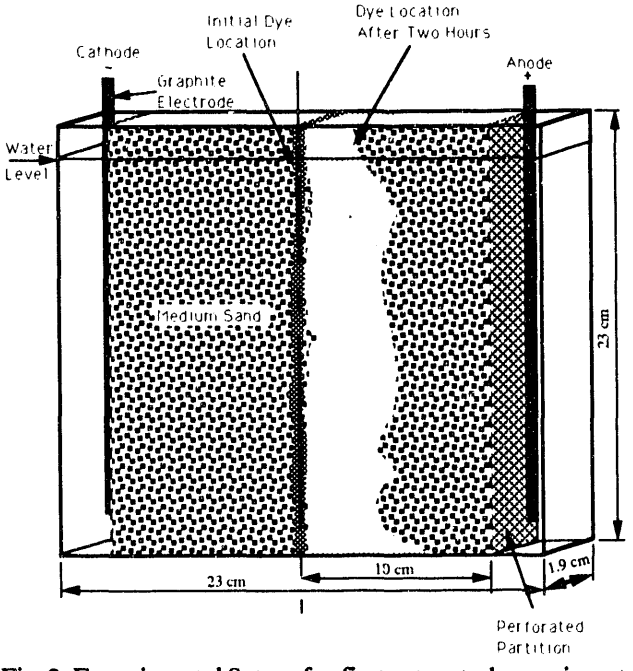


Fig. 2. Experimental Set up for first saturated experiment and dye position initially and after 2 hours of operation at 37 mA.

The dye mixture used was red food coloring which is a mixture of FD&C Red No. 3 and FD&C Red No. 40 in water and propylene glycol. The structures of these large anionic organic dye molecules are shown in Fig. 3. These dyes, like chromate ions, have a low adsorption affinity for soil and a charge of negative two. The identical charge and similar adsorption behavior make the dyes analogs for chromate ions. Depending on the differences in hydrated ionic radii, the dyes may migrate slower or faster than chromate, but the behavior

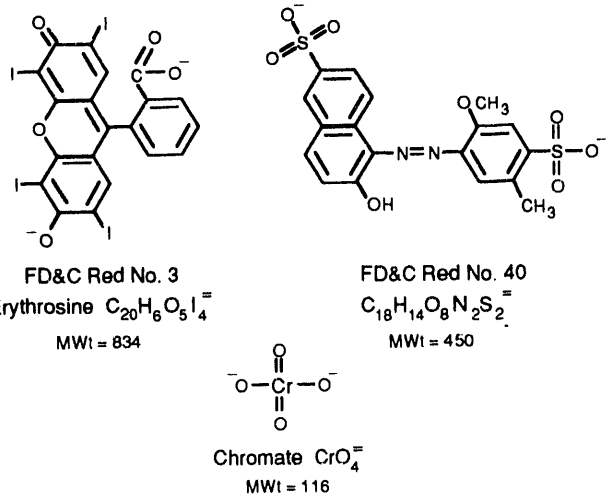


Fig. 3. Chemical structures of the dye ions and chromate ion.

is expected to be qualitatively similar. It is recognized that the use of a dye mixture complicates the interpretation of the results because the two dyes may have different electrokinetic transport properties. In the future, pure dyes and heavy metal ions will be used.

The sand used was obtained near the chemical waste landfill. The soil was dry sieved into 50 to 100 mesh (medium) and 100 to 200 mesh (fine) fractions. The first saturated experiment used the 50 to 100 mesh dry sieved sand. The dry sieved material was then wet sieved with the same size mesh to break up agglomerations and remove fines and the subsequent three saturated and unsaturated experiments used this wet sieved material.

Power was supplied by a Kenwood PD110-5D constant current/constant voltage power supply capable of supplying up to 110 VDC and controlling currents as small as 10 mA. All runs were made under constant current conditions. The electrodes used were 0.64 cm diameter graphite rods.

Saturated Runs

For the saturated experiments, electrode reservoirs were created at each end of the test cell by spacing perforated plates 2.5 cm from each end. For the first saturated experiment, dry medium sand was packed in the space between the perforated plates and tap water was slowly added until the sand was completely saturated. Red food coloring was added to the saturated sand by injecting about 6 ml of the dye in a vertical line along the front center line of the test cell. The experiment was conducted immediately after the dye was injected. This experiment was not recorded photographically; the data presented was collected by tracing the dye location a number of times during the run.

The second experiment was conducted with a layered saturated system. The bottom layer was 7 cm of wet sieved medium sand. The middle layer was 6.4 cm of wet sieved fine sand. The top layer was 8.3 cm of the medium sand. The layered sand bed was slowly saturated with tap water and the dye was injected as in the first experiment. This and the subsequent experiments were recorded photographically.

Unsaturated Runs

Two unsaturated runs were made, one with 10 wt% water and the other with 7 wt %. For both runs, the wet sieved medium sand was first oven dryed and then moistened with the desired mass of tap water. The test cell was packed with a 0.6 cm thick spacer along the center line and no electrode reservoirs. The moist sand was packed on each side of the spacer in about 2 cm high sections. After the cell was packed, the spacer was removed and the resulting void was packed with dye contaminated sand. The moisture content of the dye contaminated soil was matched to the moisture content of the uncontaminated soil. The density of the food coloring was measured to be 1.0 g/cm^3, so it was assumed the food dye was mostly water. Thus, for the 7 wt% moisture run, dryed medium sand was contaminated with 7 wt% dye mixture and likewise for the 10 wt% run. A piece of tape was placed over the top of the test cell to minimize evaporation and bare graphite electrodes, sharpened at one end, were then driven to the bottom of each end of the cell. The 7 wt% run was started immediately after set-up and at the conclusion was destructively sampled at 11 points for moisture content. The moisture sample size ranged from 15 to 20 grams each and the moisture content was determined gravimetrically after drying for 24 hours in a convection oven. The 10 wt% run was started after standing about 17 hours overnight. In that time the dye diffused about 0.5 cm in each direction which indicates that diffusion of the dye under these conditions is a slow process.

RESULTS

Saturated Runs

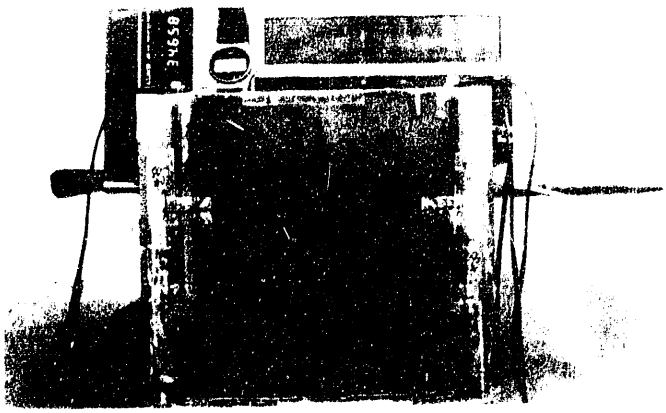
The results of the first saturated experiment are depicted in Fig. 2. This figure shows the test cell setup, the initial dye location and the dye location after two hours of 37 mA current (266 coulombs and 0.85 mA/cm^2). The voltage required dropped from about 100 V initially to about 80 V after 2 hours. The anionic dye migrated about 4 cm toward the anode for a leading edge migration rate of 2.0 cm/hr or 0.015 cm/coul. The leading edge of the migration front was diffuse while the trailing edge was sharp and concentrated. Visual inspection of the soil left after the trailing edge passed seemed to contain no residual dye.

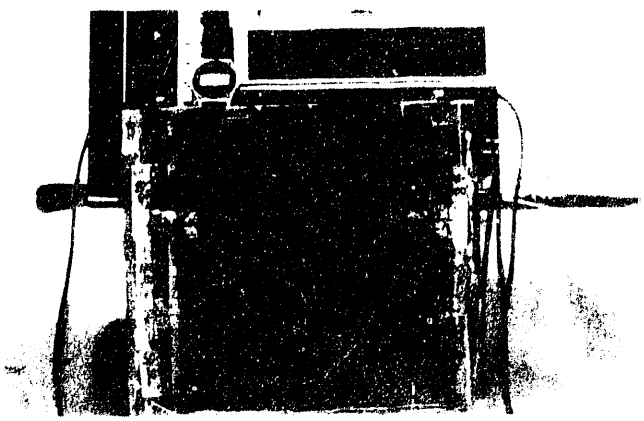
Figure 4 depicts the results of the layered saturated experiment initially, after 2 and 3.75 hours of operation. The experiment was run under constant current conditions at 34.7 mA so 250 coulombs of current were passed through the cell in 2 hours. The voltage dropped from an initial value of 82.0 volts to a low of 69.3 at 1.5 hours and rose to 74.8 after 3.75 hours. All the reasons for the voltage changes in this and subsequent experiments is not yet fully understood.

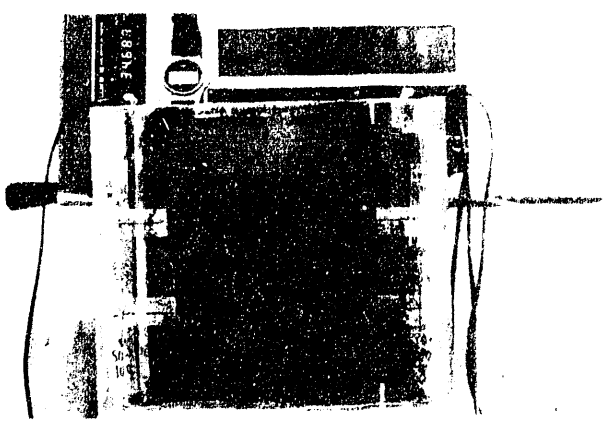
The dye migration was markedly different in the medium and fine sand. In the medium sand the dye migrated toward the anode at a maximum rate of 2.4 cm/hr or 0.019 cm/coul. Like the first saturated run, the leading edge of the migration front appears to be more diffuse and less concentrated than the trailing edge. In the fine sand, the dye migrated in both directions: toward the anode at a maximum rate of 1.9 cm/hr or 0.015 cm/coul and toward the cathode at a maximum rate of 0.44 cm/hr or 0.0035 cm/coul. The leading edge of the dye moving toward the anode was diffuse, while the finger of dye moving toward the cathode was sharp and concentrated.

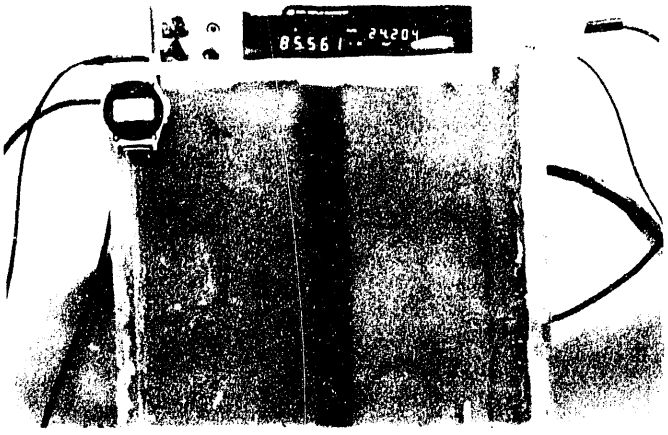
Unsaturated Runs

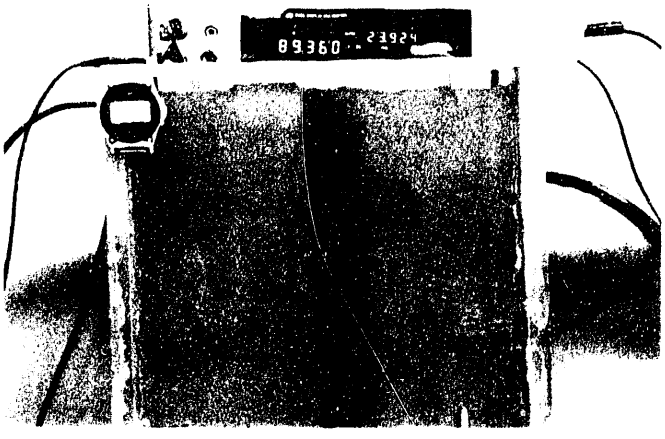
The results of the unsaturated experiment with 10 wt% water are shown in Fig. 5. The three photographs are of the











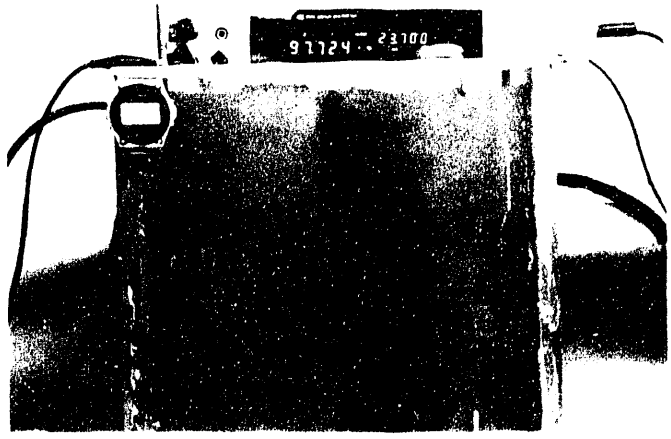
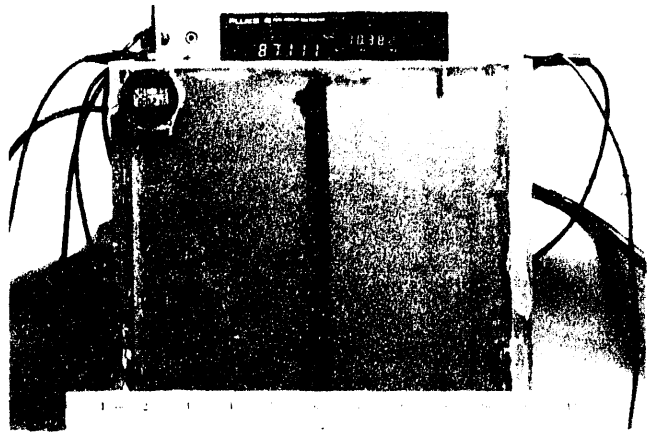
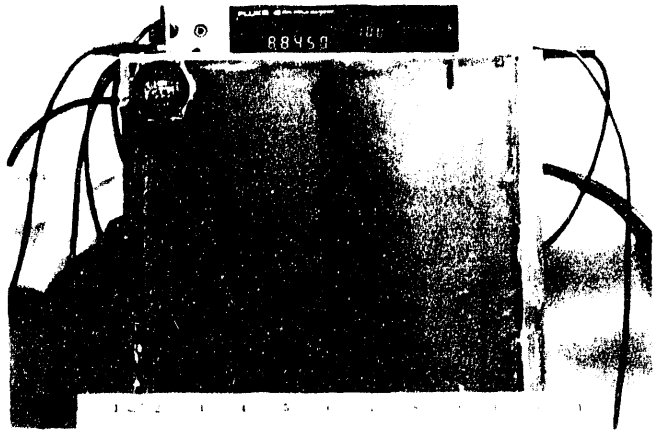


Fig. 5. Unsaturated experiment with 10 wt% water, initially and after 2 and 5.5 hours of operation at 24 mA.





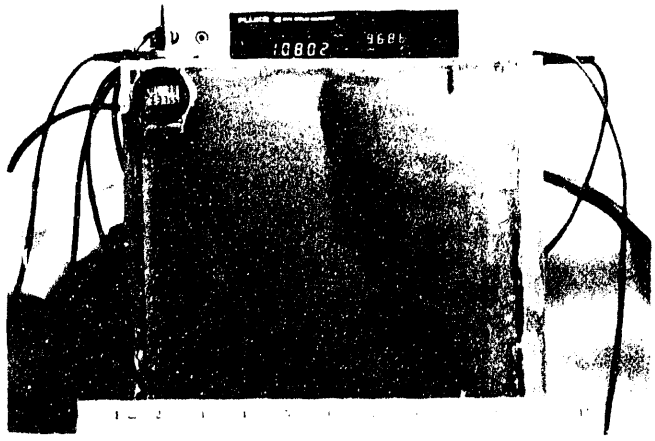


Fig. 6. Unsaturated experiment with 7 wt% water, initially and after 7 and 20.5 hours of operation at 10 mA. (Note that the watch resets to zero after 13 hours.)

toward the anode. This would create a faster moving diffuse leading edge. When dye molecules diffuse away from the concentrated region toward the cathode, they are accelerated back toward the anode and the concentrated region. This would result in a sharp, concentrated trailing edge provided the diffusion velocity is less than the electromigration velocity. In the unsaturated experiment with 10 wt% moisture the diffusion rate appeared to be about an order of magnitude slower than the electromigration rate.

In the layered saturated experiment, the dye in the fine sand layer moved in both directions at the same time. The movement of dye toward the anode was due to electromigration while the movement toward the cathode is believed to be due to the electroosmotic movement of water. The water electroosmotically moved through the fine soil probably re-

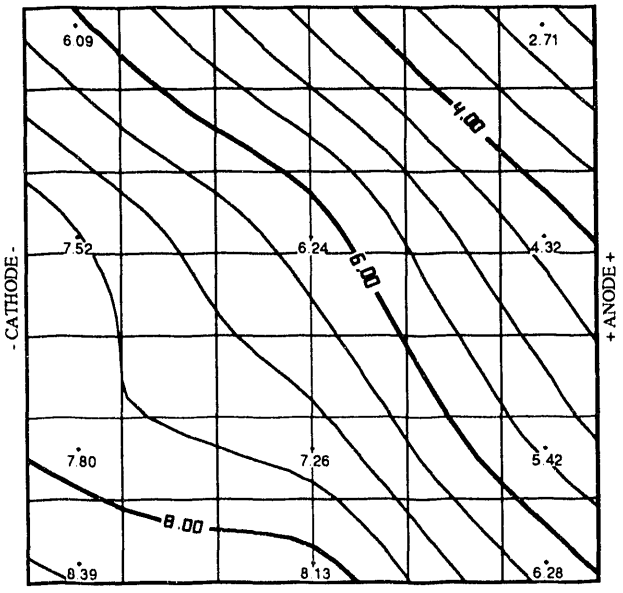


Fig. 7. Moisture distribution of 7 wt% unsaturated run after 20.5 hours of operation at 10 mA. The small crosses represent the sample positions. The number below the cross is the weight percent moisture measured at that position. The contours are constant moisture and were obtained by interpolating the data.

turned through the medium sand, which has a higher hydraulic conductivity. This may have increased the apparent migration rate of the dye in the medium sand and retarded the migration rate in the fine sand, which was observed in the experiment.

The concentration effect on electromigration can explain why the dye in the fine sand moved in both directions at the same time. Note in Fig. 4 the dye that moved in the direction of electroosmosis did so as a sharp concentrated finger. Electroosmosis will move dye toward the cathode if the rate of electroosmosis is greater than the rate of electromigration toward the anode. If the rate of electromigration is low in the most concentrated regions, then any electroosmosis would preferentially move concentrated dye toward the cathode. If this hypothesis is correct, as the dye becomes less concentrated through diffusion and electromigration to the anode, the movement toward the cathode would stop and the dye would eventually migrate back toward the anode. Unfortunately, this experiment was terminated before this effect occurred.

In the unsaturated run with 10 wt% moisture where the dye diffused from its initial position before the current was applied, the dye returned to its original position by electromigration over 8 times faster than the diffusion rate. However, this returning electromigration rate was four times slower than the electromigration rate of the diffuse leading edge in the same experiment. The concentration of the dye migrating back to its original position was clearly higher than the dye concentration at the leading edge.

Finally, the current normalized electromigration rate was greater in the 7 wt% unsaturated run than in the 10 wt% run. Since the dye concentration in the 7 wt% run was 30% less than the 10 wt% run, the comparison of these runs also shows that on a current normalized basis, the rate of electromigration was faster for more dilute dye. Another explanation is possible for this observation. Since the 7 wt% run is less saturated, the cross sectional area of water for current flow is probably less and therefore the current density in the water (on a normalized basis) may have been higher. This would contribute to a higher normalized electromigration rate.

CONCLUSIONS

Electromigration of large anionic organic dyes was demonstrated in both saturated and unsaturated sands. The moisture content of the unsaturated runs was typical of the native subsurface soils present in the arid regions of New Mexico. This indicates that electrokinetic remediation of anionic heavy metals such as chromate may be feasible even in unsaturated soils.

In both the saturated and the unsaturated experiments, the current normalized electromigration rate seemed to be concentration dependent. The more dilute dye migrated at a faster rate than concentrated dye. This resulted in an diffuse leading edge and a sharp, concentrated trailing edge. The soil left after the trailing edge passed appeared to contain no residual dye. This may mean that it is possible to clean soil to low residual levels.

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GROUNDWATER REMEDIATION VIA FOUR CASE STUDIES

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ABSTRACT

A review of some of the pertinent design philosophy for groundwater treatment precedes the principal design features of 4 operating groundwater remediation projects in the American Southwest. Hazardous chemicals for which the groundwater is being treated are chlorinated and nonchlorinated organics and heavy metals. Treatment processes used included air stripping with and without air emission controls, activated carbon adsorption, ion exchange and biological. Flow rates of the units vary from 20 to 5100 gpm. Operating concerns that have occurred during the initial operating periods are discussed.

INTRODUCTION

Groundwater contamination is a modern fact of industrial life and must be correctly remediated, in most cases. Local, state and federal regulations and court actions have provided teeth for parties who want to initiate a clean-up. Past disposal practices of 25+ years ago, which were consistent with the then existing regulations, have resulted in many contaminated groundwater plumes.

The existence and extent of the plume is the result of many site specific variables. Many common industrial chemicals; such as volatile organic compounds (VOC), heavy metals, ketones, alcohols, mixed organics (oils, phthalate, fuels) and nitrates now exist in groundwater plumes due to their widespread use. Past disposal practices such as French drains, evaporation ponds, open pit burning, and direct earth burial have, in retrospect, insured that some contamination reached the groundwater. Once a contaminant has reached the water table surface it must be or remain soluble to a significant degree, must not be adsorbed onto soil particles or undergo exchange reactions with naturally existing cations and must be persistence; i.e., not biodegrade or chemically degrade. For any contaminant to be important it must also be toxic.

Groundwater remediation design is unique in that the water flow is continuous, can be very large and requires attaining a discharge criteria which is typically in the ug/l (or ppb) range and can go into the ng/l (or part per trillion) range. Due to the continuous flow of what can be very large volumes of water, the mass balance across the system becomes very important. The removal of 1 ppm from a 0.38 m^3min (100 gpm) flow amounts to a 0.5 kg (1.2 lbs) on a daily basis. Few systems can stay operating for long if one-half kilogram a day is being deposited somewhere within the system.

POSSIBLE TREATMENT TECHNOLOGIES

A partial listing of treatment technologies is given in Table I. All the technologies could possibly be used for groundwater treatment however their cost, reliability and maintainability vary significantly.

All the physical treatment processes use a phase transfer, i.e., liquid contaminant is transferred into a gas phase or attached to a solid. This phase transfer may cause a volume reduction in the phase the contaminant is now contained in but does not destroy the contaminant. The remaining biological, chemical and thermal treatment processes can totally destroy a contaminant if the conditions are correct.

TABLE I

Processes For Treatment Of Aqueous Wastes

Physical Treatment Processes	Chemical Treatment Processes
1. Air Stripping	1. Chemical Oxidation/ Reduction
2. Steam Stripping	2. Ultraviolet Oxidation
3. Thermal Evaporation/ Distillation	3. Chemical Hydrolysis
4. Vapor Compression	4. Photochemical degradation
Evaporation/Distillation	5. Electron Treatment
5. Ion Exchange	6. Photocatalysis
6. Carbon Adsorption	
7. Ultrafiltration	
8. Reverse Osmosis	
9. Liquid-Liquid Extraction	
Biological Treatment Processes	Thermal Treatment Processes
1. Biodegradation	1. Liquid Injection Incineration
a. aerobic/anaerobic	
b. fixed/suspended	2. Wet Air Oxidation
3. Critical Water Oxidation	

GROUNDWATER TREATMENT PROCESSES EMPLOYED

Not surprisingly the most commonly used groundwater treatment technologies are low cost, reliable and low maintenance. Depending on the contaminants to be removed, other technologies that do not meet these criteria may have to be chosen. The four technologies used in the cases that follow are air stripping, ion exchange, activated carbon and biological.

Air Stripping

Air stripping is a mass transfer process in which volatile contaminants in the water are transferred into what is normally a countercurrent flow of air. Controlling factors for the mass transfer coefficient(s) are water temperature, contaminant solubility, air to water ratio and wetted surface area. This technology is suitable for VOC such as trichloroethylene, chloroform, monochlorobenzene, etc.

Ion Exchange

Ions that are in solution are removed by exchanging (substitution) with another ion that is loosely bound to a solid

medium. These solid mediums are typically synthetic resins. The technology is suitable for removing metal cations, other inorganic cations, organic acids and organic amines.

Carbon Adsorption

This process involves contacting the contaminant carrying stream with activated carbon; which has a very high surface area consisting of micropores (10-1000Å). The activated carbon selectively adsorbs certain contaminants by surface attraction. For water, the stream flows through one or more packed bed reactors that contain granular activated carbon (GAC). This technology is suitable for removing most all organics and certain metals.

Biological Treatment

Biological treatment involves providing as nearly optimal conditions as possible for microbe life and growth within a container. The microbe is encouraged or essentially forced to use the contaminant as either a carbon/food or oxygen source. This technology is suitable for destroying many organics and nitrates.

The following four cases are fairly typical of groundwater remediation systems. These four systems are presented to show what rationale was used to select the technology, basic design criteria and operating concerns.

CASE 1

Case 1 involves a confidential, specialty ceramics manufacturer in the southern San Francisco Bay area that had had a leaking, below grade, chemical sump. This leak had formed a narrow but long plume of VOC contamination. The groundwater is very shallow in this area (approx. 12 feet below ground surface), is in an aquifer material of bay muds of low permeability and is very hard water with a high total dissolved solids.

Grab sampling and hydrological estimates of aquifer characteristics formed the initial design basis as given in Table II. The low water flow rate, only VOC as contaminates, correspondingly low air emissions (which was fairly easily permitable) coupled with low cost but high reliability lead to selection of air stripping as the treatment technology.

TABLE II

CASE 1 Design Basis

	Design	Actual
Flowrate, m^3/min(gpm)	0.11 (30)	0.03 (7)
No. of wells	1	1
Contaminants & Concentration, ppb:		
1,1-dichloroethylene	300	150
1,1-dichloroethane	25	20
trichloroethylene	300	125
1,1,1-trichloroethane	300	140
t-1,2-dichloroethylene	2	22
tetrachloroethylene	0	5
Technology Selected	Air Stripping w/o Air Emission	
Operating Concern:	Scale	

Final design consisted of a single 0.46 m (18 inch) diameter stripping tower with 15 feet of packing, a single well pump providing water transfer to the top of the tower, centrifugal blower, necessary piping and ducting, safety interlocks to prevent discharge of any untreated water and gravity discharge to the sanitary sever. This discharge was later diverted to a storm sewer after the necessary NPDES permit was obtained. No startup problems occurred, other than the lower than design well output, and the discharge was less than detectable for all VOC. The system had sufficient turndown to handle the significantly less than design flow. Projected length of operation by hydrologists was one year.

After 18 months of very low maintenance operation, the discharge started exceeding drinking water standards for VOC of 1 to 5 ppb. The tower was partially disassembled with difficulty and found to have extensive carbonate scale. Many tower components were mechanically cleaned were possible. Approximately a three foot section of the tower was sawed off and disposed since it was essentially sealed with scale. The fiberglass material of the tower simplified the reconstruction. New packing was installed after the tower was reassembled. The operation was restarted without any problems and met the discharge criteria. Periodic mineral acid washes were instituted to remove the buildup of any scale.

CASE 2

An aerospace, government owned contractor operated facility at USAF Plant 44 in Arizona is the site of Case 2. Past disposal practices at the site had included lined solar evaporation ponds and direct wastewater discharge to the soil. A several square mile plume had formed. More sites than USAF Plant 44 had contributed to the plume. Depth to the "shallow" aquifer was 220 feet and 400 feet to the next aquifer. Both aquifers were contaminated. The aquifer material was principally porous sands and gravels containing medium hard water.

Grab sampling and hydrogeological estimates of aquifer characteristics formed the initial design basis as given in the upper section of Table III. The large water flow rate and presence of hexavalent chromium combined with many of the same reasons listed in Case 1, lead to selection of air stripping and ion exchange as the treatment technology.

The final design consisted of three parallel flow process trains. One train was fed by the high chromium concentration wells and was the only one to have ion exchange. The other two trains had only air stripping. The 12 foot diameter, primary air strippers in each train removed approximately 80% of the VOC which was then treated by vapor phase GAC. Steam was used to regenerate (remove the adsorbed VOC) the GAC. Condensed steam and VOC were separated with the VOC being sent for reclamation and the condensed steam slowly bleed back into the air stripper's influent. The secondary 12 foot diameter towers had no air emission controls. This strategy met local and federal air emission regulations. The ion exchange had one vessel regenerating or on standby at all times. The entire plant flow was combined, filtered and pH adjusted to prevent the possibility of aquifer plugging prior to recharge by multiple injection wells.

CASE 3

Case 3 involves an electronics manufacturer in the southern end of the Central Valley in California. Routine wastewater discharges from the facility had been sent to a lagoon. The

TABLE III

CASE 2 Design Basis

Flowrate, m^3/min (gpm)		19.29(5100)
No. of Wells		19
Contaminants & Concentrations	Low Cr	High Cr
Cr	0.13 ppm	<0.05
VOC	960 ppb	225 ppb
VOC Makeup	83% trichloroethylene 14% 1,1-dichloroethylene 3% 1,1,1-trichloroethane	
Ion Exchange (high Cr only)		
Number of Vessels; operating/standby		4/1
Vessel Capacity, M^3(gal.)		8.71(2300)
Air Stripping		
	Primary	Secondary
Number	3	3
Water Flow, m^3/min (gpm)	6.43(1700)	6.43(1700)
Air/Water Ratio	7:1	30:1
Packing Hieght, m (ft)	1.83 (6)	7.92 (26)
Air Emissions Control	Steam Regenerated Carbon	None

lagoon had been closed under RCRA guidance. A several square mile plume had formed and had impacted some of the numerous private wells in the area. The groundwater was in a sandy aquifer material at approximately a 70 foot depth and was quite soft.

Grab sampling and hydrogeological estimates of aquifer characteristics formed the initial design basis as given in Table IV. The large flow rate, low VOC concentrations, simple air emission permitting process, low cost but high reliability of a simple air stripping system lead to selection of it as the treatment technology.

A perimeter system to catch the leading edge of the plume was designed using two separate treatment systems consisting of 10 foot diameter towers with 26 feed of packing. Construction was begun on the wells and connecting pipelines. Long lead equipment was also ordered. Testing of the completed wells revealed that their production rate was only 50% of the projected value. A quick design revision blended the two separate treatment systems into one, as shown in A. Perimeter of Table IV. After construction was completed, startup proceeded smoothly. The increased flow above design capacity was handled by the engineering safety factor incorporated in the design. Both air stripping towers had been rush procured and the second tower was placed in temporary storage.

To decrease the aquifer cleanup time frame, a "source" treatment system was designed and built using four extraction wells close to the original lagoon site. Please see B. Source of Table IV. This system would treat the middle of the plume and use the air stripping tower in storage. Both treatment systems discharged to either stock ponds or irrigation systems. The perimeter system was also permitted to discharge to a nearby river.

The area was rich in manganese containing rocks. Under conditions of low electropotential, groundwater can dissolve

TABLE IV

CASE 3 Design Basis

	Design	Actual
A. Perimeter		
No. of Treatment Facilities	2	1
Flowrate m^3/min(gpm)	6.06(1600)each	6.81(1800)
No. of Wells	6/5	12
Contaminants & Concentrations, ppb:		
1,1-dichloroethylene	320	100
1,1,1-trichloroethane	4500	500
trichloroethylene	6	6
tetrachloroethylene	14	1
toluene	9	1
1,2-dichloropropane	10	1
Freon 113	-	25
B. Source		
No. of Treatment Facilities	1	
Flowrate m^3min (gpm)	3.03(800)	
No. Of wells	4	
Contaminants & Concentrations, ppb:		
1,1-dichloroethylene	120	
1,1-dichloroethane	30	
1,1,1-trichloroethane	670	
Freon 113	180	

significant quantities of manganese (also iron). When this water is aerated the manganese (and iron if present) precipitates from solution. This is known as "red water" on the East Cost. Manganese deposition on the packing was observed after 1.5 years of operation but was not impacting operations. Further deposition of manganese was controlled by the injection of carbon dioxide at several well heads to form carbonic acid and slightly lower the pH.

CASE 4

McClelland Air force Base is located on the north edge of Sacramento, California. Operations on the base had used several disposal pits to receive spent solvents, cleaning solutions, etc., and had also practiced end-of-the-runway cleaning of aircraft. A large contaminated groundwater plume was found which contained a wide variety of chemicals.

Grab sampling and hydrological estimates of the aquifer characteristics formed some of the initial design basis given in Table V. The Air Force also directed there be no air emissions of toxic compounds. Air stripping with fume incineration of the air exhaust followed by liquid phase GAC met the USAF criteria, could effectively remove a wide range of contaminants and was also flexible and reasonable cost effective. Existence of ketones in the groundwater was not detected by the field investigation group until the system design was approximately 60% complete. A biological degradation system to remove the ketones was retrofitted onto the tail end of the treatment system.

TABLE V

CASE 4 Design Basis

	DESIGN	ACTUAL
FLOWRATE, m^3/min(gpm)		
Well Field D	1.14(300)	0.38(100)
Well Field C	0.95(250)	0.57(150)
Total System	3.79(1000)	0.95(250)
NO. OF WELLS		
Well Field D	6	6
Well Field C	4	4
CONCENTRATION, ppb		
Dichloro-ethylenes & ethanes	8,000	5,280
Trichloroethylene	20,000	620
Vinyl Chloride	6,000	210
BTX	2,100	107
Mono & Di-chlorobenzenes	700	225
Ketones	44,000	26,300
Metals	5 to 8,000	5 to 6,000

The final groundwater treatment design was a complex facility using the following equipment:

- influent storage tank for flow equalization,
- 8 foot diameter air stripping tower with 28 feet of packing,
- fume incinerator to destroy organics in the air stripper exhaust,
- air-to-air heat exchanger or economizer,
- caustic scrubber system to remove acids from the incinerator offgas,
- air-to-water heat exchanger to recover heat from the incinerator and increase stripping efficiency by raising the water temperature,
- primary and secondary water-to-water heat exchangers for temperature control,
- six GAC contactors of three parallel sets of two each,
- two fixed film, decay mode (build-up biomass during a recirculation phase, then slowly starve it while processing groundwater) bioreactors in parallel.

Startup was uneventful. The low flow through the system required an internal recycle to maintain hydraulic control and prevent excessive value and pump wear.

Biological growth of bacteria was found to be occurring within the extraction wells, with subsequent transfer throughout the treatment system. Biofouling was noticed within the air stripper and several of the water-to-water heat exchangers. Chlorine injection at the most severely infected wellheads significantly reduced biofouling. Scale build-up on the tower packing was also observed. Periodic mineral acid washes of the air stripping packing were instituted to remove scaling and biofouling. Corrosion of the air-to-air and air-to-water heat exchangers was also found to be occurring. Replacement of the units with specialty alloy units brought corrosion to acceptable levels. During incinerator down times the system could effectively operate on just the GAC contactors and bioreactors.

NEPA/CERCLA INTEGRATION AT ROCKY FLATS

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ABSTRACT

Integration of two laws, the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) and the National Environmental Policy Act (NEPA) was mandated by the U. S. Department of Energy (DOE) with issuance of DOE Order 5400.4 in October 6, 1989. NEPA documentation is required for all federal actions to thereby consider the impacts of such actions prior to the action taking place. On the other hand, CERCLA actions taken by the U. S. Environmental Protection Agency (EPA) at non-federal and federal sites do not normally take NEPA into consideration, although it is not exempted at federal sites. EPA claims that CERCLA is functionally equivalent to NEPA and therefore NEPA is not required. Although EPA maintains the functional equivalency of the two laws and formerly resisted to recognize NEPA even in Inter-Agency Agreements (IAGs), Rocky Flats has been integrating the two laws within documents to avoid duplication of information and effort.

Integration of two laws, the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) and the National Environmental Policy Act (NEPA, was mandated by the Department of Energy with issuance of DOE Order 5400.4 in October 6, 1989). NEPA documentation, be it an Environmental Impact Statement (EIS) or and Environmental Assessment (EA), is required for all federal actions to thereby consider the impacts of the action prior to the action taking place. CERCLA actions taken by the U.S. Environmental Protection Agency (EPA) at non-federal sites do not normally take NEPA into consideration, although it is not exempted at federal sites. According to "NEPA/CERCLA Integration Guidance", issued by DOE on February 7, 1990, DOE representatives who are negotiating Inter-Agency Agreements (IAGs) are to ensure that schedules allow for NEPA/CERCLA integration.

Negotiation of the Rocky Flats IAG was a long and difficult process. Clearly one of the points of contention among the parties of the IAG, the DOE, the EPA and the Colorado Department of Health (CDH), was NEPA/CERCLA integration. It was the intent of EPA-Region 8 not to include NEPA into the agreement based on the interpretation that CERCLA is functionally equivalent to NEPA, an interpretation maintained by EPA in general. However, Rocky Flats had been integrating NEPA/CERCLA since the issuance of the Interim Remedial Action (IRA)/EA for the 903 Pad, Mound and East Trenches Area (OU 2), the second priority cleanup site at the plant.

In late July, the Council of Environmental Quality and the Environmental Protection Agency held a workshop on NEPA/CERCLA integration based on the fact that the EA Administrator had made a commitment, for a two year period, to allow agencies to integrate NEPA and CERCLA if they so desired, and that EPA could not prevent an agency from integrating NEPA and CERCLA. According to the DOE policy, the primary purpose of the NEPA/CERCLA integration is to avoid duplication of information and effort to implement both NEPA and CERCLA separately. From DOE's perspective, NEPA will also bring additional analyses to the CERCLA process, including an analysis of the environmental impacts of the overall environmental remediation program instead of simply an operating unit by operating unit impacts and a better balance between the benefits of environmental cleanup and the environmental cost of cleanup.

The Rocky Flats Plant will use a strategy for NEPA/CERCLA integration that is made up of two elements. The first is the preparation of a Site-Wide Environmental Impact Statement (SWEIS) covering current operations at Rocky Flats, all proposed activities or projects over the next five-to-ten years, including environmental restoration. It was the intent of Rocky Flats to issue an umbrella EIS for the Environmental Restoration (ER) Program, and then tier from the umbrella EIS with specific EAs and/or EISs for each of the specific cleanup actions. Originally, an ER-EIS was going to be prepared, however, with approval of the preparation of a new Site-Wide EIS for operations at Rocky Flats Plant, it has been determined that the Site-Wide EIS will cover both operations as well as ER activities. The SWEIS will identify the impacts and risks associated with all operations. The SWEIS will provide complete as possible NEPA documentation for Operable Unit (OU) 1 and as complete as possible NEPA documentation (as information allows) on the remaining fifteen OUs. The information on all aspects of environmental remediation that is available will be discussed. From this SWEIS, subsequent OU specific NEPA documentation will be tiered. The SWEIS will present the expected "outer-bounds" of any environmental impacts. The process to prepare this EIS has recently begun, with issuance of the Notice of Intent (NOI) on March 13, 1991, and the holding of scoping meetings on April 8 and 11, 1991. It is anticipated that the EIS will be completed by December 1993. All cleanup activities performed before issuance will be treated as interim actions.

The second element is to make NEPA concerns an integral part of the CERCLA process for judging alternative remediation plans at the earliest feasible stage. For those OUs at which an interim action is necessary, CERCLA requires preparation of an Interim Remedial Action Plan (IRAP). The IRAP, in effect, condenses the various documents required for a final action into a single document describing the nature and extent of contamination at a site, analyzing alternative remediation technologies and selecting a technology to implement. CERCLA requires alternative interim measures be analyzed against three criteria, effectiveness, implementability and cost. NEPA integration would be accomplished by adding a fourth criteria, environmental impacts. This ensures inclusion of NEPA concerns at the earliest feasible time in the decision making process as well as weighing the NEPA concerns on the same basis as the other

criteria. Interim remedial actions (IRA) are currently underway on three OUs, ie., OU 1 - 881 Hillside, OU 2 - 903 Pad, Mound and East Trenches, and OU 4 - Solar Ponds. Environmental Assessments have been written or are being written on these activities. The EA and Interim Measures (IMs)/IRAPs for OU 2 have been integrated into single documents. Documents related to final actions, namely Remedial Investigations (RI)/Feasibility Studies (FS) as well as Treatability Studies will have NEPA integration as well.

The integration of NEPA with CERCLA activities provides for a better balance between the benefits of environmental cleanup and its impacts. CERCLA has a bias for initiating remediation projects, whereas NEPA has a stated goal to inform the decision makers of the environmental impacts of the alternatives. Integration of NEPA and CERCLA will assist the decision makers in balancing the benefits of cleanup versus the environmental damage such cleanup might entail. NEPA will also provide the decision maker with information regarding the cost so that cost benefits can be considered as well. Analysis of the cumulative impacts of the entire Rocky Flats Plant remediation program will be considered under the SWEIS. Assessment of cumulative impacts is explicitly required by NEPA, but is overlooked by the CERCLA process when different cleanup actions or OUs exist under an IAG as the one at Rocky Flats. Finally, impacts at other locations will be considered as a result of NEPA integration. If Rocky Flats ships contaminated soil to a disposal site elsewhere, solving a problem at Rocky Flats, a problem is created at the receiving location. With NEPA, this type of impact will be considered and analyzed.

CONCLUSION

Effective NEPA/CERCLA integration not only fulfills the requirements of two federal laws and avoids duplication of information and effort, but also ensures that cleanup actions are performed in an environmentally sound manner with full understanding of the impacts of the actions being taken. Rocky Flats has successfully integrated NEPA and CERCLA for two IRAs thus far and will continue to do so in the future. Rocky Flats is also preparing a new Sitewide EIS to cover all operations at the facility including environmental restoration from which future NEPA as well as NEPA/CERCLA integrated documents will be tiered.

PUBLIC INVOLVEMENT IN REMEDIAL WORK PROGRAMS AT HISTORIC LOW-LEVEL RADIOACTIVE WASTE SITES, RECENT CANADIAN EXPERIENCE

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ABSTRACT

The Low-Level Radioactive Waste Management Office (LLRWMO) has, as part of its mandate, a requirement to address public information needs concerning low-level radioactive wastes. One aspect of this involves informing and consulting with the public in conjunction with remedial work projects carried out by the Office. This paper discusses the evolution of this public consultation process.

INTRODUCTION

Increasingly, people want to know what is going on around them and to have a say in it. Today, as never before, people will mobilize to voice their opinions on issues such as abortion clinics, war in the Persian Gulf and, in Canada, the Goods and Services Tax. Increasingly, also, the environment is becoming an issue of broad public concern, with the corollary that those whose work potentially affects the environment in any way can no longer go about their business secure in the knowledge that what they are doing is correct, without first discussing the project openly and frankly with virtually anyone who cares to become involved. Indeed, government departments and agencies at the federal and provincial levels in Canada are covered by environmental assessment and protection legislation, the intent of which is to prevent any undertaking of significance from going ahead until it has undergone public review, and until public concerns have been satisfactorily addressed.

Environmental assessment, while undoubtedly beneficial overall, carries with it the potential to increase the base cost of undertakings and the lead time required, and it makes some proponents decidedly nervous. Like it or not, however, it is the way business is done today. The advantage will therefore accrue to those who do the most efficient job of communications.

Under existing Canadian requirements, projects undertaken by federal government departments or agencies are subject to the federal Environmental Assessment and Review Process (EARP). This requires the initiating departments or agencies to take environmental matters into account throughout the planning and implementation of new projects, and to carry out environmental screening for all projects which may have adverse effect on the environment before any commitments or irrevocable decisions are made. Projects which may have significant effects then have to be submitted to the Federal Environmental Assessment Review Office for formal review, including public hearings. The results of these assessments shall be used in planning, decision-making and implementation. (1) Proposed modifications to this procedure will prescribe the environmental screening process more closely, and will establish a new body, the Canadian Environmental Assessment Agency, which will review the screening of projects and maintain a public registry of them. However, the basic responsibilities of the proponent to carry out the environmental screening and consultation process will remain.

This paper will review the communications experience of the Low-Level Radioactive Waste Management Office in taking projects through the environmental screening process.

BACKGROUND

Canada's Low-Level Radioactive Waste Management Office (LLRWMO) was established by the federal government in 1982 to resolve historic waste problems (those for which the original producer can no longer reasonably be held responsible) that are a federal responsibility, to ensure that a user-pay service is established for the disposal of low-level radioactive waste (LLRW) produced on an on-going basis, and to address public information needs about LLRW. The LLRWMO is operated by AECL Research through an agreement with the Department of Energy, Mines and Resources (EMR), the federal department which provides the funding and establishes national policy.

The LLRWMO is located in Ottawa, with a field office in Port Hope. It operates primarily as a project management oriented organization, and contracts projects to private sector contractors and consultants, and to other divisions of AECL Research.

SCARBOROUGH (MALVERN) EARLY EXPERIENCE

In 1983 the LLRWMO was charged, under a federal/Ontario Memorandum of Understanding, with cleanup at 40 residential properties in a neighborhood (Malvern) in the City of Scarborough, which is part of Metropolitan Toronto. An estimated 4000 cubic meters of soil on the properties is contaminated with radium-bearing waste. Since a permanent disposal site was not available for the material, the proposed solution was to excavate the contaminated soil from around the houses and remove it to an interim storage site to be chosen by the Province of Ontario. Prior to any public discussion of this idea, Ontario designated an interim storage site at an undeveloped location within Scarborough known as Reesor Road, and it fell to the Office to communicate to those who lived in its vicinity that they should not be unduly concerned. An energetic public information campaign was mounted and a change was made to the storage facility design in response to public concerns, but when the site was fixed, the battle lines were drawn. The community coalesced into an active organization which raised funds, hired a lawyer and took EMR and the Office to court. Three years and a large

amount of money later the government won the court battle, but lost the war. Although the court ruled the soil could be moved, the province had, in the interim, decided to alleviate the socioeconomic hardship on the owners by purchasing the affected homes, and elected not to proceed with the soil removal. The wastes are still where they were, even though the judge determined that the Office had properly served the public with information. The following text from his judgement is instructive in pointing out the dangers of not consulting the public early:

> Following the announcement of the site, Dr. Cameron (then Director of the Office) called on a number of residents in the affected area. Information material was, in addition, sent or distributed. He attended meetings. The Office was made available for information, answers to questions, and assistance.
>
> I am quite satisfied, on the evidence, the Office made extensive efforts to explain the project to those who were interested, or felt affected. Abundant efforts were made to allay concerns.

Mr. Justice Collier went on to say that the problem faced by the LLRWMO, as the proponent, was that the siting decision had already been made and the Office could essentially do nothing but defend it. He ruled that the Office acted fairly, given the limitation thus placed upon it, and went on to say:

> The defendants, in cross-examination of those residents who gave evidence at trial, and in the written argument filed on their behalf, suggested the Reesor Road residents decided to 'fight' rather than co-operate to create a suitable type of storage facility. The residents, it was said, unreasonably adopted a negative reaction, or the 'NIMBY' syndrome (Not In My Backyard). It was further said the true motivation of the plaintiff and its members was distrust of government.
>
> I find nothing unreasonable, or deserving of criticism, in the actions and opinions of the plaintiff and its members. The proposed Reesor Road facility was sprung on the residents completely by surprise. They had no input. The position of the provincial and federal authorities was 'fait accompli'. The element of distrust of government is, I am certain, not peculiar to the plaintiff's members. History of the last twenty years, in North America, affords a number of instances of why citizens and taxpayers distrust government, or are highly skeptical of government actions and promises. (2)

As a result of the Scarborough experience it became apparent that involvement of the public much earlier in the planning stages of a project had to start.

PORT HOPE

Port Hope is a town of just over ten thousand people, located about an hour's drive east of Toronto on the north shore of Lake Ontario. In 1933 a radium refinery opened in Port Hope. In the 1940's uranium processing was added, and as radium became less commercially valuable, its production was phased out, ending entirely in 1953. The processing of uranium continues and Cameco, formerly Eldorado Resources Limited, remains one of the largest employers in town.

Early waste management practices at the plant were not what they now are. Wastes from processing, and contaminated industrial refuse, were often dumped in open areas, sometimes being used as fill to level building lots. In 1976 the implications of these practices were realized and cleanup operations began under the direction of a Federal/Provincial Task Force On Radioactivity. Over a five year period, contaminated soil and building materials exceeding the Task Force criteria for cleanup were removed from about 330 properties and shipped to storage at the Chalk River Laboratories of AECL. When the program was terminated two situations remained. Wastes are untouched in several undeveloped areas in the town, and there are als some developed properties where contamination remains which is below the criteria to which the remedial work was performed, but is above natural background. (3)

Upon its formation, the LLRWMO became responsible for completing the cleanup work in Port Hope, and a number of steps have been taken to address the remaining contamination on private properties. In the spring of 1986 the federal government announced plans under which Eldorado Resources Limited (ERL), which had low- level radioactive waste management facilities at two communities near Port Hope, would establish a new disposal facility. ERL would decommission two old sites, and would also accept at this new facility the wastes from the Town of Port Hope. The LLRWMO commissioned technical plans for the removal of the wastes from the town and established a liaison committee, comprised of local members of the public, to discuss both the social aspects of, and the technical plans for, the cleanup.

ERL's siting initiatives resulted in substantial outcry from the public and, in the fall of 1986, the government canceled the plan, establishing instead an independent Siting Process Task Force to devise an approach to siting which would be non-confrontational. The report of that body, delivered in late 1987, recommended a sociologically-driven siting process in which communities are offered the opportunity to host a waste disposal site on a voluntary basis. (4) This siting process is now being implemented and has had good success to date with the early phases.

In 1988 the Office began interim work to remediate several of the large, undeveloped, contaminated areas in Port Hope. Critical to the success of these remedial efforts was that the Office proposed local technical solutions to local problems, and that it was able to work co-operatively with the people of the community to develop projects for which there was community support.

THE STRACHAN RAVINE PROJECT

The first large scale remediation project was at a location known as Strachan Ravine, a small ravine centrally located in Port Hope. It was heavily treed and was bounded on two sides by houses. It had been used many years before as a place to dump radioactively contaminated waste, some of which extended onto the properties of the adjacent homes. The ravine itself is owned by the Town.

Although the wastes did not pose any significant short-term health hazard, they presented an undesirable situation. There was nowhere to take the wastes, but the Office felt their impact could be reduced by consolidating them and containing them in the ravine beneath a cap. This would eliminate the radiation exposure pathways of direct gamma radiation and radon emanation, and the wastes would no longer be subject to inadvertent intrusion or to continued spread by erosion.

Prior to seeking formal approval for this work, the LLRWMO organized an evening meeting of those who lived near the ravine. It was held in one of their houses and, over coffee, discussion concerned what was in the ravine, what the levels of radiation were, and what the Office thought might be done. It was noted that, if work was done on the ravine, the contiguous wastes from the neighboring properties would also be removed. While most people favored the concept of consolidation and stabilization, one resident was very much opposed to any work being done, until such time as the wastes could be taken out of the area, because consolidation would involve creating an identifiable waste storage area within sight of his home. Although this was one of the neighboring properties with contiguous contamination the resident was adamantly opposed to having any work done which would make the wastes, or their containment, visible. Since there was general support for the concept the LLRWMO decided to broaden discussions within the town, while pursuing an acceptable solution to the particular concern raised.

By 1988 the LLRWMO had been present in Port Hope for five years. Several appearances had been made before council, and before the Town's Environmental Advisory Committee. An office in the Town functioned in part as a public information outlet, and a newsletter was distributed. As noted above, a liaison committee had been established to address issues related to removal of the wastes from the Town. An essay contest in the high school had been initiated and LLRWMO staff paid annual visits to all the public schools. The local image of the Office and its communications base were, therefore, well established.

In May 1988, Town council formed a Policy Review Committee to advise council on issues relating to radioactive wastes in the Town. The committee consisted of three members of council and the clerk, and it met frequently with representatives from the Office. LLRWMO staff pursued with this committee the concept of interim consolidation and stabilization of the wastes, and helped the committee arrange for council to sponsor a Town Hall meeting in early June to consider this and other waste-related issues. As a result, on June 20, council passed a resolution asking the Office to "proceed with plans for the consolidation and stabilization of wastes in the Strachan Street Ravine Area".

The LLRWMO then developed a specific proposal to consolidate the wastes at Strachan Ravine in a fenced enclosure, beneath a high density polyethylene cap and approximately one meter of earthen cover. A firm of environmental consultants was retained to produced a draft Environmental Screening Document (ESD) on this proposal and the draft was used as the mainstay in a broad program of public consultation. (5)

Public release of the draft ESD was announced in a news release and in the LLRWMO newsletter. At the same time, Office officials were made available to the local media. Copies of the ESD were distributed to all members of council, members of the Environmental Advisory Committee, and people whose property abutted or overlooked the site. Copies for the public were made available through the Town Hall, the library, the LLRWMO field office and the offices of the Town's two newspapers. Office staff appeared before the Environmental Advisory Committee to answer questions and solicit its views.

At the same time, the draft ESD was distributed for review to the regulatory agencies. These consist of the Atomic Energy Control Board as the lead agency, in co-operation with Environment Canada and Ontario Ministry of the Environment. The LLRWMO field office remained open in the evenings and on a Saturday to facilitate visits from interested people and all comments received were carefully documented.

After a period for comment of just under one month, it was concluded that the project was not particularly controversial, and indeed was acceptable to most people who had commented, and thus should proceed. Some minor changes to the proposal were made as a result of the comments received, the ESD was reissued in its final form, copies were distributed to those who wanted them, and the project got under way.

OTHER PORT HOPE REMEDIAL WORK PROJECTS

Coincident with the work at Strachan Ravine, the LLRWMO established a Temporary Storage Site (TSS) in the town. This is a secure area to which contaminated soil, encountered during routine excavations at new construction sites, can be taken for safe storage pending establishment of the permanent disposal facility. Public consultation was carried out in parallel with that supporting the Strachan Ravine project. Site neighbors and town officials and residents were consulted about location and design, and construction of the TSS proceeded with public support.

In 1989, the LLRWMO undertook a second consolidation similar to, but larger than, the Strachan Ravine Project. In this instance, the work involved consolidating approximately 30,000 cubic meters (about one million cubic feet) of contaminated soil, from three adjacent areas and several privately owned properties, at a single site. (6, 7) Although the work, involving several sites and approximately ten times the volume of contaminated soil, was technically more challenging, the process of communicating with people followed the pattern used successfully to support the work at Strachan Ravine.

RECENT SCARBOROUGH EXPERIENCE

In 1990, a similar process was undertaken for a project at a new site in the Malvern area of Scarborough. An LLRWMO presence was established through media announcements, a flyer distributed in the Malvern area (about 12 thousand residential properties overall) and the opening of a store-front office in a local shopping center.

In this case the problem was contamination on a site near the shopping mall which was slated for development. In addition to describing the problem, three potential interim solutions, ranging from simply fencing the site and applying some top cover, to removal of the wastes from the area, were suggested. These options, together with the pros and cons of each, were described on posters on the office wall, and people were invited to fill in comment forms to let the Office know what they thought. Other government agencies and the owners of the contaminated properties were kept abreast of the public process, and of all technical developments, through a series of bi-weekly meetings which continued throughout the consultation process and the actual remedial work.

In this Scarborough example there was substantial agreement among the government agencies and the public on what

interim remedial work should be undertaken. A draft ESD was prepared and after a relatively brief period for additional comment from both the agencies and the public, it was again possible to conclude that the chosen option was both technically viable and substantially non-confrontational, and work began. (8) The field office was maintained, although with somewhat reduced hours, for logistical support and to receive any public inquiries or comments while the work progressed.

DISCUSSION

The communications process which can lead to the successful implementation of a project does not need to take a long time in the field. Even in Scarborough, where the process was basically started from scratch in terms of public profile, the time between when the field office was opened to begin the public consultation program, and when it was possible to begin the remedial work with the support of the local population, was less than two months. In Port Hope, the formal process of public comment took even less time, although it had been preceded by extensive informal discussions to build a consensus on the proposal formally put forward. Although costs vary depending on circumstances and location, in each case the cost of the public consultation program represented a small fraction of the overall cost of the project.

There are significant benefits to be gained from going through such a process, so much so that it may be worthwhile in some cases to invoke the process even where there is no policy or legal requirement to do so. Knowing that plans will be exposed to the public and to other agencies dictates that the proposal first be scrutinized to ensure, as far as possible, that it is both appropriate and responsible. Extensive public consultation may still expose some flaws, but it is better to find these out before going into the field rather than half way through the job. This approach can also boost a company's public image, and it can definitely make the difference between undertaking a project for which the public cheers from the sidelines, as opposed to one for which the public takes a proponent to court.

For a public consultation process to be effective, it is crucial to start looking for input as early in the planning process as possible. Learning what the public and the regulators think before getting too far down the road can avoid time-consuming and costly avenues of planning which turn out to be blind alleys. In handing off some of the control over the project to others it must also be remembered that they can and will influence the direction of the undertaking.

It is important to be completely open and without a hidden agenda. A highly visible presence does not automatically cause confrontational scenes; in fact, our experience is the reverse. In the Scarborough example the store front office, even in the middle of a busy shopping mall, failed to attract significant numbers of visitors to talk about something as seemingly controversial as low-level radioactive waste. In fact, one in a series of relatively well publicized public meetings on the subject failed to attract anyone at all.

Similarly, if the project does run into controversy, pursue the issue and let the public help you find a good solution. Again in Scarborough, the LLRWMO learned that a lady in a nearby condominium complex was telling her neighbors, although not telling the Office, that she was concerned, that she wanted to have the project independently monitored, that she felt additional surveys should be done, etc. The residents' association was invited to a meeting to air these ideas. Very few people came, but when the lady suggested monitoring the LLRWMO offered help in providing instruments and instruction if the residents would organize the monitoring. When she voiced her concerns they were discussed openly. The net effect was that the issues were reduced to the satisfaction of all parties because the lady and her friends could see that there was nothing being hidden.

It is also important to be available as the work proceeds. The job of communications does not end when the public gives permission to do work. Unexpected situations may arise, the project may run late, run early, or run in an unanticipated direction, and this should be communicated. People may simply want to ask how its going, and should have the opportunity to do so. Depending on the project, a local office, newsletters or flyers, and/or a special telephone line for information can all be useful. The workers who may come in contact with the project neighbors or passersby during the job should also be briefed. They can be excellent ambassadors even if all they do is smile and hand out a copy of the latest information sheet with a phone number on it.

SUMMARY

Communications programs, in support of major work programs, which are limited to the provision of information concerning decisions which have already been made are likely to be received very negatively. True consultation with the public, particularly when combined with a local solution to a local problem, can produce much more satisfactory results. Undoubtedly, contributing factors to the smoothness with which the process has gone in Port Hope have been the familiarity of the people there with the whole issue of low-level radioactive wastes, and the ongoing presence of the LLRWMO. However, the more recent experience in Scarborough shows that the approach can be successful even when carried out in an area in which people have little or no initial familiarity with the subject.

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WORKING WITH STATES ON A JOINT DOE/STATE FUNDED CLEANUP PROJECT

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ABSTRACT

The Uranium Mill Tailings Radiation Control Act authorizes the U.S. Department of Energy to remediate mill tailings at 24 designated sites with the active participation of affected states and Indian tribes. Specific states and tribal responsibilities are detailed in cooperative agreements. This paper provides information on the Uranium Mill Tailings Remedial Action Project experience in fulfilling its mission in cooperation with states and tribes.

LEGISLATIVE BASIS

The Uranium Mill Tailings Radiation Control Act of 1978 (Act), Public Law 95-604, was enacted by Congress to address the radiation-health hazard associated with the uranium mill tailings located at active and inactive mill operations. Within the Act, the Congress designated 24 sites with associated vicinity properties that would be cleaned up through a federal program. The Act further authorized the U. S. Department of Energy (DOE) to carry out the remediation program at the designated sites. The sites to be remediated by the DOE are designated as Title I sites.

To fulfill the Congressional mandate, the DOE established the Uranium Mill Tailings Remedial Action (UMTRA) Project and assigned the responsibility to the Albuquerque Operations Office. The UMTRA Project Office has two prime contracts for the execution of the work. One contract is with Jacobs Engineering Group, which serves as the Technical Assistance Contractor; the other is with the MK-Ferguson Company, which serves as the Remedial Action Contractor. With the exception of one site in the State of Pennsylvania, the remaining sites are located in the western half of the United States. A map of the UMTRA sites is attached (Fig. 1).

COOPERATIVE AGREEMENTS

The Act also established participation by the states and Indian tribes on whose land the sites are located. The Congress legislated that the states would cost share 10 percent of the remediation activities with the federal share being the remaining 90 percent. However, remedial action carried out on tribal lands was specified under the Act as 100 percent federally funded. The costs of the Project which are not directly tied to remediation come from federal funds only. Participation in the Project was assured through the execution of Cooperative Agreements by the DOE and the states and Indian tribes. The states which have executed these agreements are Colorado, Idaho, New Mexico, North Dakota, Oregon, Pennsylvania, South Dakota, Texas, Utah, and Wyoming. In addition, the Navajo Nation and Hopi Indian Tribe have also executed these agreements. The first agreement was signed in 1981. These established not only the cost sharing but also defined the responsibilities to be carried out by the states and tribes under the UMTRA Project.

REMEDIATION ALTERNATIVES

In determining the remediation action, the DOE had three alternatives. These were stabilization in place (SIP), stabilization on site (SOS), and relocation of tailings (relocate). For the SIP option, the tailings remain in their present location and are covered. For the SOS option, the tailings remain at the mill site but are moved to another area on the site before they are covered. For the relocate option, the tailings are removed from the mill site and transported to a selected disposal cell. The selected alternative required concurrence by the affected state or tribe. The application of the disposal alternatives based on the site characterization conducted has resulted in the selection of SIP at 8 sites, SOS at 2 sites, and relocate at 13 sites. The remaining designated UMTRA site consisted of only vicinity property remediation activities, and that material was returned to the mill site which was remediated by other.

STATE/TRIBE RESPONSIBILITIES

The designated responsibilities of the states and tribes can be divided into three areas. The technical area is one by which they participate in the following manner:

1. review and comment on the draft environmental assessment/environmental impact statement,
2. participate in disposal site selection,
3. review and comment on the draft Remedial Action Plan,
4. execute the Remedial Action Plan
5. review and concur on the Radiological and Engineering Assessment defining vicinity property remedial action
6. assist DOE in obtaining an executed Remedial Action Agreement from vicinity property owners,
7. acquire millsite, vicinity property, and/or disposal site as directed by the DOE Contracting Officer,
8. procure all necessary permits and licenses,
9. accompany DOE on site inspections during remedial action, and
10. adhere to all applicable federal laws and regulations as set forth under the Cooperative Agreement.

The states and tribes have designated financial responsibilities as follows:

1. provide annual estimates of state/tribal costs to carry out UMTRA responsibilities,

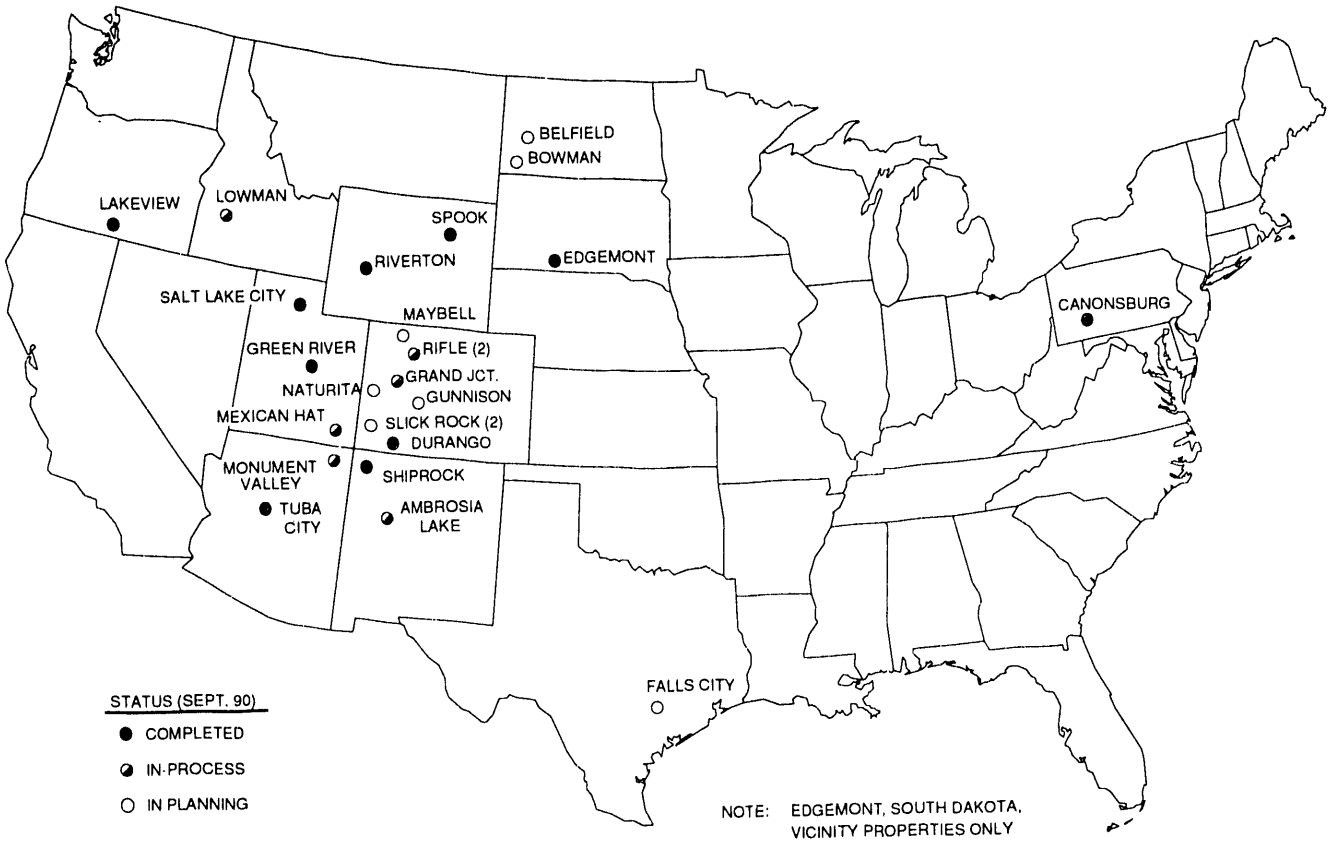


Fig. 1. UMTRA site locations.

2. obligate funds based on 10 percent of DOE estimates provided annually and 10 percent of state's estimated annual budget (states only),
3. bill DOE quarterly for actual costs, and
4. pay DOE promptly (states only).

INTEGRATING STATE/LOCAL PERSPECTIVE

Additionally, the states and tribes play an important role in the public participation program. As part of the Cooperative Agreement, they are to:

1. assist in formulating and implementing a public participation plan,
2. establish procedures for timely release of information to the public on UMTRA activities in the community,
3. consult with local advisory committees, and
4. establish, as deemed appropriate, a state advisory committee.

In participating in the UMTRA Project, the states and tribes have become involved in some of the key decisions. Oftentimes, the Project is requested to integrate the state/local perspective in the planning of activities for remedial action. The Colorado Department of Health has successfully achieved implementation of local initiatives at two sites and is supporting a local initiative at one site. In Grand Junction, Colorado, the local community was concerned with the truck haul route for tailings relocation. The haul route was planned through the center of town, and there was concern for the safety of the local residents and the impact to the local businesses. The community initiated an action to have the tailings hauled through a train/truck transportation alternative. Through agreement of the Secretary of DOE, the train/truck haul option is now ongoing. The citizens of the Dos Rios community in the County of Gunnison, Colorado, were concerned with the impacts of the old mill operation to their groundwater which supplied their wells. The DOE, the state, and the county are now working together to provide an alternate water supply system for these residents. The citizens of Naturita, Colorado, are supporting a co-disposal option for the tailings located in their community. There is a designated Title II site which they see as a viable location for the UMTRA tailings disposal. The UMTRA Project Office is currently working with the state to explore this option. One of the concerns presently being addressed is the implications of the Title II site also being designated a CERCLA site and any potential liability to DOE which could result from co-disposal.

In addition to local issues, the DOE has worked with states in integrating their requirements at sites. In Utah, the state served as the remedial action contractor and selected the alternative of relocate for the Salt Lake City site. The DOE proposed option was SIP. Congressional action initiated by Oregon resulted in their site at Lakeview being remediated earlier than scheduled. Wyoming successfully petitioned the Project Office for the relocate option for tailings at Riverton. The DOE preferred option was SIP. The tailings were relocated to a Title II site with the state paying 25 percent, rather than 10 percent, of the remediation costs over the DOE SIP estimate. At the request of the State of Colorado, the UMTRA Project Office is carrying out additional site characterization for the DOE selected disposal site for the Slick Rock tailings. The state has not concurred on the DOE recommended disposal site for the Slick Rock tailings.

SITE ACQUISITION ISSUE

As stated previously, one of the responsibilities of states is site acquisition. Problems in timely acquisition have been encountered. These sometimes are the result of the state procedures which must be followed in the acquisition process. Additionally, for some states there is a reluctance to achieve acquisition through condemnation, if that step is necessary. The acquisition is a critical step in the remediation schedule. Difficulties in the acquisition efforts have resulted in delays to the UMTRA remediation schedule at those sites.

STATE FUNDING ISSUES

The most difficult area associated with the state participation is the funding issue. States operate on a fiscal cycle which begins three months earlier than the federal fiscal cycle. Additionally, some states operate on a biennium rather than an annual cycle. The DOE estimates do not conform with the legislative cycle, and some states have experienced difficulty in obligating funds in a timely manner. The Congressional funding of the UMTRA Project limits the DOE remedial action capabilities. There is a potential for the schedule delays to result in the loss of state funding support. The UMTRA Project competes with other programs within each of these states for funding. For some state legislators, the UMTRA Project is not viable to the state as a whole; and, therefore, they do not support appropriating funds for the Project. When the economy of a state is sagging, the low revenues can result in the inability for a state to appropriate funds to support the UMTRA remediation. If cuts are made, projects such as UMTRA get hit first. For states which have appropriated funds, cost growths have resulted in the need for additional state funding. These cost growths have resulted in part from increased regulatory requirements, the discovery of additional quantities, lack of federal funding, state and local requirements, and other needs. Some states were willing to commit at the beginning but are reluctant to increase their funding support.

PARTICIPATION SUCCESS

Although there have been difficulties encountered, the DOE, the states, and the tribes have worked successfully together. State and tribal agencies fully participate in the UMTRA remedial action at their sites. They serve as partners of the DOE in working with the Nuclear Regulatory Commission and other agencies in meeting regulatory compliance. They participate with the Project staff in local community meetings to keep citizens apprised of the status of their particular site and sometimes serve as an advocate for community concerns. The participating state agencies act as proponents of the Project in seeking state legislative support and funding. They work closely with the UMTRA Project Office in identifying the appropriations needed to commit their 10 percent share of the remedial action, and they testify at legislative hearings on behalf of the Project.

The UMTRA Project provides a positive economic benefit to the community and ultimately the state or tribe. For remedial action work, the Project encourages the use of local businesses and labor where possible. As a result there is an increase in employment, in local business revenue, and in tax revenue. For some states, they can realize at least $3.00 in benefit for every $1.00 they have invested in the Project.

UMTRA LESSONS

The UMTRA Project is a success. Nine of the 24 sites have been remediated. Two sites are presently undergoing remedial action. Four sites are scheduled to start in FY-1992.

The UMTRA Project has succeeded through partnership with the participating states and tribes. It has also learned some valuable lessons which can be applied now and in future cost shared projects.

States and tribes do want to actively participate and should be involved as early as possible in any activities associated with the sites. State and local issues can and often do take precedence in the selection of alternatives. Working with these agencies requires a sensitivity to that and a willingness to openly discuss all options.

As with federal funding, state funding is sometimes difficult to obtain. State agencies have to be kept informed of recognized cost increases as they occur. The UMTRA Project Office developed an estimate at completion report which is sent to states and tribes on a monthly basis. This keeps the participants aware of the funding requirements as they change and also helps them to be responsive to their respective legislatures on funding issues.

Good lines of communications between state and tribal representatives and the DOE assure support and cooperation even when working through the most difficult issues. The state and tribal agencies can and do actively participate in meetings with regulatory agencies. They can lend support to DOE in working out issues with these agencies. The states and tribes also provide the best voice for local concerns. They need to communicate with local officials and provide early information to the DOE on local concerns which could potentially impact project schedules and costs. Encouraging good relations with the community also helps. The UMTRA Project Office assigned the site manager for Grand Junction (the largest UMTRA site in terms of volume of material, number of vicinity properties, and overall cost) to the Grand Junction area to maintain the constant communication needed with the local officials and demonstrate the spirit of cooperation desired between the UMTRA Project Office and the community. The result has been improved relations between the Project Office, the local elected officials, and the community.

Cooperation is the key to success.

DEVELOPMENT OF AN ADMINISTRATIVE RECORD SYSTEM AND INFORMATION REPOSITORY SYSTEM ON THE HANFORD SITE, BENTON COUNTY, RICHLAND, WASHINGTON

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ABSTRACT

The purpose of this paper is to describe the development of an administrative record (AR) file system for the Hanford Site in Richland, Washington. This paper will focus on the background of the AR system and its implementation at the Hanford Site; the types of documents to be included in an AR file; the management system used to develop and implement the AR system; the unique characteristics of the AR system and the role of the information repositories.

OBJECTIVE

The objective of this session is to present the methodology used in developing an AR and information repository system so that common hurdles from various sites can be addressed and resolved similarly. Therefore unnecessary effort does not have to be put forth to resolve the same issues over and over again. The concepts described can be applied to all federal facility sites with a minimum amount of modification and revision.

BACKGROUND

Administrative Record Requirement

The *Comprehensive Environmental Response, Compensation, and Liability Act of 1980* (CERCLA), also known as Superfund, authorizes the federal government to investigate and respond to releases of hazardous substances which may endanger human health and welfare and/or the environment. Congress amended and reauthorized the Superfund law in 1986 as the *Superfund Amendments and Reauthorization Act of 1986* (SARA). As required by Section 105 of CERCLA, as amended by SARA, the *National Oil and Hazardous Substances Pollution Contingency Plan* (NCP) (EPA 1988) was established to "provide the organizational structure and procedure for preparing for and responding to discharges of oil and releases of hazardous substances, pollutants, and contaminants." Executive Order 12580, *Superfund Implementation* names the U.S. Department of Energy (DOE) as the "lead agency." The DOE has the authority and responsibility for conducting a restoration program to address environmental contamination from past operations and disposal activities. It is the objective of the DOE restoration program to assess past hazardous waste disposal and spill areas on DOE sites and develop remedial actions consistent with the NCP (EPA 1988) for areas that pose a threat to human health and welfare or the environment.

The objective of establishing an AR is to provide a concise record that contains the events, studies, data, and other pertinent information documenting the decision process upon which each removal or remedial action is based. The AR established under Section 113 of CERCLA serves two primary purposes: first, to support the decision process, the judicial review of any issue concerning the adequacy of a response action is limited to the AR; second, the AR is to be used as a vehicle for public participation in the selection of the response action, ensuring that all relevant factors in selecting the response were considered, and that interested parties were given adequate notice and an opportunity to participate in the selection. In compliance with CERCLA, the requirements for an AR are given in Subpart I of the NCP (40 CFR 300.800) (EPA 1988).

Hanford Site

The Hanford Site was acquired by the U.S. Government in 1943 for the construction and operation of facilities to produce plutonium for World War II. The site encompasses approximately 1,450 km^2 (560 mi^2) within the Columbia River Basin. For over 20 yr, Hanford Site facilities were primarily dedicated to producing plutonium for national defense and managing the wastes generated. Recently, programs at the Hanford Site have become increasingly diverse, involving research and development for advanced reactors and renewable energy technologies. Currently the DOE is phasing out the defense production missions on the Hanford Site, the new emphasis of the site being research and development, cleanup of waste units resulting from past operations, and achieving compliance with federal and state laws.

The AR system at the Hanford Site began in September 1988. The early stages of the program were developed in anticipation of the signing of the *Hanford Federal Facility Agreement and Consent Order* referred to as the Tri-Party Agreement (Ecology et al. 1990b).

Systems Development

The initial step in systems development was to thoroughly research the applicable requirements and develop a system that complied with the requirements. Other basic system components were also developed such as a keywording system, document identification code, and a personal computer-based tracking system.

By January 1989 the processing and coding of documents and information had begun. A numbering system was employed that allowed the tracking of information by specific operable units or treatment, storage, and disposal (TSD) groups (i.e., specific cleanup sites for which an AR is required). Little information was available about the AR system for federal facilities. Therefore, the system logistics were centered on the requirements in federal law, specifically CERCLA. A useful tool was the *Interim Guidance on Administrative Records for Selection of CERCLA Response Action* written by the U.S. Environmental Protection Agency (EPA) (EPA 1989) which has now been amended by the final guidance (EPA 1990).

The first version of the Tri-Party Agreement was signed in May of 1989, and so began the push to comply with the recordkeeping requirements outlined in the Tri-Party

Agreement as well as the interim guidance document (EPA 1989). Initial work completed in December of 1988 regarding applicable requirements allowed for a smooth transition to full compliance in the recordkeeping program.

Staff experience and good customer service also paved the way for a smooth operation. These characteristics were the foundation for a successful system in the new and demanding area of environmental recordkeeping.

The following information focuses on the Hanford Site AR system description and implementation.

The implementation phase is in full swing at this time. Two ARs have been closed in support of recent removal action decisions. Many more ARs are being and will be generated in the future, with the last AR anticipated to be closed around the year 2005.

SYSTEM DESCRIPTION

Purpose

The basis for compiling documents for an AR is identified in the following documents:

- Executive Order 12580 (1987), which states that federal facilities and not the EPA are responsible for the compilation of the AR
- Section 113(k) of CERCLA as amended by the SARA
- Tri-Party Agreement (Ecology et al. 1990b)
- The NCP (EPA 1988)
- *Final Guidance on Administrative Records for Selecting CERCLA Response Actions*, OSWER 9833.3A (EPA 1990).

Description

Organizational Responsibilities

The Environmental Data Management Center (EDMC) has been established on the Hanford Site and develops and implements the AR system. The EDMC is responsible for the following activities:

- Managing the AR master file
- Creating, maintaining, and distributing the AR indexes
- Maintaining the DOE Field Office, Richland Public Access Room (which contains a copy of the AR documents)
- Producing and distributing the candidate review lists
- Submitting the AR indexes to the unit managers for review and approval
- Providing requested information to the EPA, Washington State Department of Ecology (Ecology), and the public
- Providing monthly status of ARs at the monthly unit managers meetings
- Distributing a copy of the AR file to the EPA and Ecology
- Ensuring availability of validated sampling data
- Updating the AR files.

Unit managers are an important part of the AR process. A unit manager from each agency (EPA, Ecology, and DOE) identified in the Tri-Party Agreement (Ecology et al. 1990b) is assigned a specific response or removal action which requires an AR. Unit managers are responsible for coordinating and directing all areas of the investigation process for that action. The unit managers are responsible for submitting documents for the ARs to the EDMC, reviewing and approving the AR indexes, and providing input on the candidate review lists.

File Structure

The official (master) file of ARs is maintained under strict control and is not available to the public. This is the record copy. There are three copies of the official file. These copies are distributed to Ecology, EPA, and DOE and are available for public review at the following locations:

- Washington State Department of Ecology
  5826 Pacific Avenue
  MS PV-11
  Olympia, WA 98504
- U.S. Environmental Protection Agency
  1200 6th Avenue, HW-113
  Seattle, WA 98101
- Environmental Data Management Center
  450 Hills Street, H4-51
  Richland, WA 99352.

Upon inception of the EDMC two main issues needed to be addressed in developing the AR system. The first was that the Hanford Site anticipated over 100 ARs were going to be needed. The second issue was that many of the same documents would support multiple ARs. In order to meet this challenge several key features were developed into the system. The following are brief descriptions of the key features:

Generic file -- Because a large number of documents support multiple ARs, a system was needed to account for the documents and apply them to the applicable ARs. The generic file was developed to meet this particular need. The generic file is a specific location where documents assigned to five or more ARs are kept and then cross referenced in the specific AR indexes. This process has eliminated the need to physically place a copy of the document in each AR file thereby eliminating the need to reproduce tremendous amounts of paper and documentation.

Indexing system -- Each AR file is indexed by the operable unit or removal action. The index is the powerful tool that identifies the location of all the AR documents that need to be included in the file. Because of their media, size, function, or sensitivity, some documents do not have to be physically located in the master file. Copies of the index are distributed quarterly to the unit managers, information repositories, and AR file locations.

The EDMC employs a smart numbering system that uses the operable unit or TSD identifier which precedes the sequential number stamped on the document. This facilitates the easy identification of a document relating to a specific AR file.

The following is an example of an EDMC number: A-U001-000001. The "A" identifies the document as an AR document, the "U001" identifies the applicable operable unit, and the "000001" is the sequential number stamped on the document during the initial processing.

Candidate review list -- The candidate review list is the vehicle for providing the EDMC with direct input from the

unit managers as to whether a document received by EDMC needs to be included into the ARs. The lists are produced monthly and distributed to the unit managers. The unit managers indicate which documents listed belong in an AR and return the marked up list to the EDMC. The EDMC then updates the data base to reflect the information from the list.

Reference review -- When a primary document is received in the EDMC a copy is made of the reference section from the document. The references are then input into a data base for easy tracking and the determination process begins. The first determination is whether the reference document is part of the ARs, the second determination is whether that document is publicly available. If the reference document supports the ARs and is not publicly available the EDMC locates the document and inputs the document into the EDMC system for inclusion into the ARs.

Record review and closeout --When a decision has been made, the EDMC prepares a draft index for review by the unit managers. The unit managers then review the index and provide any additional input that needs incorporation into the specific AR. The AR coordinator within EDMC then verifies that the AR has been collected and maintained in accordance with the established laws, regulations, guidance, and procedures governing ARs. The unit managers then sign off on the review sheet verifying their input and review of the AR.

SYSTEM IMPLEMENTATION

Compilation

Certain documents need to be included into an AR file according to the established criteria which states, "...the body of documents and information that is considered or relied on in order to arrive at a final decision for remedial action or removal action" or documents and information that provide proof of public participation.

The compilation of an AR should begin as soon as possible once work is initiated on a response action to ensure all documents are captured. The EDMC initiates an AR when work begins on a particular response action. Many of the operable units and TSD units are already identified in the Tri-Party Agreement (Ecology et al. 1990b) and the EDMC has coding already established in the system.

Document generators are responsible for submitting their information to the EDMC for possible inclusion into an AR file. The EDMC also searches and requests copies of information and documentation that need to be included into a AR file. The following section describes the methodology to be followed regarding the inclusion of documents and information and how they are to presented in the AR file and in the AR index.

The following are the primary documents of factual information/data required for a CERCLA response action:

- Remedial investigation/feasibility study work plan
- Remedial investigation Phase I report
- Feasibility study Phase I, II and III report
- Proposed plan
- Abatement proposal
- Interim response action proposal
- Documentation of preliminary assessment/site investigation
- Treatability study work plan and characterization plan
- Agency for Toxic Substances and Disease Registry health assessment
- Preliminary natural resource survey (by natural resource trustee)
- Procedures as specified in the work plans
- Supplemental work plan
- Health assessment
- Work plan change notice
- Sample data results (data packages)
- The *Resource Conservation and Recovery Act of 1976* (RCRA) facility assessment report
- The RCRA facility investigation/corrective measures study
- The RCRA facility investigation report (preliminary and final)
- Corrective measures study report (preliminary and final)
- Interim measure proposals.

The AR includes the following for the preceding documents:

- All drafts submitted by the DOE to the regulatory agencies for review and approval
- Written comments from the support regulatory agency to the responsible regulatory agency
- Written comments from a regulatory agency to the DOE (to include notice of deficiency on a permit application)
- The DOE written response to comments received from a regulatory agency
- Final documents and any subsequent revisions
- Drafts submitted for public comment
- Public comments on draft documents.

The following are other documents to be incorporated into the AR:

- Policy and guidance documents and/or data
- Memoranda on policy decisions
- Guidance documents
- Supporting technical literature
- Decision documents
  - Record of decision
  - Responsiveness summary
  - Letters of approval
  - Action memoranda
  - Waiver requests and regulatory agency responses
- Enforcement documents
  - The Tri-Party Agreement including the "Action Plan" (Ecology et al. 1990b)
  - Administrative orders
  - Consent decrees
  - Affidavits
- Documents that provide proof of public participation

- *Community Relations Plan for the Hanford Site* (Ecology et al. 1990a)
- Correspondence to or from the public
- Public notices
- Public comments
- Public meeting minutes
- Public hearing transcripts
- Responses to public comments
- Fact sheets (public information bulletins).

Index

Each AR is tracked by its index. The index enables anyone to locate and obtain documents included in the AR. The index is distributed quarterly by the EDMC. The index includes the following information:

- The EDMC file number
- Document number
- Document title
- Author (name and company)
- Recipient (name and company)
- Document date
- Document location
- Comments/number of pages
- Document type.

Identification

Three methods are used to identify documents as ARs. The first method is identifying information from the listing in attachment 1 taken from the Tri-Party Agreement (Ecology et al. 1990b). The second method is identifying information from the candidate review list. The third method is by reviewing references.

Automatic Inclusion into the Administrative Record

Certain documents, for which there is no question as to their relevance and the nonprivileged nature of the information, are placed directly into the record files, entered into the index, and made available to the public as soon as possible after generation or receipt of the documents in the EDMC. Any document that can be readily identified from the list in attachment 1 falls into this category. Two other means of identifying AR documents are as follows:

- Listed on an EDMC information transmittal
- Identified on copy coverage (CC).

Candidate Review List

When there are questions as to whether a particular document should be included into a record file, the EDMC will list the documents in question on a candidate review list. The candidate review list will then be distributed by EDMC to the unit managers. Currently the review lists are distributed monthly and are returned to EDMC within 30 days. Unit managers identify documents that need to be included in the record file by indicating with a YES or NO next to the document description on the review list.

The candidate review list is the vehicle that the EDMC uses to identify AR documents that cannot be identified by the EDMC staff. Because the AR is assembled documentation on decision-making activities, and the unit managers are responsible for making the decisions; the documents and information that cannot otherwise be identified are left for the unit managers to identify.

Reference Review

References identified within primary documents need to be reviewed for their inclusion in the ARs. References are cataloged in a data base and a systematic review of their applicability takes place. Some references are publicly available are therefore their inclusion in the indexes is not required. Those references that are not publicly available are collected and processed into the EDMC system.

Special Documents

Certain documents that are included in the record file do not have to be maintained in the EDMC. Documents in this category must be included by index or referenced in a document and included in the record file. Exceptions and specifics are described for each special category as follows.

Validated sampling data -- This data is submitted to EDMC for microfilming and a copy of the microfilm will be stored in the EDMC. The record copy will be the silver halide original of the microfilm. The hard copy originals are sent to the 712 Building Records Holding Area for final disposition.

Chain of custody -- These forms must be left in the original storage location. The title, description, location, and reference numbers must be transmitted to the EDMC for inclusion in the index.

Privileged documents -- These documents can be maintained in the confidential portion of the file located in the EDMC or can be located with the generator of the document or information. However, the title and location of the information must be transmitted to the EDMC for inclusion in the AR index. A short description of the information and the reason for the privilege must also be included with the submittal to EDMC for inclusion in the public portion of the record file.

Guidance documents -- These documents are located in the generic file in the EDMC. Although copies of guidance documents are not necessarily required, EDMC obtains copies of the documents to ensure availability. Guidance documents are also listed in the index and their location is identified. Some guidance documents may not be located in the generic file and will therefore be identified in the index along with their location (see Section 4.4 "Generic File").

Publicly available documents -- These documents are typically references or technical reports. Documents that are publicly available are not required to be physically located in the AR file. Although they must be listed in the index unless they are listed as a reference in a document already included in the ARs.

Documents Included in the Administrative Record Other Than the Index

Publicly available references are considered part of the AR file. However, if the references appear within a document already in the AR, and are publicly available, then they do not have to be listed in the index (see Section 4.3.3 "Reference Review").

Generic File

The generic file is a system of locating documents in five or more AR files without having to physically include a copy of the document in each AR file. Documents and information located in the generic file can be cross referenced to any AR file by listing the document on the specific AR index.

Generic documents are coded for specific assignments to particular AR files. Table I is a list of the codes and their associated categories.

TABLE I

Administrative Record Codes and Categories.

Code	Category
01	Generic (Assigned to candidates or specific ARs)
02	Generic to all operable units (OU) (CERCLA)
03	Generic to all TSD groups (RCRA)
04	Generic to all OUs and TSDs
05	Generic to all OUs, TSDs and removal actions (RA)
06	Generic to all RAs
07	Generic to all OUs and RAs
08	Generic to all TSDs and RAs

Location

Documents and information assigned to an AR file can be located in several places. The master AR file is considered the site file. Other files can be located on or off the site depending on the information. For example: chain-of-custody forms can be located on or off the site.

The site file is located at 345 Hills Street, near the Hanford Site. The EDMC maintains the general site file which contains all documents submitted for retention and retrieval. Using the data base, the AR files become identified portions of the site file. All AR documents are microfilmed when the documents are filmed and verified. The silver halide microfilm becomes the master file for the AR.

The EPA, Region X office has a collection of guidance documents that may be considered or relied on to make decisions and therefore need to be included in an AR. The EPA file is called a compendium. Reference to these documents can be made on the index. However, the EDMC will obtain a copy of the documents where possible and practical and include them in the generic file for ease of retrievability.

In certain situations, documents in the AR file may be subject to an applicable privilege. To the extent feasible, information relevant to the decision, which is contained in the privileged document, should be summarized to make the document disclosable. The summary should be included in the AR file. The privileged document is then filed in the EDMC site file (which has access control). The document is also coded in the data base as "confidential".

Public Participation

Public participation is a key part of the AR system. Many decision documents, especially the primary ones, are made available for public comment. Public comments must be resolved and added to the AR along with the resolutions to the comments.

INFORMATION REPOSITORIES

The public information repositories serve as a convenient point to gain access to information about the cleanup activities. Information repositories are four northwest libraries that have agreed to display certain information and documents regarding Hanford Site hazardous waste activities. They are maintained to make it easier for the public to participate in the decision making process.

The *Community Relations Plan for the Hanford Site* (Ecology et al. 1990a) outlines information gathered from the public on their concerns and interests regarding cleanup and describes how the public participation program will be managed. The EDMC is responsible for distributing information to the public information repositories and supporting the public involvement as it relates to documents and information.

An AR index is placed in the repositories to facilitate retrieval of additional information about a remedial or response action. If further information is required, then a special request can be made.

The following is a list of the information repositories that support the Hanford Site cleanup program:

- University of Washington Library
  Mail Stop FM-25
  Seattle, WA 98195
  (206) 543-4664
- Gonzaga University Crosby Library
  E. 502 Boone
  Spokane, WA 99201
  (509) 328-4220 EXT 3125
- Portland State University Library
  P.O. Box 1151
  Portland, OR 97207
  (503) 464-4617
- DOE Public Reading Room
  Federal Building Room 157
  825 Jadwin Avenue
  Richland, WA 99352
  (509) 376-8583

CONCLUSION

Development of an AR system needs to first of all comply with the laws and regulations governing the ARs. By reviewing the requirements the step-by-step process of preparing plans, procedures, and instructions can then begin. The nature of the Hanford Site has lent itself to some unique problems associated with the development of such a system. The shear size of the site has mandated the need to apply documents common to "more than five" cleanup sites to a generic file that can be cross-referenced to multiple AR files. The problem of locating and identifying documents for inclusion into a particular AR file also has its unique problems. The candidate review list process has been a successful program that directly involves unit managers with the collection and assembly process. Other good recordkeeping practices have also lead to the success of the AR system at the Hanford Site.

The information presented here is just a portion of the AR system in a condensed version. There are many details and exceptions to the system that make it function well. The knowledge presented is to help clarify the basic concepts of the Hanford Site AR system and also serves as an invitation for further inquires. The EDMC serves as customer oriented

organization and is always ready to provide information and share knowledge and resources.

REFERENCES

Comprehensive Environmental Response, Compensation, and Liability Act of 1980, as amended, Public Law 96-510, 94 Stat. 2767, 26 USC.

Ecology, EPA, and DOE, 1990a, *Community Relations Plan for the Hanford Site*, Washington State Department of Ecology, U.S. Environmental Protection Agency, and U.S. Department of Energy, Olympia, Washington.

Ecology, EPA, and DOE, 1990b, *Hanford Federal Facility Agreement and Consent Order*, Vols 1 and 2, Washington State Department of Ecology, U.S. Environmental Protection Agency, and U.S. Department of Energy, Olympia, Washington.

EPA, 1988, *National Oil and Hazardous Substances Pollution Contingency Plan,* Title 40, Code of Federal Regulations, Part 300, U.S. Environmental Protection Agency, Washington, D.C.

EPA, 1989, *Interim Guidance on Administrative Records for Selection of CERCLA Response Action*, OSWER Directive 9833.3A, U.S. Environmental Protection Agency, Washington, D.C.

EPA, 1990, *Final Guidance on Administrative Records for Selecting CERCLA Response Actions*, OSWER-9833.3A, U.S. Environmental Protection Agency, Washington, D.C.

Resource Conservation and Recovery Act of 1976, as amended, Public Law 94-570, 90 Stat. 2795, 42 USC 6901.

Superfund Amendment and Reauthorization Act of 1986, Public Law 99-499, 100 Stat. 1613, 42 USC 11001.

Superfund Implementation, 1978, Executive Order 12580, 3 Code of Federal Regulations, 1987 Comp., p. 193, 42 USCA 9615 nt.

DECOMMISSIONING OF THE 105-F AND 105-H FUEL STORAGE BASINS IN THE 100 AREA AT THE HANFORD SITE

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ABSTRACT

The U.S. Department of Energy (DOE) owns the eight surplus production reactors at the Hanford Site north of Richland, Washington. The fuel storage basins at the 105-F and 105-H reactors were filled with equipment, associated with the operation of the basins and clean fill in 1970. This was done to stabilize the residual sediment and a few feet of water in the reactors' fuel storage basins. This project investigates the subject basins to locate and remove overlooked fuel elements left in the basins.

INTRODUCTION

An Environmental Impact Statement (EIS) has been prepared to examine the environmental impacts associated with several alternatives being considered for decommissioning the surplus production reactors at the Hanford Site. The EIS analysis assumes that the basins are free of reactor fuel elements before the start of final decommissioning. Because the 105-F and 105-H fuel storage basins are filled with debris and dirt that may possibly cover spent fuel elements that had inadvertently been left in the basins, this project will locate and remove any fuel elements that may be present. The project will leave the facilities in a suitable condition for the decommissioning alternative that is selected by the EIS Record of Decision (ROD).

BACKGROUND

Physical Characteristics of the Basins

A fuel storage basin is contained in each of the surplus production reactor facilities. The fuel storage basin served as a collection, storage, and transfer facility for the irradiated fuel elements discharged from the reactor. This storage facility is composed of approximately 24-m (80-ft) wide by 30.5-m (100-ft) long by 6-m (20-ft) deep concrete basins that contained 6-m (20-ft) of water to act as a coolant and shielding for the irradiated fuel. The fuel was stored in stainless steel baskets in rows separated by a 1-m (3-ft) high concrete wall. Over the years, considerable sediment collected on the bottom of the basins. The sediment contains transuranics, fission products, and activated coolant materials. Each basin contains an estimated 50,000 kg of sediment.

In preparing for stabilizing the basins, the water level was reduced to approximately 0.6 m (2 ft) deep. Some of the fuel storage baskets were removed from 105-H and 105-F basins. The wood deck was dropped into the basins. A monorail system above each aisle that originally provided access to the fuel baskets was cut from the ceiling and dropped into the basin. Miscellaneous objects removed from the building were also placed in the basin before backfilling. The backfill material, approximately 3,420 m^3 (4,500 yd^3), placed in the 105-F basin was obtained from the local surface and is essentially aeolian sand. At the 105-H basin the backfill, approximately 4,400 m^3 (5,800 yd^3), was obtained from a nearby barrow pit and is mostly cobble dispersed with rock up to 15 cm (6 in.) in diameter. In either case the backfill was not compacted.

Basins Remediation Design

A definitive design for remediation of the 105-F and 105-H basins was accomplished in fiscal year (FY) 1990. The design provided drawings for the 105-F and 105-H building modifications and material handling equipment needed to excavate and monitor the fill removal. The construction and procurement specification for major work components were prepared during the definitive design phase. A 150-hp vacuum will be used as the primary backfill removal system at the 105-F basin. By eliminating the need for the belt conveyor system at 105-F, installing, dismantling, and transferring components for the 105-H basin effort will not be required. This will result in a potential savings of approximately $343,000.

Basins Remediation Action Plan

During FY 1991 and 1992, the fill (soil and water) in 105-F and 105-H basins will be sampled and analyzed to define the material packaging and disposal strategy, and determine the methods to be used for the fill dispositioning. The basin fill material will be characterized both for radionuclides and chemicals parameters. The analytical results will serve as boundaries for these materials to determine if the fill should be designated as noncontaminated, radioactive-contaminated, dangerous, or mixed waste, and to identify proper disposal methods.

The basin operations will install an air handling systems for the work area that filters, preheats, and exhausts outside air via an exhauster with one bank of nine prefilters, and two banks of nine HEPA filters [0.472 m^3/s (1,000 ft^3/m) per filter]. The exhaust stack contains differential pressure port, velocity, and radiation sampling probes. Radiation sampling of the stack effluent discharge is on a continuous basis utilizing alpha and beta-gamma continuous air monitors, and record samples.

Water in the 105-H basin will be pumped out before backfill removal is initiated. The residual water collected will be transported for disposal in an approved Hanford Site facility. Fill removal from the basins will be performed by the 150-hp vacuum and small loader tractors using clamshell buckets at 105-H basin (Fig. 1) to discharge the fill onto conveyor systems leading into trucks and/or shipping containers. Metal and radiation detectors will be mounted on the conveyor systems. Metallic or radioactive material passing the detectors will immediately stop the systems so the material can be removed.

Debris, sediment, and soil that is highly contaminated (greater than 100-mR/hr) will be placed in concrete-lined

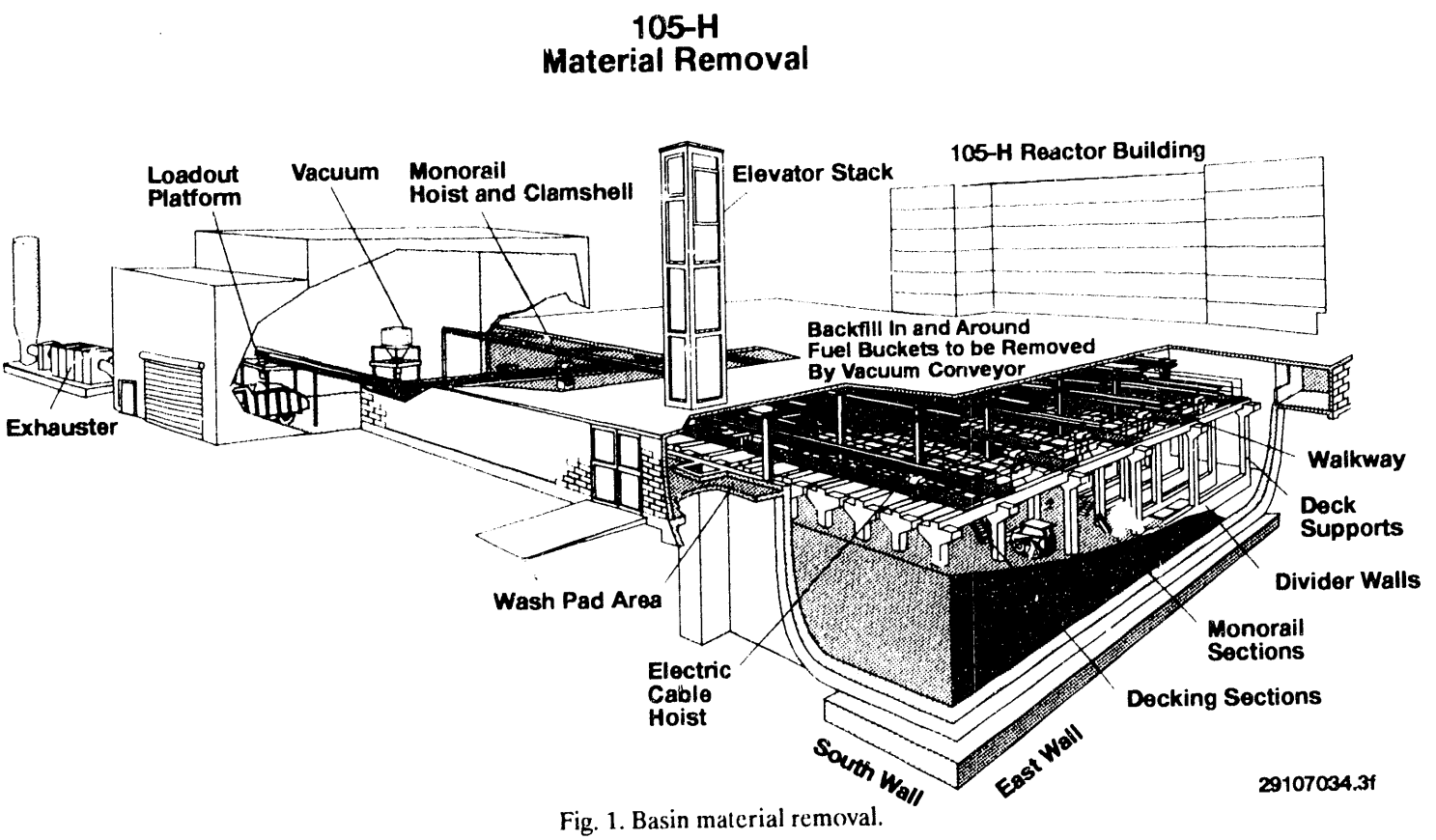


Fig. 1. Basin material removal.

steel containers and sent to the 200 Area for disposal. Uncontaminated and low-level radioactive contaminated fill will be disposed of at respective approved locations.

Fuel elements will be placed in certified shipping casks for transfer to 100-K Area basins. The material containing dangerous waste will be removed for disposal at an appropriate *Resource Conservation and Recovery Act of 1976** (RCRA) compliant facility. Mixed waste will be segregated from other waste to reduce the volume requiring processing and dispositioning as mixed waste.

The 105-F and 105-H basins' fill removal may present some radiological hazards if irradiated fuel items are found. Experience gained in past basin cleanout projects (i.e., 105-B, -C, -D, and -DR basins) will prove invaluable in dealing with the expected radiological conditions. As the backfill removal process approaches the bottom of the basins a layer of soil will be used for shielding approximately 1-m (3-ft) from the bottom of the basins. This will keep exposure levels at a minimum and prevent workers from coming in contact with high dose rate items. From that depth downward, only small areas will be excavated at a time within the 105-H basin and a small backhoe attachment will be used on a loader tractor and will provide shielding and distance for the operator allowing for prudent extraction of high dose rate items. At both basins the actual removal of some items may require the use of remotely operated equipment or tools. The control of contamination problems will be achieved using existing standard equipment and procedures. Experience show these procedures to be effective in keeping radiological hazards as low as reasonably achievable with respect to the work force.

As the initial basin area is cleared of unnecessary equipment, the walls and floor will be either coated with a fixative in preparation for in-place decommissioning or stabilized for dismantlement decommissioning.

PROJECT ACTIVITIES

Fill Sampling and Analyses

Sampling and analyses of the 105-F and 105-H basins' fill (soil and water) is required to characterize the basin materials. These data will be used to define the material packaging and disposal strategy, including methods that will be used for the fill dispositioning. The basin fill material will be characterized for both radionuclides and chemicals parameters. The analytical results will be used to determine if the fill should be designated as noncontaminated, radioactive-contaminated, dangerous, or mixed waste, and to identify the boundaries of these materials so that they can be disposed of properly.

The sample methodology utilizes a stratified three dimensional random and bias grab sampling strategy (e.g., landfill strategy) based on process knowledge with analytical methods used in accordance with the U.S. Environmental Protection Agency's (EPA) guidelines or their equivalent. The sampling plan was developed to provide a statistically representative sample database for characterization of the fill, sediment, and water in the basins.

* Resource Conservation and Recovery Act of 1976, as amended, Public Law 94-580, 90 Stat. 2795, 42 USC 6901 et seq.

Each basin will have ten sites for vertical sampling. Four sites will be for inorganic/organic (I/O) and radionuclide/transuranic (R/T) sampling, and six will be for near-surface radionuclide sampling. The four sites designated for vertical I/O and R/T sampling will have four locations for obtaining strata samples the "surface" 0 m (0 ft), -3.1 m (-10 ft), -5.2 m (-17 ft), and the "bottom" -6.1/-9.1 m (-20/-30 ft) materials. Five of the six sites designated for vertical near-surface radionuclide sampling will have three strata sampling locations at surface level, -3.1 m (-10 ft), and -5.2 m (-17 ft). The sixth near-surface site will have strata sampling locations at 0.305-m (1-ft) intervals from the surface to the -5.2 m (-17 ft) depth.

The basins' backfill method and known conditions before the basin was filled is contemplated to have established a uniform stratified I/O distribution throughout the majority of the fill. The greatest concentration of radionuclides and chemicals near the basins' floor may have been in contact with residual basin water and sediment material. The vertical sampling locations designated to sample bottom materials were selected utilizing a bias sampling strategy. This was based on previous basin high concentration of material locations identified when cleaning the 105-B, -C, -D, and -DR basins. The near-surface sample locations were selected utilizing a random and bias sampling strategy, and will be used as a backup site for obtaining bottom samples in case the primary bottom sites fail to reach the basin bottom.

Based on the previous activities and known conditions in the 105-F and 105-H basins, four potential populations have been identified for sampling purposes. Two populations for the I/O related sampling are -6.1 m or -9.1 m (-20/-30 ft) "bottom" to a -5.2 m (-17 ft) basin surface. Two for the R/T related sampling are also a -6.1 m or -9.1 m (-20/-30 ft) "bottom" to -5.2 m (-17 ft) surface, with a possible -5.2 m (-17 ft) to -3.1 m (-10 ft) strata that may contain radionuclide concentrations levels between those of the bottom material requiring low level burial disposal and those above levels of release for local demolition disposal sites. In this situation the -5.2 m (-17 ft) to -3.1 m (-10 ft) strata may allow local facilities using allowable residual concentration level (ARCL) methodology for below grade space in situ disposal alternatives to be utilized. The two I/O related sampling populations consist of those basin strata where material that could be designated as dangerous waste are not anticipated to be present [-5.2 m (-17 ft) to basins' surface] and the basin strata where material that could be designated as dangerous waste may be present [-67.1/-9.1 m (-20/-20 ft) at the basins' bottom] to -5.2 m (-17 ft). The two R/T related sampling populations consist of those basin strata where radionuclide concentrations levels for low level and/or transuranic (TRU) materials are not anticipated [-5.2 m (-17 ft) to basins' surface] to be present and those basin strata where radionuclide concentrations levels for low level and/or TRU materials are anticipated [-6.1/-9.1 m (-20/-30 ft) to -5.2 m (-17 ft) at the basins' bottom] to be present.

The two I/O and R/T related sampling populations have been identified due to the residual basin material (sediment and water) residing in proximity of the basins' floor during the backfill placement (dump truck/dozer) operation from the top-sides of the basins' area. It is postulated that the 105-F and 105-H basins have a uniform distribution of inorganic and organic which are probably present in insufficient concentrations to be designated as mixed waste based on the past backfill material sampling of the 105-F and -H basins and the sampling of residual basin material from 105-B, -C, -D, and -DR basins.

The two R/T related sampling populations have been identified because of irradiated fuel breakage during defueling operations. The breakage has the potential of spreading the TRU material to other parts of the basin through fuel handling operations. The sampling strategy was to select the basin areas where sediment processed fuel segment was found in 1984, while cleaning the basins. It is anticipated that TRU materials in insufficient concentrations requiring TRU disposal will most likely be present in these areas only.

Based on the four anticipated populations discussed above and previous functional uses of the basin areas listed below, the areas have been stratified into the bottom [-6.1/-9.1 m (-20/-30 ft) to -5.2 m (-17 ft)], middle [-5.2 m (-17 ft) to -3.1 m (-10 ft)], and top [-3.1 m (-10 ft) to basins' surface] strata.

- The transfer pits are where the fuel elements were removed from the fuel storage buckets and placed into well-car transfer casks.
- The fuel element discharge chute area is where the elements entered the basins after discharge from the reactor process tubes, and then were picked up and placed in the fuel storage buckets before being moved from this area for basin storage.
- The wash pad area is where process components could be lifted out of the basins via an elevator onto the wash pad.
- The center of the basins' storage area is considered to be the area that best represents the majority status of the basin materials without the above influences.

Based on EPA guidelines, a stratified three dimensional bias and random grab sampling plan has been applied to each of the three stratums listed previously. Using this plan, four basin site locations have been identified for sample collection. The cost for one I/O analyses is substantial and the distribution is expected to be uniform throughout the majority of the basin area. Fill/sediment (F/S) from only the bottom [-6.1/-9.1 m (-20/-30 ft), -5.2 m (-17 ft), and -3.05 m (-10 ft)] levels in each of the four sites will be sent to the laboratory for I/O analyses or 12 of the 16 samples obtained. The F/S from all 20 samples will be sent to the laboratory for radioisotopic (R or R/T) qualitative and quantitative analyses. Two duplicate F/S samples (6.5 liter samples divided into containers according to test laboratory requirements) will be collected from two of the four sites in the basin areas designated for both I/O and radioisotopic analyses, and will be sent to the appropriate laboratory for analyses, along with the other samples, to check the consistency of laboratory results.

Within each of the four locations identified for sampling, the locations for collecting the samples will be specified in the sampling procedure. The sampling points will be based on the sediment areas identified when the basins were cleaned in 1984.

A total of four, 4.5-liter water samples will be collected during the sampling of the basin areas. The water in the basin became mixed during the 1970 pumpdown and to layaway levels during backfilling and has remained dormant for 21 years. A 6.5-liter sample will be taken at each basin when

obtaining the bottom [-6.1/-9.1-m (-20/-30-ft)] F/S sample at the transfer pit, chute pick up area, and the center of the basin. These samples will be subjected to I/O and radioisotopic (including tritium) analyses.

If the I/O or R/T analyses identify I/O substances or radionuclides in the samples designating the materials as mixed waste or TRU waste, then statistical analyses shall determine the boundaries of these material so that they can be disposed of appropriately.

Quality control (QC) samples will be prepared and shipped with samples subjected to I/O analyses to ensure that sampling, transportation, and analyses processes have not contaminated these samples. The QC samples will consist of one trip blank for each 20 sample location points. These samples will be subjected to I/O analyses. For each medium sampled a QC field/rinsate blank sample will be obtained (i.e., one for water sampling, one for F/S sampling, and one for slurry sampling).

The sample collection will be accomplished using a combination of sampling equipment. The basin wireline core-barrel sampling (WCBS) will utilize the vibratory drill unit to advance the boring/sample components. A head assembly attached to the inner barrel allows it to remain stationary while the outer barrel is rotated. The vibratory drill exerts pressure on the bit and rotation is not considered necessary for basin sampling. The WCBS does not have to remove the outer barrel from the boring each time a sample is taken. If needed, the core-barrel can be fitted with a plug bit and the boring advanced without taking subsurface samples.

Depth measurements shall be logged in the field log and are based on cumulative measurements of drill rods, length of down hole tools, constants, and amount of stick-up at the borehole collar. Particular attention must be paid to ensure that the sample depth of the bit is at the correct location.

The basin liquid pumping method will utilize the WCBS/vibratory drill unit to provide the access channel for the sample tube. Liquid samples will be obtained from the basins' bottom using a peristaltic or roto-flex pumps.

The laboratories will separate the liquid and solid phases to obtain material required for the analyses. The four sets of two 40-ml samples will be collected in 40-ml volatile organic analysis septum bottles. The septum bottles shall be filled ensuring that no air bubbles are trapped within the bottles when closed.

The sampling lines and apparatus will be replaced with new precleaned components after each location point is sampled to prevent cross-contamination of the samples. The sampling apparatus before being reused will be swiped, surveyed, and radiologically decontaminated. After use the apparatus will be sent to the 1706-KE RCRA Decontamination Facility for chemical cleaning. The QC sample (i.e., trip blank and rinsate) described in the sample work procedure will be prepared and analyzed along with the other samples to determine if the samples were contaminated during sampling, transportation to the laboratory, or during laboratory analyses. If contamination of the sample is determined from this QC sample, resampling may be required.

105-F Basin Fill Removal Work

The sandy fill in the 105-F basin will be removed by a 150-hp vacuum equipped with a 7.6-m^3 (10-yd^3) hopper and double-tipping discharge valve for continuous operation. Up to three 10.2-cm (4-in.) diameter pick-up nozzles at the end of flexible hoses will be connected to the six fixed pick-up stations located throughout the basin. The nozzles will be supplied with an intake screen to prevent the entry of materials larger than 3.493-cm (1.375-in.). The vacuum will be mounted over the lower end of a inclined screw conveyor on an elevated platform located in the transfer bay. The screw conveyor will discharge into trucks or containers on the floor through a loading spout at maximum rate of 27,213 kg/h (30 tons/h). A dust collector connected to the screw conveyor and the loading spout will be provided.

A metal detector surrounding the vertical chute under the vacuum discharge, and one or more radiation detectors will be mounted over the high end of the screw conveyor.

To facilitate the removal of buckets and miscellaneous items from the basin floor, five monorails equipped with 1,814 kg (2 ton) capacity motorized hoists will be provided. Because the strength of the existing roof beams, the maximum hook load on the hoist will be limited to 1,360 kg (1.5 tons) at this basin. Prefabricated metal catwalks for the hoist operators and a 1.52-m (5 ft) wide wood walkway for moving the recovered items to the wash area will be also provided. The catwalks are designed for 800.5-kg/m^2 (50-lb/ft^2) uniform loading, and the wood walkway for a 2,401-kg/m^2 (150-psf) uniform or a 226.8-kg (500 lb) concentrated moving load to accommodate the platform trucks used on the walkway. Two sets of access stairs to the excavation area will be provided. Each section of the stair will cover a 1.37-m (4.5-ft) excavation depth and will be supported by hangers from the existing concrete beams. As the excavation deepens a new stair section will be installed.

Fill removal will start at the transfer pits followed by the basin area which will be excavated in .61-m (2-ft) deep lifts. To reduce dust at the beginning of the excavation, and to reduce or totally eliminate the need for dewatering as the work reaches the lower part of the fill, the top of the excavation will be sloped 10 percent or more to the north. The three nozzles will be arranged to operate in the lower (wetter) and higher (dryer) fill areas at any one time. This will result in a more uniform moisture in the reclaimed sand. Near the end of the excavation, the sand may have to be partially dewatered to remove "free moisture." This will be done by slowing down the speed of the screw conveyor (i.e., changing reducer pulley(s) and V-belts) to allow more time for dewatering. Water removed by the screw conveyor weir section may be collected in two steel settling tanks placed next to the equipment, then pumped to Frac-tanks or drums in an adjoining area for solidification and disposal. These tanks will be filled and emptied alternately to allow for silt settlement.

Any metallic material leaving the hopper or radioactive material passing the detectors will immediately stop the double-tipping discharge valve and the screw conveyor so that the material can be removed. The vacuum will remain online until its hopper is filled to capacity and the system is shut down automatically.

Operations will resume by starting the screw conveyor and hopper discharge valve, followed by the vacuum system when the material level in the hopper has fallen below the low-level detector.

Steel lifting hooks, lifting grips, and sharp pointed lifting tongs attached to the hoist will be used to remove the buckets, monorail beams, and wood material. These will be placed on

the platform trucks operating on the 1.52-m (5-ft) wide wood walkway connected to the wash pad area.

Debris, sediment, and soil that is highly contaminated (i.e., reading greater than 100 mR/h) will be placed in concrete-lined steel containers and sent to the 200 Area of the Hanford Site for disposal. Uncontaminated fill will be disposed of in the area's concrete clearwell basin or other approved location. Low-level radioactive contaminated fill will be analyzed to determine if it can be disposed of in the below-grade spaces in the 105 facility or other approved location. Disposal cannot cause the facility to exceed the 25 mrem/yr release limit when they are decommissioned. Fuel elements would be placed in containers for transfer to 100-K Area basins. The material containing dangerous waste will be removed for disposal in an appropriate RCRA-compliant facility. The mixed waste will be segregated from the other waste categories to reduce the volume of waste requiring processing and dispositioning as mixed waste.

As the initial basin area is cleared of unnecessary equipment, the walls and floor will be coated with a fixative for in-place decommissioning, or stabilized for dismantlement decommissioning.

105-H Basin Fill Removal Work

The sandy gravel fill with some cobbles in the 105-H basin will have approximately 74% passage through a 3.8-cm (1.5-in.) standard sieve and can be vacuumed; the remaining 26% must be removed by small loader tractors. The three loaders will remove more of the fill since the buckets will pick up some of the fines. Dewatering of this basin will be completed before fill is removed.

Fill removal in this basin will be by the 150 hp vacuum and loader/clamshell buckets, both discharging onto a belt conveyor. The conveyor will discharge onto the trucks or containers of the floor through a loading spout at maximum rate of 27,313 kg/h (30 tons/h). Dust collectors connected to the conveyor head chute and the loading spout will be provided. Monorails [1,814-kg (2-ton) capacities], with operator catwalks, and a 3.96-m (13-ft) wide wood walkway design to support the belt conveyor and a 2,401 kg/m^2 (150 psf) uniform load or the empty weight of a loader tractor will be provided.

The metal detectors and the radiation detectors will be mounted on the belt conveyor downstream of the vacuum discharge.

Fill removal will be in .61-m (2-ft) deep lifts starting with the vacuum removing the minus 3.8-cm (1.5-in.) material in a designated area (initially, in the two rows where the deck beams were removed) of the basin. The loaders will follow to remove the plus 3.8 cm (1.5 in.) material and some of the sand in the same area, while vacuuming of the minus 3.8 cm (1.5 in.) material is performed in other areas of the basin. These steps will be repeated until the basin is cleared of all material.

Any metallic or radioactive material passing the detectors will immediately stop the double-tipping discharge valve and the belt conveyor so that the material can be removed. The vacuum will remain on line until its hopper is filled to capacity and the system is automatically shut down.

Operations will resume by first starting the belt conveyor and the hopper discharge valve, followed by the vacuum system when the material level in the hopper has fallen below the low-level detector. The loader tractor may also resume working as soon as the conveyor has started.

Steel lifting hooks, lifting grips, and sharp pointed lifting tongs attached to the hoist will be used to remove the buckets, monorail beams, wood material and place them on the platform trucks operating on the 3.96-m (13-ft) wide wood walkway connected to the transfer bay area.

Debris, sediment, and soil will be dispositioned and disposed of in a manner similar to the 105-F basin materials.

As the initial basin area is cleared of unnecessary equipment, the walls and floor will be coated with a fixative for in-place decommissioning or stabilized for dismantlement decommissioning.

CONCLUSIONS

The project design will leave the facilities in a condition for the decommissioning alternative that is selected by the EIS ROD. The project will ensure that the basins are free of fuel elements and are ready for final decommissioning.

The basins' fill sampling and analysis will identify, establish boundaries, and facilitate disposal of the materials as nonradioactive contaminated, mixed, and/or hazardous chemical waste. The fill sample analyses report will reduce or eliminate the need for in-process material analyses except for specific disposal conditions and may make the field survey instruments the primary, material disposal designating tool.

The basins' material disposal will be considered under the jurisdiction of DOE. If hazardous chemical waste are identified, activities related to permitting and conduct will be implemented in accordance with the EPA and Washington State Department of Ecology.

A ROD for the surplus production reactor decommissioning EIS is expected to be issued in the last quarter of FY 1991. It is anticipated that the ROD will select decommissioning the reactor facilities by dismantlement and moving the reactor block material to an approved burial ground near the 200 Area of the Hanford Site. The ROD is also expected to concur on dispositioning of the remaining rubble using ARCL methodology.

DETERMINATION OF THE PROBABILITY FOR RADIOACTIVE MATERIALS ON PROPERTIES IN MONTICELLO, UTAH

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ABSTRACT

The former uranium mill site at Monticello, Utah, is a surplus facility subject to clean-up under the Surplus Facilities Management Program (SFMP). Surrounding properties contaminated with mill site material are also subject to cleanup, and are referred to as Monticello Vicinity Properties (MVP). The Pollutant Assessments Group (PAG) of Oak Ridge National Laboratory (ORNL), Grand Junction, Colorado (GJ), was directed by the U.S. Department of Energy (DOE) in July 1988 to assess the radiological condition of properties in Monticello, Utah. Since the Monticello activities are on the National Priority List, extra measures to identify potentially contaminated properties were undertaken. Thus, the likelihood that a random property could contain radioactive materials became a concern to the DOE.

The objective of this study was to determine the probability that a vicinity property not addressed under the MVP project could contain Monticello mill-related residual radioactive material in excess of the DOE guidelines. Results of this study may be used to predict the potential number of unassessed properties in Monticello that contain radioactive contamination that exceeds DOE guidelines and will require remedial action.

Statistical methods were used to select forty-eight random properties in the Monticello area. Consent to access the properties was obtained from the landowners involving sensitive public relations. Radiological screening surveys were performed in accordance with radiological survey procedures developed by the ORNL/PAG/GJ. The surveys covered the entirety of the forty-eight land parcels. Gamma exposure rates were recorded and mapped. Soil samples were collected at each property from locations exhibiting elevated gamma levels or from locations exhibiting general background if no elevated gamma exposure rates were detected. Each sample was thoroughly described in the field for petrologic makeup, color, texture, and content. The soil samples were then analyzed for ^{226}Ra using a Sodium Iodide (NaI) gamma spectrometer.

Results suggest approximately 20% of the properties in the Monticello area contain Monticello mill-related residual radioactive material in excess of the DOE guidelines. This suggested that further designation measures be taken prior to the close of the designation phase. A public relations effort that included a property-owner mailing effort, public posting, and newspaper advertisement was one measure taken to ensure that most properties were assessed. As a consequence of this study, DOE directed that radiological screening surveys be conducted on the entirety of the Monticello area.

INTRODUCTION

In 1978, under the authority of the Atomic Energy Act, the U.S. Department of Energy (DOE) established the Surplus Facilities Management Program (SFMP) to manage the maintenance and surveillance of numerous DOE-owned, radioactively contaminated facilities that were declared surplus and to conduct a program leading to the ultimate disposition of those facilities. The former uranium mill site at Monticello, Utah is one such facility and is referred to as the Monticello Remedial Action Project (MRAP). Surrounding properties contaminated with mill site material were also subject to cleanup under the SFMP and were referred to as the Monticello Vicinity Properties (MVP) project. The primary responsibility of SFMP was to protect public health and the environment from potentially harmful radioactive contamination contained within or derived from DOE-owned facilities. Management of SFMP activities is currently directed by the Division of Eastern Area Programs, Office of Environmental Restoration and Waste Management, U. S. Department of Energy Headquarters, Washington, D.C.

Prior to the remediation of the Monticello mill site under MRAP, privately owned properties surrounding the mill site were assessed for inclusion in the MVP Project. The Pollutant Assessments Group (PAG) Oak Ridge National Laboratory (ORNL), Grand Junction, Colorado (GJ), was directed by DOE in July 1988 to assess the radiological condition of properties identified as potentially containing Monticello mill-related materials. Those with associated radiation levels that exceed Environmental Protection Agency (EPA) standards set forth in 40 CFR 192 (1) and DOE standards are eligible for cleanup under the MVP Project (2). ORNL/PAG performed gamma radiation screening surveys to detect potential mill-related materials. The properties subjected to screening surveys were those that were detected during mobile gamma radiation scans (3) and also from information provided by property owners and mill employees. The Superfund Amendment and Reauthorization Act of 1986 (SARA) placed the SFMP-MVP activities under the regulatory framework of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA). Since the Monticello properties are on the National Priority List (NPL),

extra measures to identify potentially contaminated properties were undertaken. The likelihood that a random property could contain radioactive materials became a concern to the DOE.

OBJECTIVE

The objective of this study was to determine the probability that a vicinity property not addressed under the MVP project could contain Monticello mill-related residual radioactive material in excess of the DOE guidelines. Results of this study may be used to predict the potential number of unassessed properties in Monticello that contain radioactive contamination that exceeds DOE guidelines and will require remedial action (1). Further vicinity property investigations may be conducted depending on these results.

BACKGROUND

Mill Sites

The mill site at Monticello, Utah, was built in 1942 by the United States government to provide vanadium during World War II. Various government agencies operated the mill until 1947. In 1948, the Atomic Energy Commission (AEC) obtained the mill and operated it under contract through 1959 for the purpose of producing both uranium and vanadium. During the AEC era, the mill processed approximately one million metric tons of uranium ore. Because uranium and vanadium were the only substances extracted in the milling process, other constituents of the ore such as radium and thorium remained in the tailings at the time of disposal. Throughout the mill's operation, area residents used these tailings as fill material and as aggregate in mortar and concrete. On January 1, 1960, mill operations were terminated. In July 1965, the ore stockpiles and other contaminated material were removed from public access and the mill site foundations covered with topsoil. During 1974 and 1975, additional clean up by the DOE included demolition of concrete foundations and subsequent trench burial. In 1981 the mill site was declared surplus and accepted into SFMP; the site is now awaiting remedial action to bring its condition up to current DOE decontamination and reclamation standards.

Another mill site in the area is a privately owned former vanadium mill, the Dry Valley mill site, located approximately 40 km northeast of Monticello. This mill produced vanadium from 1931 to 1938. Monticello residents and building contractors used radioactive material from this site extensively. The Dry Valley mill site was covered and revegetated in 1984.

Previous Surveys

Several radiological investigations and surveys were conducted in Monticello prior to the assignment of ORNL/PAG as the survey contractor. In 1971, the EPA sponsored a survey which investigated 494 structures in Monticello and recorded 62 radiological anomalies. In 1980 an EPA-sponsored survey examined 810 structures and recorded 55 gamma anomalies (gamma measurements 20% greater than background) (4). The EPA surveys were performed with mobile gamma detection and also at the request of property owners. These properties combined represent the original list of properties considered for remedial action in the MVP project. In 1982, Bendix Field Engineering Corporation surveyed the properties identified by the EPA surveys to provide further information on their radiological condition. In 1983, ORNL, Oak Ridge, Tenn., conducted a mobile gamma scan which located 36 new properties exhibiting anomalous gamma levels (3). On-site surveys were conducted at the additional properties and at the previously identified properties to once again assess radiological contamination. By the end of 1984, 170 properties had been surveyed, and 47 properties were found to exceed the DOE guidelines. By March of 1989, 204 properties had been surveyed, and 87 properties were found to exceed the DOE guidelines. The increase in properties surveyed was due to the discovery of contamination which spilled over to adjacent properties and additional owner requests. The number of properties which exceeded DOE guidelines increased due to: 1) the application of current DOE protocol involving "hot spots" of uranium ore, and 2) spill-over contamination detected during remedial action of other properties (5).

In addition to investigations and surveys performed by the EPA and DOE, other radiological studies took place in Monticello in the early 1980's. A legal action alleging that seven leukemia deaths in Monticello were caused by ionizing radiation from the Monticello mill tailings piles prompted studies by the University of Utah and others. These studies involved the measurement of cumulative gamma radiation dose from brick and porcelain samples obtained from residences throughout the town (6).

In light of the history mentioned in the previous paragraphs, the Superfund Amendment and Reauthorization Act of 1986 placed the MRAP and MVP under the regulatory framework of CERCLA. Both the MRAP and MVP have been NPL sites since 1987.

Windblown Contamination

Properties suspected of containing windblown radioactive contamination from the Monticello mill site were excluded from this study to avoid any bias. Properties in close proximity to the mill site were known from previous surveys to contain radioactive material broadcast by wind, resulting in contamination exceeding the DOE guidelines. Therefore, the boundary of the windblown contamination from the Monticello mill site was defined as described below to initiate this study (See Fig. 1).

The concentration limit for ^{226}Ra was set at approximately 0.26 Bq/g (0.19 Bq/g above a background of approximately 0.07 Bq/g) for defining the boundary of windblown contamination. This boundary shows the areas where windblown contamination has a high potential for exceeding DOE guidelines. The DOE intends to address the southern boundary of the windblown area at the time of mill site remediation, and, therefore, ORNL/PAG defined only the northern half of the boundary. The land parcels to the south are large tracts of public land and agricultural fields which may potentially be acquired by DOE.

To establish the windblown boundary, topographical maps were studied, and a conceptual model of windblown contamination was developed from a 1982 to 1986 meteorological survey based on wind direction, wind velocity, and turbulence patterns (7). Property surveys documenting windblown contamination were reviewed, and these locations were added to the model. The winds predominate from the south, west-southwest, and northwest, the strongest coming from the south and northwest. The boundary encircling the mill site where ^{226}Ra concentrations in soil are 0.26 Bq/g or more was

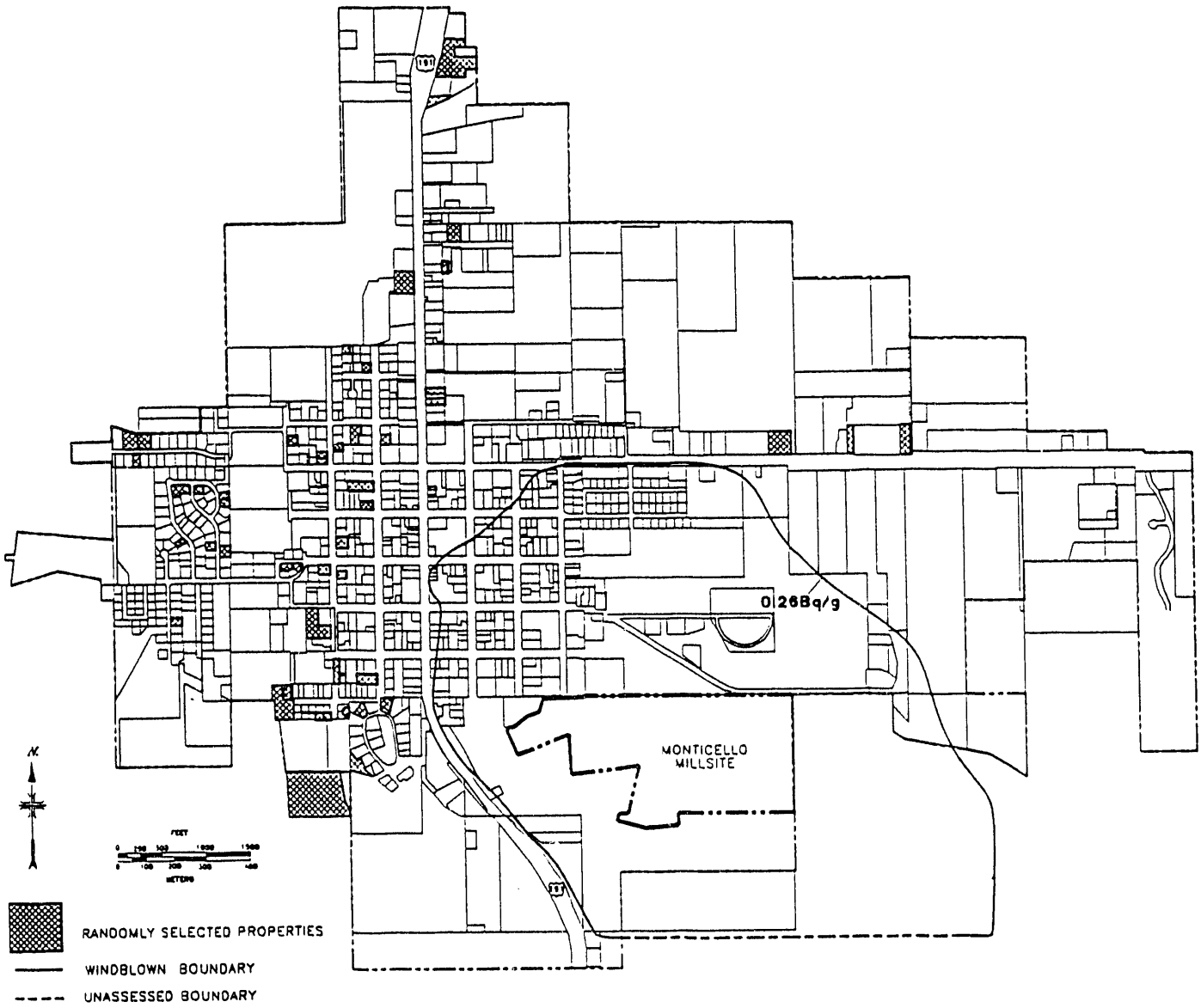


Fig. 1. Randomly selected properties outside the windblown boundary in Monticello, Utah.

estimated to be within approximately 0.5 to 1.0 km of the mill site. Subsequently, 18 locations were selected within this approximate distance, and radiological surveys of those locations were conducted to establish a more accurate boundary. The resulting data from these surveys provided the final estimate of the windblown boundary and were also used as a preliminary estimate for the study this paper addresses. These 18 surveys will be termed "the preliminary surveys" for the purpose of this report.

The preliminary survey results indicated varied sources of contamination. Not only was windblown contamination documented, but other sources, such as material from the Dry Valley mill used in brick and masonry structures, point sources of mill-related ore, and ore fill, were also recorded. Because of the unforseen presence of these various sources, the DOE questioned that other such material may have been undetected by earlier surveys. Since there was a high potential for exceeding guidelines, the properties within the 0.26 Bq/g windblown line were excluded from the sample set of this study.

METHODS

The initial definition of the sample size used the preliminary surveys which were found to contain a wide variety of radioactive sources in addition to establishing the windblown line. The percentage of properties in the preliminary surveys which exceeded DOE guidelines was high (72%) because of their close proximity to the windblown contamination from the mill site. This fact does not significantly affect the resulting sample population. The following paragraphs detail the assumptions and statistical methods used to establish the sample population.

Sample Design

The objective of sampling was to perform radiological assessments on randomly selected properties which had not

been previously surveyed and were outside the windblown boundary and to determine from the data collected whether radiation levels exceeded DOE guidelines. The sampling would then provide a statistical view of the potential existence of radioactive materials on properties in the vicinity of the Monticello mill site.

The study area was limited to inside the city of Monticello boundaries; adjacent agricultural fields were not candidate properties. This assumption narrowed the sample population to smaller parcels of land, enabling a more expedient survey and increasing the chance of detecting contamination in a more densely populated area where risk associated with radioactivity is greater. Property definitions provided by the city of Monticello map were assumed to be sufficiently accurate for the purpose of this study; therefore, the plat map delineating the exact parcel definitions was not used. This assumption provided an expedient method for comprehensive selection of properties. Properties outside the city limits were not considered in the study because they consist of agricultural or public lands that exceed 81,000 m^2 and present too large a parcel to be surveyed in a reasonable time limit. The size of the properties is not homogeneous and exhibits variation in land use. Sizes of properties surveyed ranged from less than 4,000 m^2 to approximately 40,000 m^2.

The preliminary surveys used to define the windblown boundary were also used to design the sample population for this study. Again, these locations were hand-picked in areas determined by ORNL/PAG to have the best potential for locating the windblown boundary. Results of the preliminary surveys indicated that 13 properties (72%) had radiation levels that exceeded DOE guidelines and five (28%) had radiation levels that fell below DOE guidelines (DOE 1987). Again, the high percentage of those that exceeded the DOE guidelines was due to the fact that these properties were in such close proximity to the windblown area. This would result in a conservative estimate of size for the sample population.

The procedure used to design the best estimate of sample size to represent the entire population of properties (376) was determined as follows: (8).

$$n' = \frac{2.7pq}{L^2}$$

where

n' = preliminary sample size

p = percentage of preliminary property surveys exceeding guidelines, 72%

q = percentage of preliminary property surveys below guidelines, 28%

L = acceptable error, 10%.

Note: L is the allowable error in the sample mean. The confidence level for this study was 90%. Our projections showed that a lower confidence interval would not significantly decrease the sample number but could conceivably compromise accuracy. A higher confidence interval would significantly increase the sample population, resulting in increased data analysis and extended time frame which did not seem justifiable to meet the objectives of this study.

Therefore,

$$n' = \frac{2.7(0.72)(0.28)}{(0.10)^2} = 54.43.$$

The sample size was further defined by using the finite population correction as follows:

$$n = \frac{n',}{\frac{1+n'}{N}}$$

where

n = corrected sample size for finite population

n' = preliminary sample size

N = population.

Thus,

$$n = \frac{54.43}{1+\frac{54.43}{376}} = 47.55.$$

On the basis of this statistical analysis, 48 properties were randomly selected for radiological surveying as the sample population using an electronic number generator on a personal computer. The properties included in the sample set are shown in Fig. 1.

The total population of 376 properties was developed for the study by selecting properties outside the 0.26 Bq/g windblown line. Properties intersected by the windblown line were conservatively considered to be inside the line.

Survey Procedure

Consent to access the properties was obtained from the landowners, radiological screening surveys were performed, soil samples were collected and analyzed, and reports were issued for each vicinity property.

The radiological surveys performed on the sample set were in accordance with DOE approved radiological survey procedures developed by the ORNL/PAG for use in the MVP and also in the Uranium Mill Tailings Remedial Action Project (UMTRAP) (9). The surveys covered the entirety of the land parcel. Gamma exposure rates were recorded and mapped. Soil samples were collected at each property from locations exhibiting elevated gamma levels or from locations exhibiting general background if no elevated gamma exposure rates were detected. Each sample was thoroughly described in the field for petrologic makeup, color, texture, and content. The soil samples were then analyzed in a laboratory for ^{226}Ra, ^{40}K, and ^{232}Th using a NaI gamma spectrometer.

It was noted that the potential percentage of properties exhibiting elevated radiation levels may include non-Monticello mill-related contamination. Examples of radioactive contamination not resulting from Monticello mill site activities include contamination originating from the Dry Valley mill site and ore samples acquired by area residents as "collectors' items." When possible, the existence of non-Monticello mill-related contamination was documented in the survey by a statement from the property owner, and these properties were not included for remedial action in the MVP Project. However, in some instances documentation of contamination origin was not possible, or the contamination was a combination of sources related and not related to the Monticello mill site. When these cases were encountered it was the policy of the DOE to take the conservative approach

of including these properties for remedial action if they exceeded the DOE guidelines.

RESULTS

Table I gives the source of contamination and the remedial action status for each of the 48 properties surveyed. Table II summarizes the data presented in Table I by providing the percentage for each status classification given in Table I and by categorizing the type of radioactive material found and the percentage of properties containing that material. The values in Tables I and II show that there is a 90% probability that at least 21% of the properties in the Monticello area contain Monticello mill-related residual radioactive material in excess of the DOE guidelines.

Twenty-one percent of the 376 tot properties outside the windblown lines is 79 properties. Subt the 10 properties from the sample population alre termined to exceed DOE guidelines, the potential remains for 69 additional properties which are currently unassessed to have contamination exceeding guidelines.

DISCUSSION

In view of the fact that approximately one out of every five properties outside the windblown line that had not already been surveyed could exceed the DOE guidelines and given the risk associated with radiation, it was evident to the DOE that further measures to assess properties in the area should be taken. Thus, the DOE determined to assess 100% of the properties in Monticello.

Further study of the Dry Valley mill site and the masonry contractors who built these structures has been undertaken to more accurately identify those properties solely contaminated with materials from Dry Valley for which the DOE has no authority. Since the type of contamination present on these properties has the potential to produce indoor radon concentrations above EPA standards, this further study was undertaken immediately so that appropriate action could be taken as soon as possible.

The results of this study may influence the language used in public relations. Over fifty percent of the properties examined during the study had elevated gamma radiation levels (although only 21% exceeded DOE guidelines), indicating that properties in Monticello have a high probability of containing residual radioactive material. Therefore, efforts should be made to communicate this fact and the associated risk effectively to the public in order to obtain maximum participation.

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TABLE I

Analytical Summary of the 48 Monticello, Utah, Properties Outside the Boundaries of Windblown Contamination, Randomly Chosen for Statistical Study

No.	Source of contamination	Status
1	Ore and tailings	Exceeds guidelines
2	Ore fill	Exceeds guidelines
3	Tailings	Exceeds guidelines
4		No elevated gamma
5	Tailings	Exceeds guidelines
6		No elevated gamma
7	Ore and ore fill	Exceeds guidelines
8		No elevated gamma
9		No elevated gamma
10	Ore	Exceeds guidelines
11	Petrified wood	Exclusion +
12	Ore	Exclusion
13	Radium dial	Exclusion
14		No elevated gamma
15		No elevated gamma
16		No elevated gamma
17		No elevated gamma
18	Fireplace/woodstove	Requires RDC *
19	Ore fill	Exceeds guidelines
20		No elevated gamma
21		No elevated gamma
22	Ore and tailings	Exclusion
23	Ore	Exclusion
24	Brick/mortar, fireplace/woodstove	RDC measurement
25		No elevated gamma
26		No elevated gamma
27	Tailings	Exceeds guidelines
28		No elevated gamma
29	Old mine tarp	Exclusion
30		No elevated gamma
31	Ore	Exceeds guidelines
32	Fireplace/woodstove	Exclusion
33		No elevated gamma
34	Ore	Exclusion
35		No elevated gamma
36	Ore, removed	Exclusion
37	Tailings	Exclusion
38		No elevated gamma
39		No elevated gamma
40	Brick pile	Exclusion
41	Brick/mortar, fireplace/woodstove	Exclusion
42		No elevated gamma
43		No elevated gamma
44	Point source	Exclusion
45	Ore, cinder blocks	Exceeds guidelines
46		No elevated gamma
47		No elevated gamma
48		No elevated gamma

* RDC: radon daughter concentration

\+ Exclusion: a property with detectable gamma radiation that does not exceed DOE guidelines.

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TABLE II

Statistical Summary of the 48 Monticello, Utah, Properties Outside the Boundaries of Windblown Contamination, Randomly Chosen for Statistical Summary

Classification	No. of Properties	Percentage of Sample Size
Remedial action status		
No elevated gamma levels[a]	22	46
Exclusion	14	29
Exceeds DOE guidelines	10	21
Requires RDC measurement[b]	2	4
Total	48	100
Radioactive material[c]		
Ore (or ore fill) material	10	21
Tailings material	6	13
Building material (brick/mortar, fireplace/wood stove)	5	10
Other (e.g., petrified wood, radium dial, old mine tarp, brick pile, point source, cinder blocks)	5	10

[a] Properties 11 and 33 were counted as exclusions.
[b] Based on ORNLPAG procedures that require RDC measurement if gamma measurments are >20% above background but $< 20\,\mu$R/h above background (i.e., a "gray" area).Based on UMTRAP protocol.
[c] Some properties contain more than one type of material.The number of properties listed represent only those of the 48 surveyed which contained radioactive materials. The associated percentages relate to the total sample setof 48 (i.e. 54% of the 48 properties surveyed contained radioactive materials).

ACCELERATED CLEANUP OF THE 316-5 PROCESS TRENCHES AT THE HANFORD SITE

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ABSTRACT

In October, 1990, the U.S. Department of Energy, the U.S. Environmental Protection Agency, and the Washington State Department of Ecology signed an Agreement in Principle to accelerate remedial actions on the Hanford Site. Removal of contaminated sediments from the 300 Area (316-5) Process Trenches was one of the three initial candidate locations identified for the accelerated remediation. The trenches have received small quantities of radioactive and hazardous wastes in large volumes of process water (up to 11,360,000 L/day). The trenches are approximately 300 m west of the Columbia River and 7 m above the water table. The trenches are an active interim permitted disposal facility that may remain active for the next few years.

In order to reduce the potential for migration of contaminants from the trench sediments into the groundwater, an expedited response action to remove approximately 2,500 m^2 of soil from the active portion of the trenches is being performed. Field activities were initiated in July 1991 with site preparation. The first trench to be excavated was completed by August 15, 1991. Approximately 2 weeks were needed to begin removal activities in the second trench. The second trench should be completed by October 1, 1991, with the subsequent construction of an interim cover over the consolidated materials completed by December 1991.

INTRODUCTION

The U.S. Environmental Protection Agency (EPA) and Washington State Department of Ecology (Ecology) encouraged the U.S. Department of Energy (DOE) to proceed with the planning necessary to implement an expedited response action (ERA) for the 300 Area (316-5) Process Trenches. The EPA was designated the lead regulatory agency, with Ecology the support agency, for the ERA. The ERA was classified as non-time-critical and is being conducted in accordance with the applicable requirements [40 CFR 300, Subpart E (EPA 1990); the "Hanford Federal Facility Agreement and Consent Order" (Part 3, Article XIII, Section 38) (Ecology et al. 1989) (1); the "Comprehensive Environmental Response, Compensation and Liability Act of 1980" (CERCLA) (2); the "Resource Conservation and Recovery Act of 1976" (RCRA) (3); and the State of Washington "Model Toxics Control Act" (MTCA) (4)]. The ERA required preparation of a rapid, focused evaluation of available technologies using specific screening factors to assess feasibility, appropriateness, and cost. The results of the evaluation were incorporated into a proposal that was submitted to the EPA and Ecology for review. The proposal was modified to incorporate comments from the regulators before being submitted to the public for a 30-day comment period. A request to extend the comment period for an additional 15 days was received by the EPA and granted. The comments received at the end of 45 days did not require changing the proposal. The EPA and Ecology issued the necessary Action Agreement Memorandum authorizing implementation of the preferred alternative described in the ERA proposal.

OBJECTIVE OF THE EXPEDITED RESPONSE ACTION

The objective of the ERA is to reduce the potential for migration of contaminants from the sediments in the trenches to the soil column, groundwater, and Columbia River. A reduction in the potential source of contaminants provides a reduction of risk to the river environment. The ERA is being conducted as an interim action pending final cleanup activities for the 300-FF-1 operable unit. The ERA activities are being conducted to minimize impacts on the ongoing remedial investigation (RI) and feasibility study (FS) tasks for the 300-FF-1 and 300-FF-5 operable units.

SITE DESCRIPTION

The 316-5 Process Trenches are an active RCRA treatment, storage, and/or disposal (TSD) unit located within the 300-FF-1 operable unit. The trenches also impact the 300-FF-5 groundwater operable unit, which is located beneath the 300 Area. Both operable units are categorized as CERCLA past-practice units. The trenches are located near the western boundary of the 300-FF-1 operable unit, approximately 300 m west of the Columbia River. The trenches are approximately 500 m in length, 3.5 m deep, 3 m wide at the bottom, and 10 m wide at the top. The two parallel trenches are separated by an earthen berm. The bottom of each trench slopes slightly to the north and is approximately 7 m above the water table. There is a small 30 m by 50 m by 3 m depression located at the northwest corner of the west trench. This area was an active part of the west trench and received effluent from 1975 until 1990 when the area was separated from the west trench by placement of an earthen berm to facilitate placing of screens over the west trench.

The trenches presently operate under a RCRA Interim Status Permit. The trenches were constructed and activated in 1975. Process liquid effluents from various locations within the 300 Area are collected in the process sewer and discharged into a concrete outlet structure located at the south end of the trenches. The effluent discharged to the trenches average approximately 26,000 L/min. Peak discharges to the trenches may have been as high as 11,360,000 L/day. Before 1985, when administrative controls were instituted to reduce and eliminate discharges of hazardous wastes to the process trenches, the effluent discharged to the trenches contained small quantities of radioactive and hazardous wastes. The present effluent discharge consists of (1) purified or potable water, (2) equipment cooling water, (3) laboratory and research facility wastewater, and (4) precipitation (e.g., rain and snowfall runoff). The potable water and equipment cooling

water are estimated to account for 70% of the flow discharged to the trenches. The fuel fabrication activities conducted in the 300 Area may have been the most significant source of contaminants. The fuel fabrication facilities have not operated since 1987.

The effluent currently discharged to the trenches is not designated as a dangerous waste according to procedures specified in the Washington Administrative Code (WAC), Chapter 173-303. The administrative controls implemented in 1985 directed attainment of drinking water standards for effluent discharged to the trenches.

Milestone M-17-06 of the "Hanford Federal Facility Agreement and Consent Order" requires that discharges to the 300 Area Process Trenches cease in December 1991. The DOE submitted a change request form to EPA and Ecology requesting an extension of that date to December 1994, at which time a 300 Area wastewater treatment plant would be operational. The EPA and Ecology denied the change request on April 8, 1991, and have agreed to examine a revised change request that will include consideration of the success of the ERA.

The source of contaminants in the trenches is the process sewer system. The system was constructed in 1943 to transfer process liquid wastes from the various buildings in the 300 Area of the Hanford Site. The process sewer system receives, or has received, process water from fuel fabrication operations, cooling water, steam condensate, water treatment salts, and a wide variety of waste liquids from laboratory drains throughout the 300 Area. The number of laboratories and the diverse nature of the research and development activities over the years may have contributed laboratory quantities of almost any chemical used in the 300 Area, to the sewer system and subsequently to the process trenches.

CONTAMINANTS

Historical data provided in the 300-FF-1 Operable Unit RI/FS work plan indicate that the process trench sediments are contaminated with radionuclides and inorganic components. The contaminants of concern for the ERA were identified based on the previous sampling and analytical efforts.

Soil Sample Data

Soil samples from the process trenches were analyzed for potential contaminants. The earliest sampling consisted of six composite samples obtained from the west trench. These samples were obtained from three depths: 0 m, 0.3 m, and 0.6 m in the trench bottom. The samples were analyzed for a range of metals, including many for which background characteristics are unknown.

A more extensive sampling program was implemented in 1986 to specifically address the process trench sediments. Soil samples were obtained at 30.5-m intervals along the bottom of each trench at three depths: 0 m, 0.1 m, and 0.46 m. The samples were analyzed for metals, gross alpha and beta, total organic halogen (TOX), and total organic carbon (TOC). Seventeen samples were subjected to a more complete analytical characterization and six surface soil samples were tested for extraction-procedure toxicity. Table I provides a summary of data for the contaminants of concern in the trenches.

Six exploratory borings were drilled on 91-m centers along the berm separating the process trenches during the 1986 investigation. Soil samples were taken from drill cuttings at intervals of 1.5 m to a maximum depth of 12 to 13.7 m.

Several metals, including antimony, arsenic, cadmium, chromium, copper, lead, manganese, mercury, nickel, selenium, silver, thallium, vanadium, and zinc were detected at elevated levels. Other metals (e.g., uranium) probably also exist at highly elevated concentrations; however, background distributions for several such metals have not been established.

Extraction-procedure toxicity data obtained from six samples of process trench sediments samples collected in 1986 are shown in Table II. The data indicate that at the time of analysis the sediments did not exceed criteria for dangerous waste designation. Toxicity Characteristic Leach Procedure tests were performed on composite samples from the east trench. The results will be used to assist in proper handling and disposition of wastes generated during the ERA activities.

Elevated levels of gross beta and lo alpha (assumed to be gross alpha) indicated the presence of radionuclides in the sediments. Based on the estimated volumes of waste

TABLE I

Concentration of Constituents in Sediments
(parts per million).

	Shallow samples							
	Loose		Shallow (4 in.)		Deep (18 in.)		Well samples	
Constituents	Average	Peak	Average	Peak	Average	Peak	Average	Peak
Arsenic	1.5	10	0.9	6	1	14	0.6	7
Cadmium	2.4	20	1.8	5.4	1.3	2.9	0.49	0.9
Chromium	274	551	59	319	30	131	6	10
Copper	3550	7320	1109	8470	522	2230	18	42
Lead	205	486	33	230	21	86	3	7
Mercury	15	58	6	69	2	21	0	0.1
Nickel	529	1550	306	4700	95	1030	5	11
Silver	137	405	35	245	12	110	<1	<1
Uranium	7400	20400	1200	6900	3400	27700	7.3	15.5

Source: Zimmerman and Kossick (1987).[6]

TABLE II

Extraction-Procedure Toxicity Results for Process Trench Soils. Constituents

	Regulatory[a] criterion (mg/L)	Sample location					
		W5LA	W10SA	W10DA	E1DA	E6SA	E2LA
Arsenic	5.0	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20
Barium	100.0	12	6.6	7.20	10.30	11.6	6.90
Cadium	1.0	<0.01	<<0.01	0.10	0.03	<0.10	<0.10
Chromium	5.0	0.02	<0.01	0.01	<0.01	0.06	0.02
Lead	5.0	0.46	<0.20	0.23	<0.20	<0.20	0.24
Mercury	0.2	0.10	<0.05	<0.05	<0.05	<0.05	<0.05
Selenium	1.0	<0.25	<0.25	<0.25	<0.25	<0.25	<0.25
Silver	5.0	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02

Source: Zimmerman and Kossick (1987).[6]
[a]WAC 173-303-100(d).

constituents discharged to the process trenches (Table III), uranium is the dominant radionuclide present. Data associated with previous activities at the trenches indicated that uranium would be the predominate radionuclide. Several organic compounds were identified in the soils; only two compounds, methylene chloride and tetrachloroethylene, were detected in more than one sample. Tetrachloroethylene was the only detected organic compound known to have been disposed of in the trenches in greater-than-kilogram quantities.

Given the nature of the soils underlying the trenches, little lateral dispersion of contaminants by capillary diffusion would be expected. Therefore, the maximum contamination was expected to be located directly beneath the trenches.

ERA REMOVAL ACTION

Following site preparation activities and receipt of the Action Agreement Memorandum on July 15, 1991, removal of the contaminated material was initiated. Excavation activities were initiated in the east trench in order to provide ease of access, the trench was not currently in use, and had sufficient time to drain.

TABLE III

Estimated Total Amount of Constituents in the Sediment.

Constituent	Shallow sediments (kg)
Arsenic	2
Cadmium	3
Chromium	341
Copper	2,261
Lead	108
Mercury	12.8
Nickel	578
Silver	74
Uranium	720

Source: Zimmerman and Kossick (1987).[6]

A hydraulic excavator was obtained to perform the excavation. Site preparation included lowering the berm between the trenches approximately 1 m to provide a better work area. The material removed was stockpiled near the material consolidation area for future use as a clean cover over the excavated sediments. The trench had a bird screen cover that was moved just prior to pre-excavation sampling. The pre-excavation sampling was conducted to provide data to support other activities related to the process trenches. The excavated material was removed from the trench, loaded into off-road dump trucks and hauled to the north end of the site for consolidation. The trucks were filled short of capacity to reduce the potential for spillage on the haul route to the consolidation area. The center berm was used as the haul route to reduce the potential for creating areas with surface contamination. This also eliminated the need to remove portions of the security fence that surrounded the location, thus eliminating the potential for inadvertent personnel from entering the work site during nonwork hours. The haul route made it necessary to use a single dump truck to service the excavator. This made the actual excavation process slow at times but the cost savings versus the time and cost to create a second haul route were positive for completion of the work.

Control of fugitive dust generation was the only specific operational safety limit that was identified through the safety assessment process. The application of water or clean fill to the different work areas was used to meet the requirements of the safety limit. The nearly constant application of water to the excavation areas was accomplished through the combined use of 1 or 2 water trucks and a water spray system that pumped process effluent from the weir box at the south end of the trenches. Clean fill, which had been stockpiled from the lowering of the center berm, was continuously applied to the contaminated material consolidation area to provide a clean surface for vehicles to travel over and reduce the potential for resuspension of contaminated material.

As excavation progressed in each trench, the recently excavated portion was monitored with field radiation-detection instruments (e.g., dose rate meters, count rate meters) to assess the level of contaminant removal. The tentative goal for removal had been set for radiation measurements not to

exceed 3 times the upper tolerance limit of background radiation levels. Pre- and post-excavation sampling was performed and the results will provide a better assessment of the effectiveness of the ERA removal activity. The field radiation levels were reduced to less than twice background (e.g. 15,000 counts per minute to less than 150 counts per minute). Additional field data was obtained through the use of an x-ray fluorescence analyzer. The system was being used to evaluate the potential for use of the unit to reduce the need for expensive laboratory analysis of each sample and provide quick turnaround field data to verify field activities. The preliminary results are encouraging and with further time, funding and support should provide a valuable tool for field screening use at Hanford. The ERA was also able to use a field screening laboratory to analyze post-excavation samples. The analyses provide positive indications that the removal was successful within a few days versus the 2 weeks for preliminary results from the offsite laboratories.

After soil removal was completed in a trench, a clean fill berm was placed between the sediments and the active trench area. The area directly in front of the discharge outfall apron at the weir box, where sediments were removed was backfilled with clean aggregate and graded to reduce or prevent erosion and sloughing of the banks and/or undermining of the outfall apron once water is reintroduced.

Following removal activities in the east trench and before starting in the west trench, the residual sediments in the diversion box were removed using a siphon hose that discharged the material to the west trench to ensure that the trenches would receive minimal residual contaminants following completion of removal activities. After the weir box cleanout was completed, the effluent discharge was switched to the east trench. Removal operations were initiated in the west trench approximately 10 days after the discharge was switched to the east trench. This provided time for the sediments in the west trench to drain the free standing water. Operations in the west trench are proceeding in a manner similar to the east trench with an anticipated completion date for sediment removal on October 1, 1991.

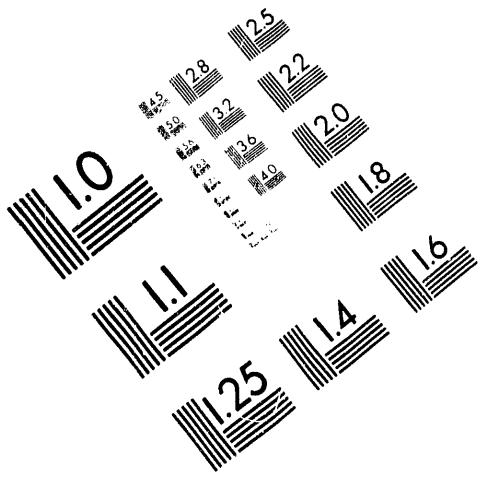
After completion of the excavation and consolidation, a 10 mil thick polyethylene layer will be placed over the consolidated material with a layer of clean aggregate (approximately 0.3 m thick) placed on the polyethylene. Soil sterilization agents or herbicides may be applied to reduce the potential for vegetation growth on the interim cover.

Preliminary sample data indicate that the ERA has been able to accomplish the objective of removing and isolating the contaminants from the active portion of the trench. The effectiveness of the project should assist in allowing for continued use of the trenches until an inspection and treatment facility is constructed.

The ERA did not incorporate any materials or actions that preclude consideration of a technology (e.g. physical separations/soil washing) for final remediation of the operable unit.

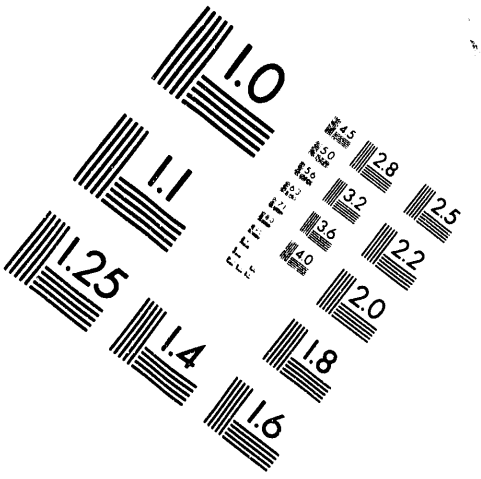
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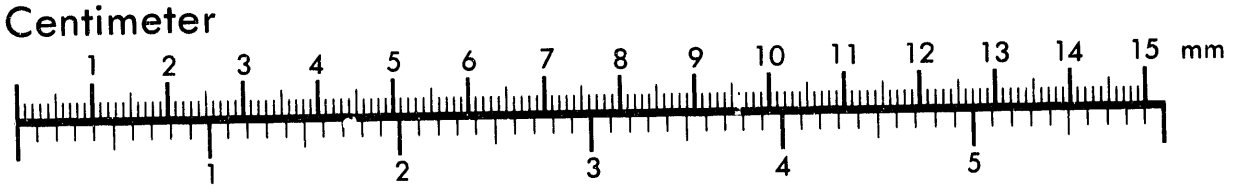
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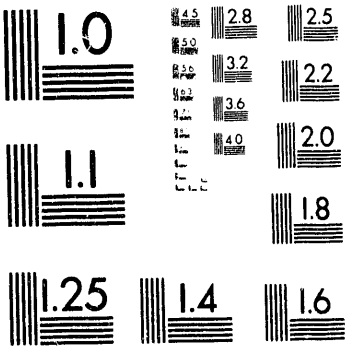


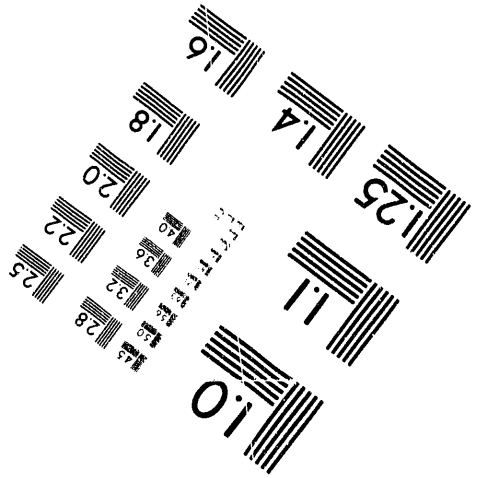


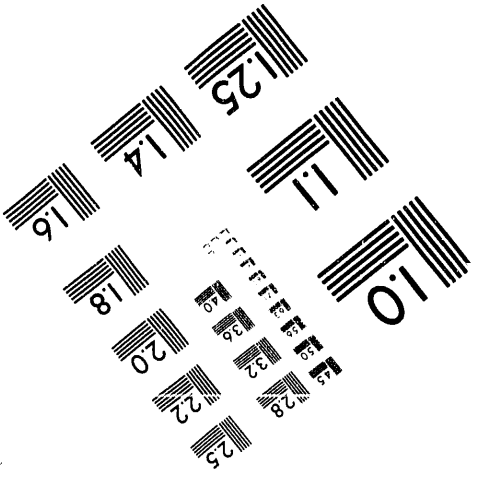
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DETERMINING THE NUMBER OF SAMPLES REQUIRED FOR DECISIONS CONCERNING REMEDIAL ACTIONS AT HAZARDOUS WASTE SITES

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ABSTRACT

An important consideration for every risk analyst is how many field samples should be taken so that scientifically defensible decisions concerning the need for remediation of a hazardous waste site can be made. Since any plausible remedial action alternative must, at a minimum, satisfy the condition of protectiveness of human and environmental health, we propose a risk-based approach for determining the number of samples to take during remedial investigations rather than using more traditional approaches such as considering background levels of contamination or federal or state cleanup standards.

INTRODUCTION

The process of collecting, analyzing, and assessing the data needed to make decisions concerning the cleanup of hazardous waste sites is quite complex and often very expensive. This is due to the many elements that must be considered during remedial investigations. The decision maker must have sufficient data to determine the potential risks to human health and the environment and to verify compliance with regulatory requirements, given the availability of resources allocated for a site, and time constraints specified for the completion of the decision making process. It is desirable to simplify the remedial investigation procedure as much as possible in order to conserve both time and resources while, simultaneously, minimizing the probability of error associated with each decision to be made. With this in mind, it is necessary to have a practical and statistically valid technique for estimating the number of on-site samples required to "guarantee" that the correct decisions are made with a specified precision and confidence level. Here, we will examine existing methodologies and then develop our own approach for determining a statistically defensible sample size based on specific guidelines that have been established for the risk assessment process.

STATISTICAL CONCERNS

In most cases, the first statistical test performed on collected data is a hypothesis test to determine if the average (mean) concentration of a particular contaminant is significantly different from corresponding background levels. A hypothesis test is simply a rule used for deciding whether or not a statement (the null hypothesis) should be rejected in favor of a specified alternative statement (the alternative hypothesis). For initial screening of data from a hazardous waste site, the null hypothesis might be expressed as "there is no difference between contaminant concentrations in background areas and on-site," and the alternative hypothesis might be expressed as "concentrations are higher on-site." The appropriate sample size would then be determined so that the null hypothesis is accepted or rejected with a specified likelihood of error.

There are two types of errors associated with hypothesis testing: Type I errors (i.e., rejecting the null when it is actually true) and Type II errors (i.e., not rejecting the null when it is false). An example of a Type I error at a hazardous waste site would be to conclude that contaminant concentrations in on-site soil are higher than background soil concentrations when, in fact, they are not higher. The corresponding Type II error would be to conclude that on-site contaminant concentrations are not higher than background concentrations when, in fact, they are higher. A Type I error could result in unnecessary remediation, and a Type II error could result in a failure to clean up a site when such action is warranted.

The customary notations used for denoting the probability that a Type I or Type II error will occur are alpha (α) and beta (β), respectively. Alpha is known as the level of significance of a test (the difference, $1 - \alpha$, is called the confidence level) and the difference, $1 - \beta$, is known as the power of a test. Increasing the sample size will increase the confidence level and the power, thereby reducing the likelihood of Type I and Type II errors, respectively.

DETERMINING AN ADEQUATE SAMPLE SIZE

The Environmental Protection Agency (EPA) provides an equation, Eq. (1), in the *Soil Sampling Quality Assurance User's Guide* (EPA/600/8-89/046, March 1989) (1) for determining **n**, the minimum number of samples required to achieve a specified power and confidence level at a defined minimum detectable relative difference, D.

$$n \geq \left[\frac{(Z_\alpha + Z_\beta)CV}{D}\right]^2 + 0.5Z_\alpha^2 \qquad \text{(Eq. 1)}$$

In this equation, Z_α and Z_β are the percentiles of the standard normal distribution such that $P(Z \geq Z_\alpha)$ and $P(Z \geq Z_\beta)$ are α and β, respectively; CV is the coefficient of variation of the contaminant concentrations in a preliminary data set; and D is the minimum relative detectable difference. The number of samples required per site is dependent upon the power ($1 - \beta$) and confidence ($1 - \alpha$) levels required, the variability of the data, and the smallest admissible difference between the true concentrations and the sampled (representative) concentrations. In this equation, only the CV is data

dependent, while acceptable levels of α, β, and D are set by the decision maker.

The EPA's *Guidance for Data Useability in Risk Assessment* (EPA/540/G-90/008, October 1990) (2) suggests an α of 0.2 and a β of 0.1 and defines D as the percent difference required between site and background concentration levels before the difference can be detected statistically, regardless of the levels of α and β. Since this "difference" is a number which must be determined by the risk assessor, it would be beneficial if D were defined in terms which would allow the actual risk posed by the contaminants at the site to influence the sample size required.

To help incorporate this idea into the EPA's existing equation for **n**, we used Lawrence Lapin's estimate (Eq. 2) for determining an appropriate sample size (*Probability and Statistics for Modern Engineering*, PWS-KENT Publishing Company, Boston, 1990) (3).

$$n = \left[\frac{s(Z_\alpha + Z_\beta)}{\mu - \mu_0}\right]^2 \qquad \text{(Eq. 2)}$$

where μ and s are the mean and standard deviation of the contaminant concentration data, respectively, and μ_0 is the true mean.

Equating the EPA's equation with Lapin's equation and then solving for D gives:

$$D = \frac{CV(\mu - \mu_0)}{s} \qquad \text{(Eq. 3)}$$

Since

$$CV = \frac{100\,s}{\mu} \approx \frac{100\,s}{\mu_0}, \qquad \text{(Eq. 4)}$$

$$D = \left(\frac{\mu - \mu_0}{\mu_0}\right) \times 100. \qquad \text{(Eq. 5)}$$

For risk assessment purposes, D should be defined in terms of the risks posed by contaminants at the site. That is, let D be the relative difference between the actual concentration of each contaminant in the initial set of samples (for any given medium) and a risk-based criterion concentration (guideline value) above which remedial action would be required. That is, let

μ = *actual concentration in preliminary data set, and*

μ_0 = *criterion concentration.*

Thus, define D for the i^{th} contaminant as

$$D_i = \frac{(AC_i - CC_i)}{CC_i} \qquad \text{(Eq. 6)}$$

where AC_i is the actual (sampled) concentration and CC_i the derived criterion concentration of the i^{th} contaminant.

SITE AND DATA DESCRIPTION

To test the methodology for deriving a risk-based sample size, we analyzed soil sample data collected from a hazardous waste site on the Oak Ridge Reservation (ORR) and examined the relationship between the sample size, **n**, and power, $1 - \beta$, using the EPA's equation and our definition of D. The site selected is a 30 ft × 140 ft storage area for inorganic wastes from metal plating operations. The wastes are temporarily stored (90 days or less) in 600-gal polyethylene tanks before being transported to treatment facilities. The waste stream includes spent caustics, inorganic acids, nickel solution, copper plating bath, chrome tank wastes, rinsewaters, and waste cyanide.

Fifteen locations were sampled at the surface and at depths of 2 ft and 4 ft. For each contaminant, the mean concentration was calculated at each depth, and the maximum value among the different depths was chosen as the representative concentration, or maximum mean concentration (mmc). The coefficient of variation (CV) was calculated based on the data taken at the same depth as the mmc.

To apply our definition of D, we must select a criterion concentration (CC) against which we can compare the calculated mmc. We used standard EPA exposure assumptions and toxicity values in order to derive our criterion concentrations. As suggested in the *RCRA Facility Investigation (RFI) Guidance Volume I and II* (EPA 530/SW-89-031, May 1989) (4) manual and the *Risk Assessment Guidance for Superfund (RAGS)* (EPA/540/1-89/004, September 1989) (5) manual, for systemic toxicants we assume ingestion of 200 mg of soil per day by a 16 kg child between the ages of 1 and 6 years. The criterion concentration is set at the concentration that would result in a dose equal to the EPA's Reference Dose (RfD), which is defined to be an estimate of a daily exposure level for humans that is unlikely to cause significant harmful effects during a given period of a person's lifetime (RAGS). Thus, the criterion concentration of the i^{th} systemically toxic contaminant is calculated as in Eq. (7).

$$CC_i\left(\frac{mg}{kg}\right) = RfD_i\left(\frac{mg}{kg\text{-}day}\right) \times \left(\frac{16\,kg}{200\,\frac{mg}{day} \times 10^{-6}\,\frac{kg}{mg}}\right) \qquad \text{(Eq. 7)}$$

where the 10^{-6} kg/mg is a unit conversion factor.

For carcinogens, we assume continuous exposures of 100 mg of soil per day by a 70 kg adult for 70 years. The criterion concentration is set at the level associated with an excess lifetime cancer risk of 10^{-6} (or 10^{-5} for class C contaminants) and is calculated using the EPA's cancer potency factor (CPF), which is defined as an upper bound estimate of the probability of a response per unit intake of a chemical over a lifetime, and is used to estimate the upper bound probability of an individual developing cancer as a result of a lifetime of exposure to a given level of a carcinogen or potential carcinogen (RAGS). The criterion concentrations for the i^{th} carcinogenic contaminant is calculated as in Eq. (8).

$$CC_i\left(\frac{mg}{kg}\right) = \left(\frac{10^{-6}}{CPF_i\left(\frac{mg}{kg\text{-}day}\right)^{-1}}\right) \times \left(\frac{70\ kg}{100\ \frac{mg}{day} \times 10^{-6}\ \frac{kg}{mg}}\right) \quad \text{(Eq. 8)}$$

For contaminants with both systemic and carcinogenic effects, the lower of the two criterion concentrations is used. Table I lists the mmc, standard deviation, coefficient of variation, and the criterion concentration for each contaminant in the data set.

Incorporating all of the above information, a computational formula for D (Eq. (9)) can be obtained:

$$D_i = \left(\frac{mmc_i - CC_i}{CC_i}\right) \times 100 \quad \text{(Eq. 9)}$$

Since our study is concerned with power (the likelihood of not detecting a problem when in fact there is one), we only calculated **n** for contaminants that were measured at concentrations below the criterion concentration in the preliminary set of samples. We assume that contaminants which exceed criterion concentrations would be identified as contaminants of concern and remediation activities would already have been initiated.

POWER CURVES

Power curves for each of the contaminants at the site were constructed to illustrate the relationship between the sample size and power. Power curves for each of the contaminants are shown in Fig. 1. For illustrative purposes, α was set equal to the EPA's recommended value of 0.2 (i.e., the confidence level, 1 - α, is 0.80) and β was allowed to vary between 0 and 0.5 (i.e., the power, 1 - β, ranged from 0.5 to 1.0). From this figure, the "key contaminant" can be identified. The key contaminant is the contaminant which requires the greatest number of samples to detect the specified difference at the given levels of alpha and beta. For this study, cyanide is the key contaminant since it requires 15 samples to achieve an α of 0.20 and a β of 0.10. Since 15 samples must be collected to satisfy cyanide's requirements, all other contaminants in the data set would be detected at a **minimum** confidence of 0.80 and power of 0.90.

As intended, with other things being equal, **n** is higher for: 1) contaminants whose actual concentrations in the initial sample set were closest to criterion concentrations (i.e., the contaminants that posed the greatest health threat), and 2) contaminants that had highly variable concentrations from sample to sample. Simulations show that the rate at which power improves with increasing **n** is lower for contaminants that are close to criterion concentrations and/or are highly variable. To get a feel for how both α and β affect sample size, we varied α and β simultaneously between 0.10 and 0.20. The most stringent case for cyanide ($\alpha = 0.10$ and $\beta = 0.10$) called for a sample size of 22 while the least stringent case ($\alpha = 0.20$ and $\beta = 0.20$) required only 15 samples. Table II lists the results for all the contaminants in the data set.

TABLE I

Contaminants Associated With the Waste Site

Element	Maximum Mean Concentration	Standard Deviation	Coefficient of Variation	Criterion Concentration
Cyanide	1.119	2.0131	179.956	1600
Mercury	0.454	0.572	125.964	24
Nickel	28.347	26.066	91.955	1600
Barium	152.467	104.243	68.371	5600
Vanadium	16.333	4.842	29.110	560
Zinc	80.000	126.449	158.061	16000

TABLE II

Varying α and β Simultaneously

		n		n	
		$\alpha = 0.1$		$\alpha = 0.2$	
Element	D	$\beta = 0.1$	$\beta = 0.2$	$\beta = 0.1$	$\beta = 0.2$
Cyanide	-0.555	22	15	15	10
Mercury	-0.779	12	8	8	5
Nickel	-1.068	7	5	4	3
Barium	-1.423	4	3	3	2
Vanadium	-3.333	1	1	1	1
Zinc	-0.630	17	12	12	8

Since we define cyanide as the key contaminant, we would recommend 15 samples to sufficiently identify the contamination at the site if we apply the EPA's recommended levels of power and confidence ($\beta = 0.10$ and $\alpha = 0.20$). This would provide us with an even greater power and confidence for the remaining contaminants. Interestingly, 15 was the number of samples taken for the preliminary data set, indicating that no further sampling would be required at the site. The chosen site is known to be a fairly innocuous site and, therefore, the low **n**-values were not surprising.

A problem will arise at less innocuous sites when the **n**-values derived suggest collecting an economically infeasible

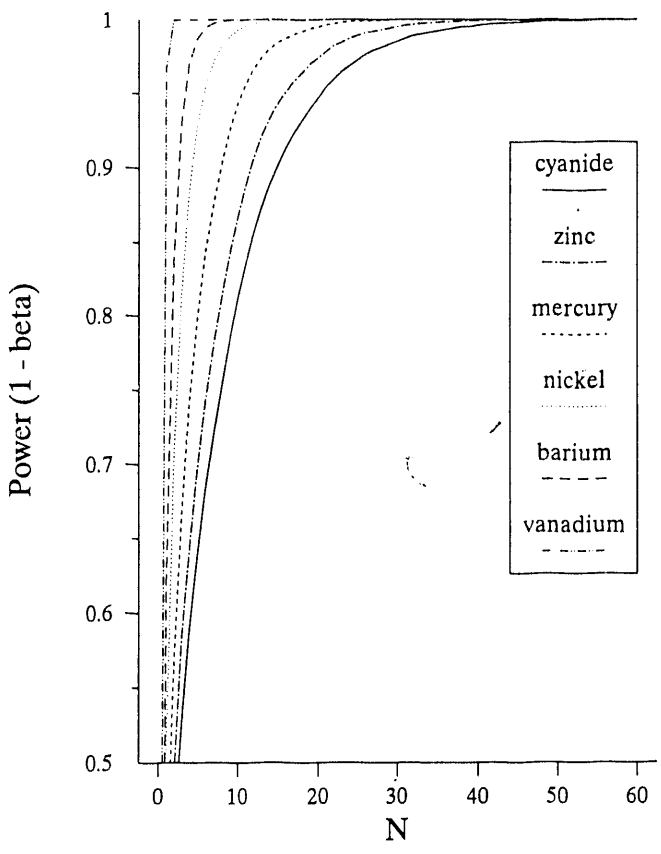


Fig. 1. Power curves for each of the contaminants (alpha = 0.2).

or impracticable number of samples. However, the fact that power is a decelerating function of **n**, implies that choosing a smaller value of **n** may not significantly reduce the power of the test. Furthermore, this reduction in power may not cause significant reductions in the risks to human or environmental health associated with a decision error.

LIMITATIONS AND RECOMMENDATIONS

The sample size determination issue is complicated by the fact that a suite of contaminants may be present at a hazardous waste site, and we want to avoid making decision errors (especially not cleaning up when we should) for all contaminants associated with the site. The rate at which power increases with increasing **n** will be different for each contaminant: the rate will be lowest for the key contaminant because this contaminant is likely to be highly variable, close to criterion concentrations, or a combination of the two. Thus, the methodology we have used needs to be adapted in a manner that will ensure that the sample size selected will take into account the combined risks posed by all contaminants at a site.

SUMMARY

We believe this general approach to determining an adequate sample size is a useful one for ER programs since it ensures that the actual risks posed by the site will drive the sampling strategy. We have described an approach for determining the number of soil samples. The method can be easily adapted for other media by incorporating the appropriate exposure assumption and toxicant values into Eqs. 7 and 8. Moreover, the methodology can be fine-tuned as more information is gathered throughout the Remedial Investigation/Feasibility Study (RI/FS) program. For example, more realistic exposure assumptions may be used to determine the risk-based criterion concentrations used to define D, and as more data are gathered from the site, the number of samples for each subsequent stage of investigation can be quickly determined by incorporating the updated means and standard deviations for each contaminant into the simple equation. This approach will also encourage the involvement of statisticians (or, at the very least, force the consideration of the statistical "weapons" needed in order to make scientifically defensible decisions) at an early stage of ER activities at hazardous waste sites.

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PROGRAM MANAGEMENT STRATEGIES FOR FOLLOWING EPA GUIDANCE FOR REMEDIAL DESIGN/REMEDIAL ACTION AT DOE SITES

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ABSTRACT

At the U. S. Department of Energy (DOE) facilities, environmental restoration is being conducted in accordance with Federal Facilities Compliance Agreements (or Interagency Agreements). These agreements establish a cooperative working relationship and often define roles, responsibilities and authorities for conduct and oversight of the Remedial Action Programs. The U.S. Environmental Protection Agency (EPA) has guidelines on how to initiate and perform remedial actions for sites they are remediating under the Comprehensive Environmental Response Compensation and Liability Act (CERCLA) as amended by the Superfund Amendments and Re-Authorization Act (SARA). This paper addresses some of the difference and commonalities between the DOE project management procedures and EPA guidance documents. This report covers only the RD/RA phase of environmental restoration.

On the surface, there are many apparent differences between the DOE and EPA project management processes. Upon closer review, however, many of the differences are the result of applying different terminology to the same phase of a project. By looking for the similarities in the two processes rather than hunting for differences, many communication problems are avoided. Understanding both processes also aids in figuring out when, how and to what extent EPA should participate in the RD/RA phase for DOE lead cleanup activities.

The DOE Remedial Design and Remedial Action process is discussed in a stepwise manner and compared to the EPA process. Each element of the process is defined. Activities common to both the EPA and DOE are correlated. The annual DOE budget cycle for remediation projects and the four-year cycle for appropriation of remediation funds are discussed, and the constraints of this process examined. DOE orders as well as other requirements for RD/RA activities are summarized and correlated to EPA regulations where this is possible. Finally, schedules for typical RD/RA activities are presented and DOE project schedules are compared to EPA restoration schedules. An innovative schedule is presented to meet CERCLA time constraints requirements for continuous remedial activity within 15 months of the ROD.

INTRODUCTION

At the U.S. Department of Energy (DOE) facilities, environmental restoration is being conducted in accordance with Federal Facilities Compliance Agreements (or Interagency Agreements). These agreements establish a cooperative working relationship and often define roles, responsibilities and authorities for conduct and oversight of the Remedial Action Programs. The U.S. Environmental Protection Agency (EPA) has guidelines on how to initiate and perform remedial actions for sites they are remediating under the Comprehensive Environmental Response Compensation and Liability Act (CERCLA) as amended by the Superfund Amendments and Re-Authorization Act (SARA). However, EPA Remedial Project Managers (RPM) and On-scene Coordinators (OSCs) are not familiar with the DOE project management procedures for initiation and performance of remediation projects. The consequence of this scenario is confusion in concepts, planning, budgeting and terminology during communications between DOE and EPA project managers. This paper addresses some of the differences and commonalities between the DOE project management procedures and EPA guidance documents. Since DOE procedures do not specifically cover the conduct of a Remedial Investigation/Feasibility Study (RI/FS), EPA guidance documents are normally adopted. Both agencies, however, have Remedial Design/Remedial Action (RD/RA) procedures. This report covers only the RD/RA phase of environmental restoration.

On the surface, there are many apparent differences between the DOE and EPA project management processes. Upon closer review, however, many of the differences are the result of applying different terminology to the same phase of a project. For example, DOE's terminology "Title III Reviews" is used for the activities associated with inspecting and evaluating workmanship against drawings and specifications during the construction effort. Analogously, EPA's terminology "Pre-final Inspection" performs a similar function. Basically, both accomplish the same activity but use different terminology. By looking for the similarities in the two processes rather than hunting for differences many communication problems are avoided. Understanding both processes also aids in figuring out when, how and to what extent EPA should participate in the RD/RA phase for DOE lead cleanup activities.

In the following sections, the DOE Remedial Design and Remedial Action process is discussed in a stepwise manner and compared to the EPA process. Each element of the process is defined. Activities common to both EPA and DOE are correlated. The annual DOE budget cycle for remediation projects and the four-year cycle for appropriation of remediation funds are discussed, and the constraints of this process examined. DOE orders as well as other requirements for RD/RA activities are summarized and correlated to EPA regulations where this is possible. Finally, schedules for typical RD/RA activities are presented and DOE project schedules are compared to EPA restoration schedules. An

innovative schedule is presented to meet CERCLA time constraints requirements for continuous remedial activity within 15 months of the ROD.

RD/RA PROCESS COMPARISON

In order to fully understand the similarities and differences of the EPA and DOE processes, one must understand the phases of each. This section provides definitions and an overview of the phases for the EPA remediaton project process and the DOE remediation project process. These are followed by a comparison to show distinct similarities and differences.

EPA REMEDIATION PROJECT PROCESS

The following summary of the EPA process will focus on the RD/RA phases. This summary has been organized to reflect the general sequence of events that occur prior to, during, and after remedial design and remedial action at Superfund sites. The Superfund Remedial Design and Remedial Action Guidance Document of June 1986 was used, although it does not strictly apply to Federal facilities, unless called out in a Federal Facilities Compliance Agreement. Table I is a list of key personnel and their function for the EPA Remediation Project Process.

Figures 1A and 1B show flow charts for the EPA RD/RA Remediation Project Process. RD/RA conducted by other Federal agencies was not addressed in the guidance document referenced. The guidelines for Federal (EPA) lead were used to address Agency RD/RA activities.

Remedial Design

The selection of the Architect/Engineering Firm (A/E) for the Remedial Design can be initiated during the Feasibility Study after the selection of the alternatives. This process consists of the Pre-Design Report, the A/E bid and Proposal, and the selection of the A/E contractor.

The optional Pre-Design Report shall be prepared by the lead RI/FS party and provided to the lead design party. The objective of the Pre-design Report is to describe the engineering parameters and institutional concerns of the selected remedy and package all pertinent project information for transfer to the lead design party. The Pre-Design Report replaces the conceptual design task of the FS. The Pre-Design Report should be completed within two weeks following remedy selection, and the cost should be limited to approximately 5 per cent of the cost of the feasibility study.

Activities involved in selecting an A/E firm for the remedial design will be dependent on the lead party. The following are activities required to retain an A/E firm for the engineering design:

- Synopsize requirements in Commerce Business Daily (CBD)
- Develop A/E pre-selection list
- Contact A/E firms on the pre-selection list to ascertain interest in project
- Develop A/E Selection list (at least three firms)
- Select A/E firm

Following EPA approval of the ROD, action must be taken to initiate design activities. The Lead design party shall ensure the design package is developed consistent with the approved ROD and applicable CERCLA policy and procedures.

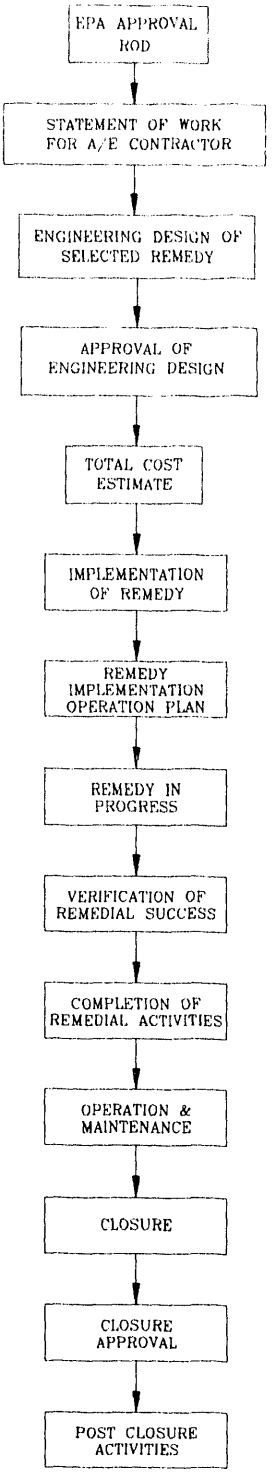


Fig. 1a. EPA RD/RA remediation process.

It is essential that the A/E firm retained to accomplish the design for a specific remedial action have a clear understanding of the project scope and subsequent required design documents. The following elements of a statement of work are intended as guidance in preparing site-specific A/E instructions. The Design Project Officer (PO) shall ensure that the appropriate elements are addressed. The SOW for remedial design should require the A/E to prepare the final

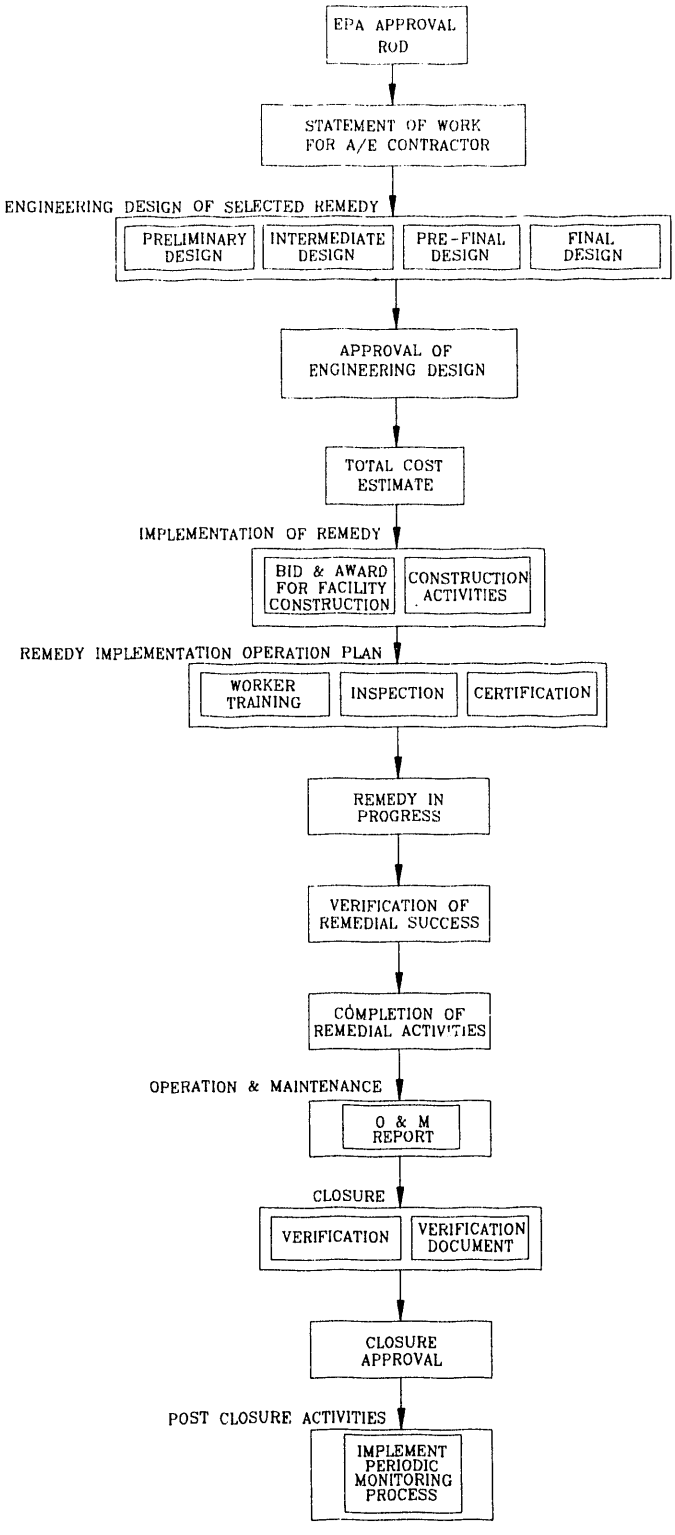


Fig. 1b. EPA RD/RA Remedial Process.

construction plans and specifications to accomplish the remedial action alternative as defined in the ROD. The specification should include quality assurance provisions in all proposed work. In general, the plans and specifications portion of the SOW should include the following phases:

- Preliminary Design (30%)
- Intermediate Design (60% optional)
- Prefinal/Final Design (90%)
- Correlated Plans and Specifications
- Selection of Offsite Resource Conservation and Recovery Act (RCRA) Facilities
- Compliance with the Requirements of Other Environmental Laws
- Equipment Startup and Operator Training

Any additional activities and documents that need to be addressed during the design phase are completed by the A/E firm. Any additional studies needed to supplement the technical data available from the RI/FS activities such as bench scales test and pilot test are initiated. The Operation and Maintenance Plan, the Quality Assurance Project Plan and the Specific Site Safety Plan are developed and finalized during the design phase. Also completed at this time is the scoping of A/E services during construction.

A preliminary design package shall be submitted by the A/E when design effort is approximately 30% complete. The submittal shall contain plans and specifications previously described, bench and pilot studies interim report if required, and the preliminary cost estimate. The submittal shall be reviewed for environmental and technical compliance. The submittal should address full environmental compliance with the ARARs identified in the ROD and technical compliance with the SOW, constructability, and cost accuracy.

At the discretion of the design PO or consent Decree, the intermediate design package shall be submitted at approximately 60% completion.

When design reaches approximately 90% completion, the Prefinal Design Package shall be submitted. The Submittal shall include all plans and specifications, O&M plan, QAPP, specifications for Site Safety Plan (SSP) and the cost estimate. The submittal undergoes an extensive environmental and technical review. The Environmental Review ensures:

- compliance with all ARARs identified in the ROD
- utilization of currently accepted environmental control measures and technology
- the adequacy of the O&M plan, QAPP, and SSP specifications
- consistency with ROD, environmental and public impacts.

Technical Review ensures:

- bidability and constructability of the design
- the accuracy of the construction cost estimate
- utilization of currently accepted construction practices and techniques
- the ability of a construction contractor to submit a fair and reasonable bid based upon the bid schedule included in the specifications
- the accuracy of any estimated quantities of materials specified in the design.

Final Design Submittal consists of the final design plans and specifications, the A/E firm's final construction cost estimate, final draft O&M plan, final QAPP and SSP specifications. Final Approval of the design is done by the Agency contracting the A/E firm.

All permits, approvals and site access must be acquired and established during the design phase. Concurrently, the Community Relations Plan (CRP) must be revised to include any changes in the level of concern or information needs of the community during design and construction activities.

Remedial Action

After completion and approval of the RD package, action must be taken to initiate remedial action activities. The activities accomplished during the RA are discussed.

Procurement for a remedial action should be through a fixed price contract and should be by formal advertising to assure full free competition. Site inspection may be done by bidders to answer questions regarding design or implementation. The review of bid documents is conducted to ensure that the bidder is both responsive and responsible.

During actual construction monitoring, oversight and inspections must be done. Records and reports maintained during construction and remedy implementation must be adequately documented for use in the final certification of the remedial action. The lead party is responsible for construction inspection during the RA activities. A full-time inspector ensures compliance with environmental and technical requirements. Construction reports are submitted at agreed upon intervals. Progress reports are due to EPA throughout the project. Operator training and procedures are established during construction.

Completion and acceptance for construction must be clearly defined to ensure proper end of project, approval, and closeout. The objective of the Prefinal Construction Conference is to discuss procedures and requirements for project completion and closeout. Prefinal inspection occurs when the preliminary project completion is accomplished. A walk-through inspection of the entire project site is required. When the RA includes construction of a treatment system, the facility start-up and shakedown shall have been completed as part of the RA. The contractor certifies that the equipment and retests have successfully been completed where deficiencies were previously revealed. A Prefinal Inspection Report shall be submitted.

The remedial action activities continue until all ARARs are met and maintained. For remediation of surface water or groundwater, the process shall be under the remedial action phase for a maximum of ten years and then it shall progress to the operation and maintenance phase. At the completion of the remedy, a final inspection and Certification shall be done. A Remedial Action Report shall be submitted for approval.

After the review of the Remedial Action Report and governing bodies are satisfied that the remedy is complete and performing adequately, a written notice of acceptance of completion shall be provided. After acceptance, site closeout activities are conducted, i.e. deletion of the site from the NPL.

Operation and Maintenance

Operation and Maintenance (O&M) is required to ensure the integrity of the remedy. An Operation and Maintenance Report is required at the final completion of O&M activities.

DOE REMEDIATION PROJECT PROCESS

The following defines and clarifies the phases within the DOE Remediation Project Process. This summary has been organized to reflect the general sequence of events that occur prior to, during, and after project initiation at DOE facilities. Figures 2A and 2B are the flow charts of the DOE Remediation Project Process as described in DOE Order 4700.1. Table II is a list of key personnel for the DOE Remediation Project Process.

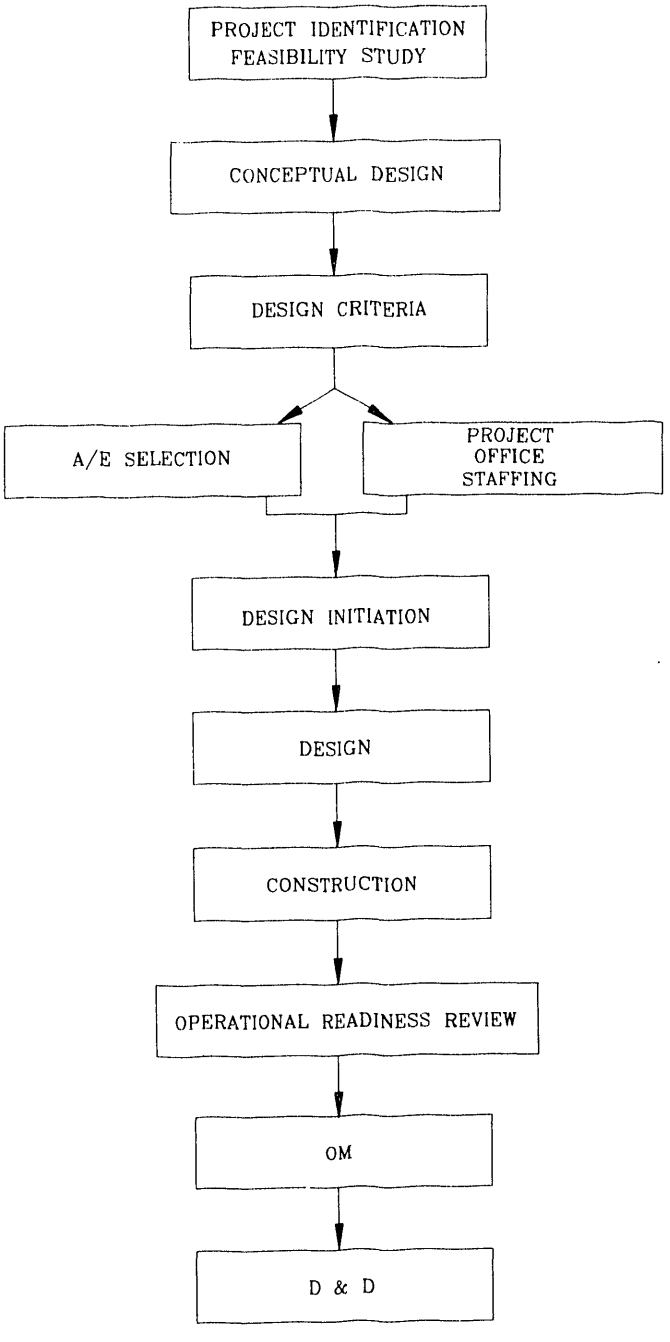


Fig. 2a. DOE Remediation project process.

Project Identification Phase

The project identification phase of the DOE Project Process consists of several sub-phases that need to be completed before Conceptual Funding Process can be started and the next phase can be initiated. These sub-phases include:

- The Environmental Assessment

TABLE I

EPA RD/RA Key Personnel
EPA Superfund Remedial Design/Remedial Action Key Personnel

Title	Function
EPA Remedial Project Manager (RPM):	The designated EPA regional official who coordinates, manages, and monitors site activities.
M&O Project Officer (PO):	The official designated by the lead party for the RD or RA who coordinates, monitors, and manages RD or RA activities.
Design Project Officer (DPO):	The designated A/E official who coordinates, monitors and manages the design activities.
Construction Project Officer (CPO):	The designated contract official who coordinates, oversees, monitors, and manages the construction activities.
Supervisor and Administrator (S&A):	The designated official who supervises and administrates the construction/cleanup activities. Duties also include contract administration.
Full Time On-Site Inspector (OSI):	The official designated by theEPA RPM who oversees the construction activities to ensure compliance. The OSI is authorized to stop all activities not in compliance or which endanger human the health and welfare.
Additional On-Site Inspectors:	For complex project additional OSIs may be required.
A/E Field Representative (A/E FR):	The designated official who advises the construction PO on engineering interpretation of the Facility plans and specifications. The A/E FR also assist the CPO in interpreting the impacts on the design of proposed changes and preparing sketches and/or revised drawings to add construction contract modifications.

TABLE II

DOE RD/RA Key Personnel DOE Remedial Design and Remedial Action Key Personnel

Title	Function
DOE Project Manager (RPM):	The designated DOE overall official who cordinates, manages, and monitors site activities.
Project Manager (PM):	The official designated by the lead party for the RD or RA who coordinates, monitors, and manages RD or RA activities of the A/E.
Operable Unit Manager (OUM):	The designated DOE official who coordinates, monitors and manages the operable unit activities.
Construction/Project Engineer (CPE):	The designated DOE official who follows construction activities: QA, Safety, Design, Inspection etc..
A/E Project Director (PD):	The designated A/E official who supervises, coordinates, manages, and monitors the A/E activities construction/cleanup activities.
Field Engineers (FE):	The official designated by the DOE who is responsible for Title III inspection and oversees the construction activities to ensure compliance.
A/E Operable Unit Managers (A/E OUM):	The designated official who is responsible for accomplishing the design for Operable Unit.

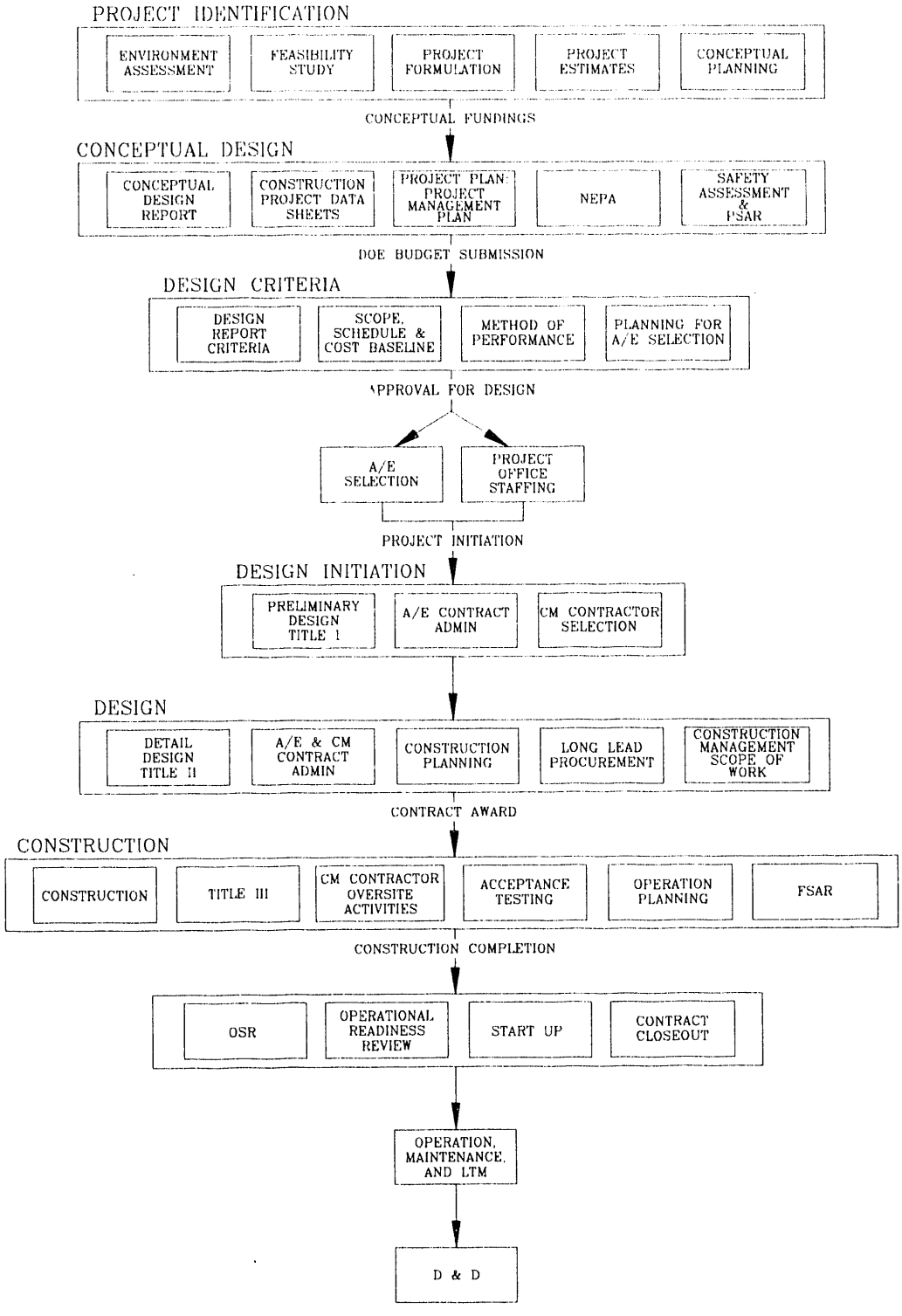


Fig. 2b. DOE Remediation Project Process.

- Specific Project Identification Report
- Project Formulation Report
- Project estimates
- Conceptual Planning Phases and Report.

Conceptual Design Phase

The Conceptual Design Report (CDR) includes such things as the equipment sizing and layouts, preliminary process and instrument drawings (P&IDs), material balances, process calculations, process control philosophy, operating philosophy, material take-off cost estimates, an integrated project schedule and a total project cost estimate. The construction project data sheets, which include all data and justification, are required to include the construction effort in the Departmental Budget. The Project Plan, which includes the project charter, is a summary of the dimensions of the project to be executed. The Plan includes objectives, schedules, resources, priorities, controlled milestones and environmental requirements. The Project Management Plan (PMP) is the document that sets forth the plans, organization, and systems

that shall be utilized by those responsible for managing the project. When required, the Environmental Impact Statement (EIS) shall be initiated at this time and completed before project initiation. After all sub-phases are complete, a submission for DOE Budget is done.

During the Conceptual Design Phase, the preliminary safety analysis shall be initiated. In accordance with DOE order 6430.1A, all DOE facilities shall be evaluated for potential risks to the operators, the public, and the environment. Timing, content, format criteria and approval provisions of Safety Analysis Report (SAR) are contained in DOE 5481.1B (Fig. 3). Facility design and construction features identified as a result of the Preliminary Safety Analysis Report (PSAR) shall be factored into the conceptual design before establishing the project cost estimate and requesting Congressional authorization for design and construction. The PSAR shall be completed and approved prior to the start of construction (including site preparation), consistent with DOE 4700.1.

Design Criteria

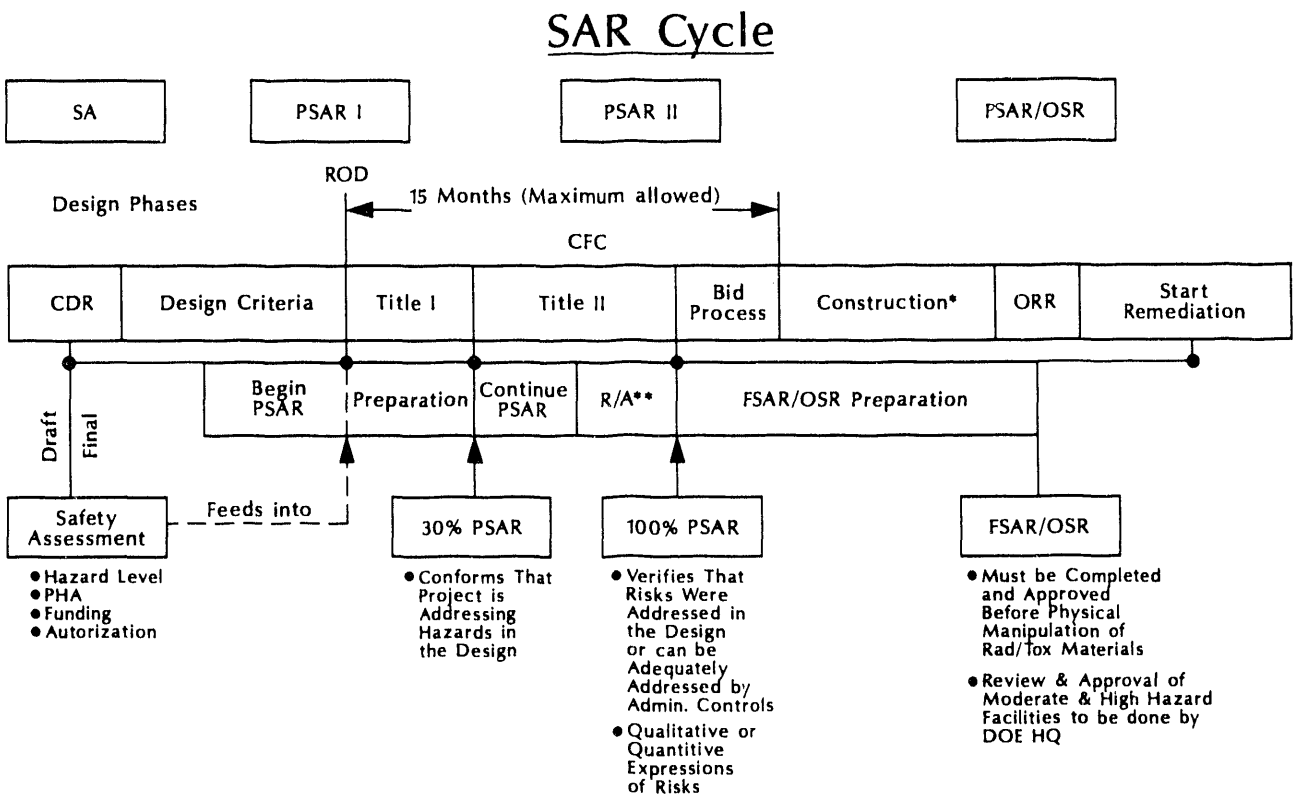
The Design Criteria phase organizes all activities for the design. It includes the Design Criteria Report (DCR) which expands the CDR framework to list the specific design and operating parameters (criteria) upon which the A/E shall base the detailed design. It also includes management organization, scope, schedule and cost baseline, method of performance and planning for A/E selection. All of these factors need to be addressed to obtain approval for the design. Upon approval for design, the A/E selection process and Project Office Staffing commence. At their completion the project is initiated.

Design Initiation Phase

The Design Initiation Phase comes after the project initiation. The PMP must be activated and implemented, and the A/E contract Administration must be established. Simultaneously, the design effort and PSAR are continued in the Title I (preliminary design) utilizing the conceptual design and the project design criteria as a basis for project development. In Title I, design topographical and subsurface data are developed and the requirements and criteria which will govern the definitive design are determined. The selection process for Construction Management (CM) Contractor is completed during this phase. At the conclusion of Title I, the PSAR and the Design are 30% completed.

Design Phase

The activities undertaken during the design are discussed below. The PMP is updated to reflect current project management status. The planning for construction of the project includes objectives regarding schedules, plan and control of technical tasks, and the management of the integrated technical effort to meet cost. Concurrently, the A/E and CM contract administration is established and defined. In the Title II



* Note: Some ERA Projects (e.g., Emergency and Time-Critical) Will Have a "Construction" Phase Within Which to Prepare a FSAR. Physical Operations Involving the Rad/Tox Material Will Begin After Title II. In Those Cases, the 100% PSAR Will Have to be Developed to the Extent OSRs Can be Prepared. Development of Procedures, Training, and As-Builts Will Also be Moved into Title II Phase.

** Note: Review and Approval of Safety Documentation Will Include Site Contractor, FSO, and (in the Case of Moderate and High Hazard Facilities) DOE-HQ.

Fig. 3. PSAR/FSAR continuum.

or Detailed Design, the work of the project, based on approval of the preliminary design, is continued and includes any revisions required of the Title I effort. For Title II, final working drawings, specifications, bidding documents, cost estimates, and coordination with all parties which might affect the project are prepared. The PSAR is completed during Title II. Firm construction and procurement schedules are developed and proposals or bids are analyzed. During the Design Phase, any equipment or service which might be needed by the construction operations of a project are identified and purchased by the Long Lead Procurement activities. These purchases are made on a need for the future basis to minimizing delays in construction or operation start-up times due to lengthy acquisition procedures after project award. The CM plan is developed. The CM plan must be consistent with the quality, size, scope and complexity of the project involved. The CM must establish technical interface requirements and procedures, establish a configuration control board, and indicate approval levels for changes. Concurrent with design activities, the construction contract is presented for Pre-Award. Completion of the bid and award procedures leads to project construction. At the conclusion of Title II, the PSAR and the Design are 100% completed.

Construction Phase

The Construction Phase encompasses many activities. Concurrent with the actual construction, planning for facility Operations is initiated. The Final Safety Analysis Report (FSAR) shall be developed during the construction phase and shall be completed and approved prior to the initiation of the facility operations. The FSAR shall be updated as appropriate to reflect changes affecting safety that are made to the facility during its lifetime. Title III activities are performed. These activities assure that the project is constructed in accordance with the plans and specifications (i.e. construction inspection), and that the quality of materials and workmanship is consistent with environmental and technical requirements of the project. The PMP is updated to reflect the current status. The A/E Contractor assumes administrative responsibilities. The CM contractor activities described previously continue until completion of construction. Upon conclusion of construction activities, all reports and documentation for fulfillment of the contract are completed.

Operational Readiness Review

At the completion of construction phase, the final inspection and acceptance take place. Operational Readiness Review (ORR) is completed. These activities include: assignment of test and acceptance functions, establishment of acceptance tests for equipment, operator training, establishment of procedures, establishment of on-the-job worker surveillance programs, and final acceptance and inspection. At this time the Operation Safety Report (OSR) is developed. The contract for construction is then closed out and operations commence.

Project Operation

The Project Operation Phase lasts for the active life of the facility. During Operations, the DOE Annual Budget process is still in effect. At the end of Operations, the decontamination and decommissioning process takes place.

COMPARISON

Figure 4 show both processes with a similar placement of events. Figure 5 shows these in greater detail. Similarities existed between the DOE and EPA requirements. Although the presentation differs, the design items defined in the SOW for the A/E firm are essentially the same components needed for the DOE Design Criteria Report. While specific contents of the reports may differ, most of the requirements needed for the EPA RD work plan are found within the requirements of the DCR and the SOW. Excerpts from both the DCR and the SOW could be used to meet the requirements for the EPA RD Work Plan. Greater similarities can be see in the actual designing of the project. The DOE Title I Design meets the requirements for the EPA Preliminary Design and the DOE Title II meets the requirements for the EPA Intermediate, Pre-Final and Final Design. Requirements for quality assurance, site and worker safety, worker training, inspection and certification are congruent. The DOE Construction Phase and Operations corresponds with the EPA RA and O&M phases. Although, as previously discussed, some requirements for DOE are not requirements for EPA and vise versa. Furthermore, as presented earlier, DOE Operations start within the EPA RA phase and continue into the O&M Phase making direct time comparison difficult.

EPA review and comment associated with DOE milestones present certain advantages. EPA involvement and insight would provide valuable direction in remedial proceedings. Possible DOE milestone review and comment by EPA is presented in Table III.

DOE PROJECT BUDGET PROCESS

The project budget is a continuing process that systematically provides funding for design and construction projects. This process is repeated every fiscal year and is used for planning and acquiring funds for budget years BY, BY + 1, BY + 2, and BY + 3. The annual budget chronology (Fig. 6) is described followed by a multi-year chronology description.

ANNUAL BUDGET PROCESS

In October, the DOE closes out prior year projects. Congress appropriates funds for the current year at the same time.

In the November-December time frame, the Office of Management and Budget (OMB) approves the President's budget for Budget Year (BY) and provides guidance for BY + 1, BY + 2, and BY + 3.

The President's budget for Budget Year is sent to Congress in January. The Field Office receives the BY + 1 Budget from the contractor. Prior to including a project in the budget, a conceptual design is completed, and sent to Headquarters. Project data sheets are submitted for both new and on-going project efforts requiring additional funding. This documentation is used with the conceptual design report for project validation and to defend the project in the internal review budget.

During February through April, the field offices conduct internal review of BY + 1 and complete the call. BY + 1 is then returned to the project offices, Controller, and Office of Project and Facilities Management. Also, during this time, Congress conducts hearings on the Budget Year and DOE defends the BY budget and legislation.

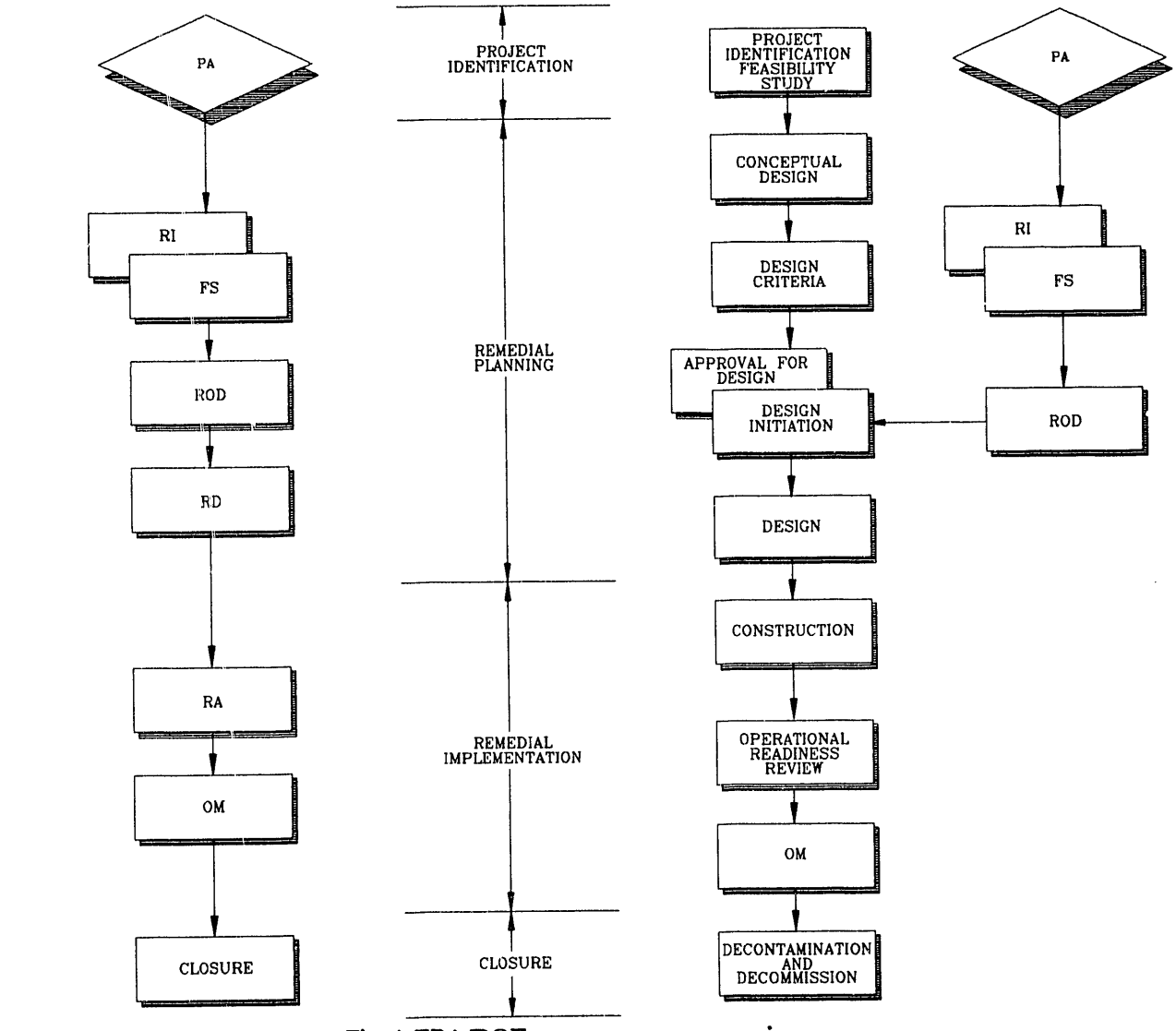


Fig. 4. EPA/DOE macro process comparison.

From April through May, the Controller issues a field budget call incorporating any budget planning decisions that have been made and an internal review budget call for BY + 1. The Field Office submits BY + 1 to Head Quarters (HQ). Project validation occurs for projects in BY + 1. Validation is conducted by the Program offices and the Office of Project and Facilities Management and evaluates the projects for readiness to proceed into the Department's budget process. It also examines the planning, development, and baseline of a project to ensure that the funds requested are commensurate with the project's anticipated scope and schedule. Normally, the project must be validated prior to inclusion in the internal review budget. By May, HQ Internal Review Broad (IRB) makes the call for BY + 1.

In June, the IRB submits the BY + 1 budget. The Secretary conducts an internal review for projects included in BY + 1 during July through August. Congress passes BY appropriation bills or continuing resolution.

The Department prepares OMB Budget for BY + 1 in August and September.

MULTI-YEAR BUDGET CHRONOLOGY

The interconnected planning and budget cycles encompass an approximate 4-year period. During this time, project identification, project selections, project scope and construction requirements, reliable cost estimates, and advance project planning needed to assure timely project initiation are developed and accomplished. This time must be well utilized and adequately scoped so that sufficient conceptual design work is completed. The budget cycle and planning steps for a project with authorization anticipated in BY + 3 is shown in Fig. 7. This indicated the steps required to be taken in proceeding years to authorize a budget in BY + 3 project.

In the Current Fiscal Year (CFY), lists of candidate projects accompanied by short form data sheets are delivered to the appropriate program division and the Office of Project and Facilities Management (OPFM) for BY + 3 candidate projects. Headquarters reviews the projects to be considered for inclusion in the BY + 3 budget. Program Organizations revise the BY + 2 requests to include BY + 3 requirements as determined through the planning, programming, and budgeting process. Work on Conceptual Design Reports begins at this time for projects to be included in BY + 3.

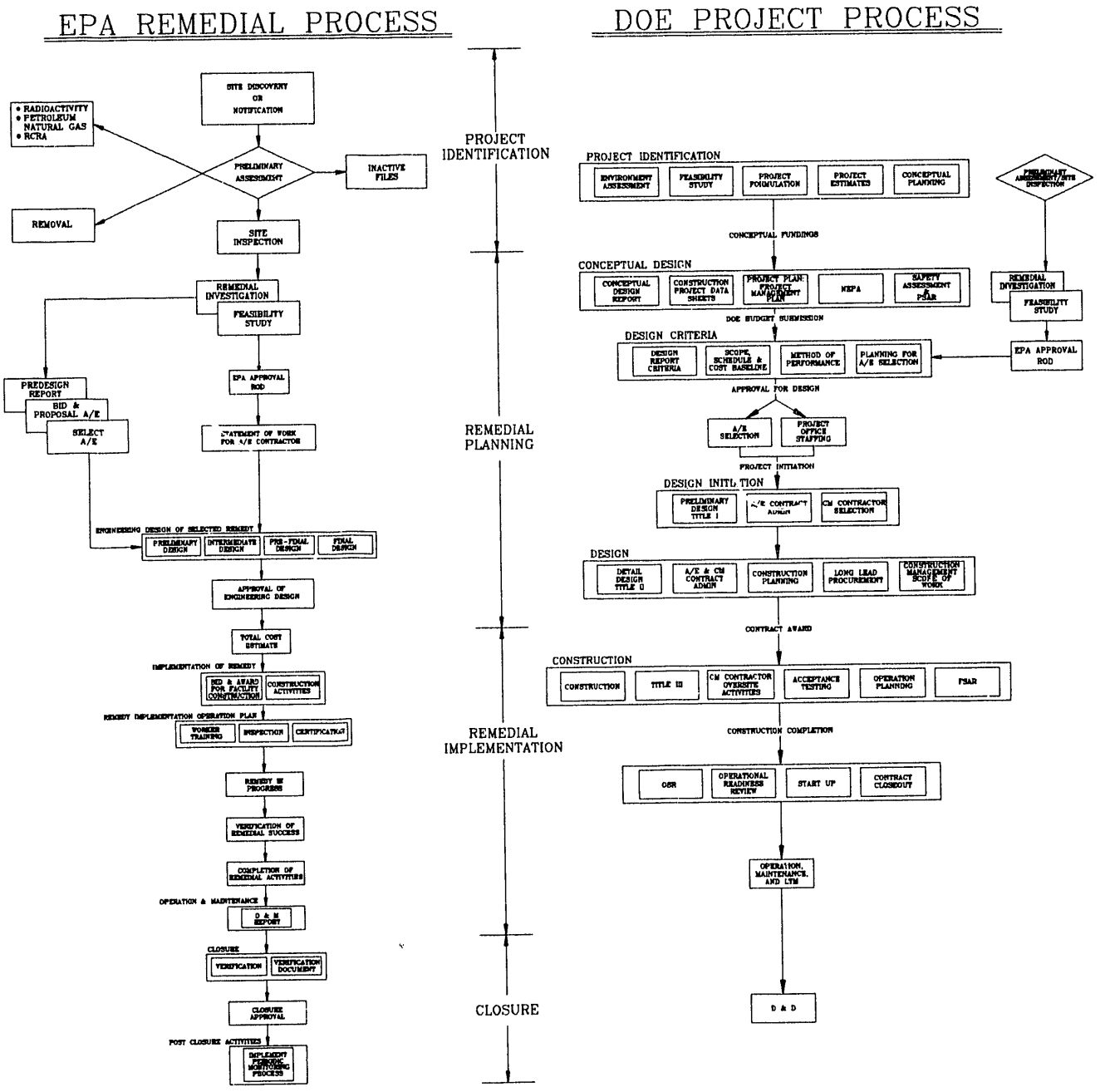


Fig. 5. EPA/DOE detailed process comparison.

In BY + 1, the program organizations review the tentative construction program for BY + 2 in light of the approved CFY program and the BY + 1 program as submitted to the OMB. Upon completion of this review, program organizations notify field offices and the Office of Project and Facilities Management of the BY + 2 budget projects for which planning should continue. Information provided by the short form data sheets, the BY + 1 OMB budget, and the current appropriation act is utilized to complete this action. The Field elements shall submit the construction project data sheets and the conceptual design reports to the appropriate program office and the OPFM. The OPFM validates the construction project data sheets planned for inclusion in the BY + 2 Internal Review Budget submittal. Headquarters completes all actions required by the planning, programming, and budgeting system. Headquarters incorporates the updated construction project data sheets for BY + 2 projects and submits to the OMB. In BY + 2, funding is made available for BY + 3 Projects. Field organizations accomplish plant engineering and design. Other actions may take place with respect to BY + 3 budget but do not require specific action by the field elements. This includes the President's budget being submitted to Congress and the authorization and appropriation Acts being passed.

In BY + 3, the OMB apportionment and the DOE allotment occur. These fund the design or construction activities. The field elements initiate the design and construction of a project.

VALIDATION

The Budget Validation evaluates the project for planning, development, baseline, and proposed funding. Budget validation is needed for any new project or to increase funding of

TABLE III

EPA Involvement
Potential Required DOE Milestones to be Submitted to EPA for Review and Comment

Health and Safety Plan
Sample and Analysis Plans
Quality Assurance Project Plans
Site Safety Plans
Removal Site Evaluation
Action Memorandum
Environmental Assessment
Environmental Impact Statement
Engineering Evaluation/Cost Analysis (EECA)
Remedial Design Work Plan
Remedial Action Work Plan
Title I/II Design
Test and Startup - verification of Remedy
Operational Readiness Review
Operation and Maintenance Plan
Closure Plan
Air Emissions Permit to Install (APT)
Air Emissions Permit to Operate (APTO)
Air Emissions Notice of Intent
Water Discharge Permit to Install (WPTI)
Water Discharge Notice of Intent (WNOI)
Safety Assessment
Preliminary Safety Assessment Report
Final Safety Assessment Report

any prior project. The Validation Process consists of reviewing project planning and conceptual development documentation. Through discussion with principal parties, validation determines:

- source basis,
- procedures,
- validity of requirements,
- validity of scope,
- validity of cost, and
- validity of schedule.

Validation findings are used for the Annual Budget Formulation.

DOE REMEDIATION PROJECT REQUIREMENTS

DOE Orders/EPA Equivalents

DOE Orders and requirements for environmental restoration activities are summarized in Fig. 8. These requirements have been compared to equivalent EPA requirements.

SCHEDULE FOR RD/RA PROJECTS

Traditional EPA/DOE RD/RA Schedule

Figure 9 depicts the traditional EPA/DOE RD/RA schedule and the DOE Budget Cycle. The figure portrays a need for the design budget submittal to occur at the very early stages of the RI/FS process and the construction budget submittal to occur in the middle of the RI/FS process. This brings into focus the conflicts in time frames for each activity. Viable correlation between the two processes begins to occur within the Design phases. CERCLA requires physical and substantial and continuous ongoing remedial activity to begin 15 months after the signing of the ROD. This is improbable due to the DOE procedures for construction activities. The solution to this dilemma is discussed in the next section.

Innovative EPA/DOE RD/RA Schedule

Figure 10 presents the solution to the 15 month physical, substantial and continuous ongoing remedial action dilemma. "Common threads" (construction items which need to be done for all remedial activities selected) which could be identified

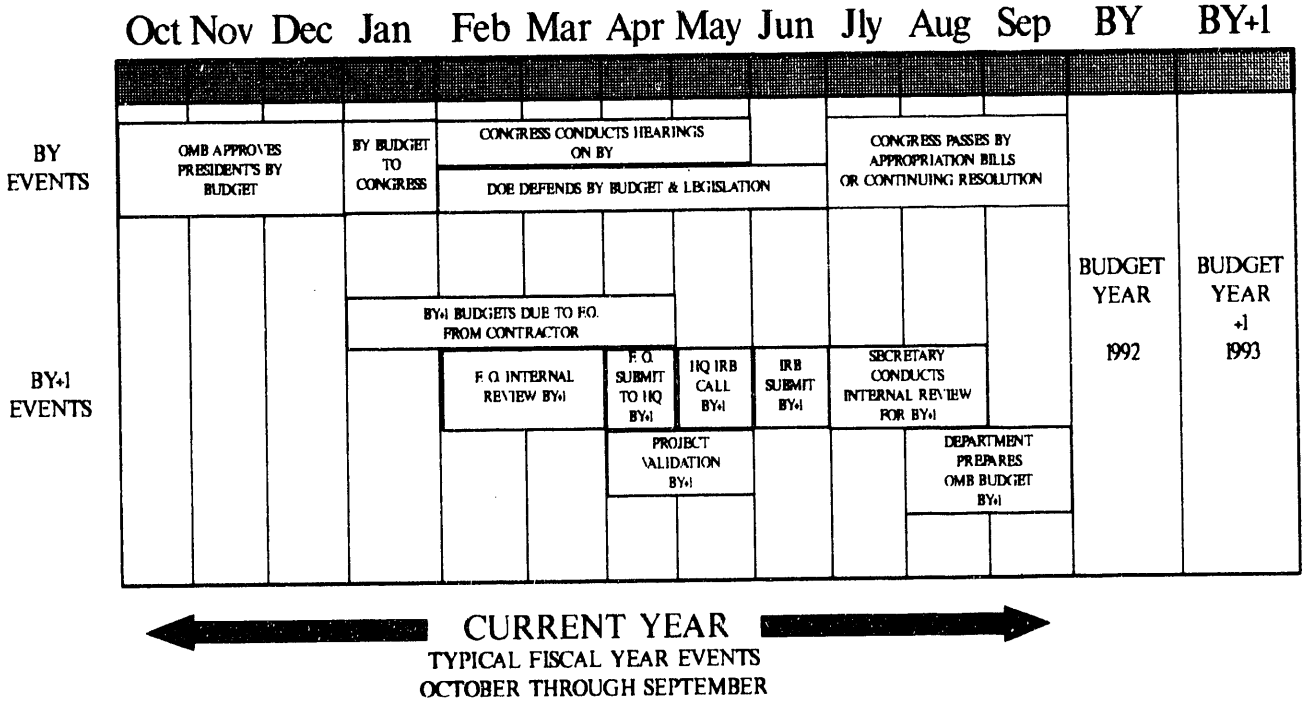


Fig. 6. Annual budget process.

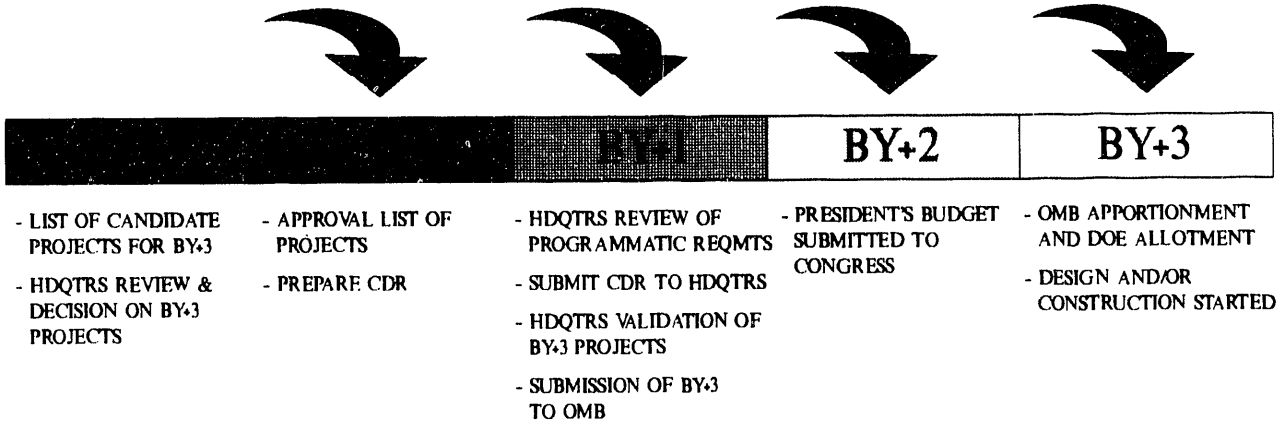


Fig. 7. Appropriation of funds.

early in the RI/FS can be broken out into distinct design packages. After ROD approval, these "distinct design packages" could then go through the DOE project process and be awarded for construction. The "packages" would progress from the simplest to the most complex ending with the remedy selected by the EPA ROD. By breaking the overall Design into separate pieces, continuous and ongoing remedial action can be logically implemented within the 15 month criteria.

INNOVATIVE SCHEDULE CONCLUSIONS

As seen by the comparison in the preceding sections, the traditional DOE remediation project process requirements are quite similar to the EPA remediation process requirements. While differences exist, the sequence and content of the design and approval documents are congruent. Although these similarities exist, time allocation problems still arise. DOE must manage the remediation activities to meet both remediation requirements and budgeting requirements. The annual budget cycle and the line-item allocation process constrain the remediation process. In addition to DOE budget constraints, the DOE design process for a complex remediation exceeds the 15 month time allotment. The Title I and Title II phase of a complex design alone could conceivably take several years to complete. In order to meet the requirements of the traditional remediation project schedule, funding (and cost estimates) for the RD/RA activities would have to be requested in the initial stages of the RI/FS. Furthermore, design of the project would need to start at the middle of the RI before selection of the alternative is even under way. The inherent risks of this approach are apparent.

By using an innovative project methodology, the DOE remediation process can be altered to meet the requirement of substantial continuous physical on site remedial action. The requirements for continuous activity within 15 months of the ROD can be met by dividing the selected remedies into separate design "packages". Common threads activities (such as roads, utilities, etc.) necessary for all remedies will be defined and broken out. This will allow the "common thread" designs to be started upon the signing of the ROD. While construction of the "common threads" are being completed, the more complex parts are being designed. By overlapping the construction activities of the "common threads", a physical, substantial and continuous ongoing remedial activity will be maintained. By breaking out the design packages, the requirement for the 15 month time constraint is met while the complex design is being completed.

DISCLAIMER

This paper was prepared as an account of work sponsored by an agency of the United States Government. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government of any agency thereof. The views and opinions of the authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

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REQMNT	DOE ORDER	DEFINITION	PURPOSE	EPA EQUAL
SAFETY DOCUMENTATION Safety Assessments, PSAR's, FSAR's, and OSR.	DOE 5480.1B DOE 5481.1B DOE 6430.1A	Prepare safety documentation that identifies the hazard classification, facilty use classification, and safety class items within the facility which protects equipment and personnel.	Identify hazards within facility to provide appropriate mitigating design features and/or administrative controls.	29 CFR 1900 MSDS
QUALITY ASSURANCE Quality Assurance Plans & Risk Assessment Reports.	DOE 5700.6B	Prepare QA documentation for each project and establish overall facility wide QA program consistant with the requirements set forth in ANSI/ASTM NQA-1 Standard. Assures that all projects are performed in a controlled manner and maintained in a manner consistant with good engineering standards, quality practices, and technical specifications. The RAR specifically identifies the key areas or concerns of any given project.	Identify concerns to be addressed in design and operation. Establishes QA levels to guide project.	40 CFR 300 Quality Assurance Project Plan
FEASIBILITY STUDY	DOE 4700.1	Identifies the initial design recommended for any new given project. The FS is prepared as the basic document for obtaining funding for any new Major Project or MSA.	Identifies need for funding for all new projects. Evaluates feasibility of meeting objectives via allocation, ROM, Cost, & Schedule.	40 CFR 300 Feasibility Study
CONCEPTUAL DESIGN REPORT	DOE 4700.1	CDR is prepared as a revision to the FS. Provides a greater level of detail and is prepared at BY-3	Sets baseline scope, cost and schedule.	
DESIGN CRITERIA	DOE 4700.1 DOE 6430.1A DOE 6410	Provides summary of the requirements, codes, orders, etc. that must be adhered to during the Title I/II design effort. Provides an even greater level of detail for the proposed design and is prepared at BY-2	Further refines cost estimate.	40 CFR 300 Remedial Design Remedial Action OSWER 9355.04A Statement of Work
TITLE I/II GENERAL DESIGN REQUIREMENTS	DOE 4700.1 DOE 6430.1A	Provides details for the national standards and codes that must be met for all aspects of design for all new facilities. Identifies special design features that must be incorporated into the design based upon the facility use classification.	Standardizes all design effort using similar guidelines.	40 CFR 300 Record of Decision OSWER 9200.3-010 RD&RA Work Plans
TITLE I/II DESIGN PACKAGES	DOE 4700.1 DOE 6430.1A	Provides 30% to 100% design of project.	Preparation of drawings and specifications (CFC) package.	OSWER 9355.04A Preliminary Design Intermediate Design Prefinal Design Final Design
HUMAN FACTORS ENGINEERING	DOE 6430.1A	Requires that a human factors analysis be performed for all designs to assure operability and maintainability of the equipment in which human interface is required.	Assures properly ergonomically design systems and facilities.	OSWER 9355.04A Certification; Operation and Maintainence Plan
LIFE CYCLE COST ANALYSIS	DOE 6430.1A DOE 4330.2C	Requires that a Life Cycle Cost (LCC) Analysis be performed for all new facilities having a minimum power usage.	Provides mechanism for review and optimization of equipment or systems not deemed energy efficient.	OSWER 9355.04A Cost Estimate; Operation and Maintainence Plan

Fig. 8. DOE Order/EPA Equivalents.

REQMNT	DOE ORDER	DEFINITION	PURPOSE	EPA EQUAL
VALUE ENGINEERING	DOE 4101.1 DOE 6430.1A	Provides for the independent review of all designs to assure that they are performed and constructed in the most cost effective manner.	Identifies potential cost savings and improvements in constructability of a project	OSWER Directive 9355.0-4A Remedial Design and Remedial Action Guidance Document
RADIATION PROTECTION STANDARDS	DOE 5400.5 DOE 5480.1B DOE 5480.11	Provides for a standard and guidelines on which systems, equipment, and facilities must be operated by establishing exposure limits for radionuclide exposure. This combines with the safety document process to assure maximum protection to the operator and to the general populous.	Identifies exposure limits on which to guide technical designs of new facilities and projects.	49 CFR 190 49 CFR 191
NEPA DOCUMENTATION Catagorical Exclusion, Environmental Assessment, Environmental Impact Statement	DOE N 5440.1	Establishes guidelines for the need for the necessary environmental documentation to satisfy the requirements of the National Environmental Policy Act. Establishes guidelines for the type of projects requiring the documentation and the approvals required. Documentation approval must be recieved before any Title II design is initiated.	Assures that all projects are performed in accordance with the intent and spirit of the law, and that environmental impacts are properly assessed	CFR
TITLE III SERVICES	DOE 4700.1	Activities required to assure that a project is constructed in accordance with its plans and specifications. Assure through inspection that the quality of the material and workmanship is consistent with the plans and specifications. Also assure through inspection that all required testing is performed.	Provides for a better product at completion that meets the design criteria	RD/RA GUIDANCE - Prefinal Inspection Report - Certification
HEALTH AND SAFETY PLAN	DOE 5480.14	A Health and Safety Plan shall be prepared for all activities associated with the characterization of hazardous wastes sites and with clean-up operations involving hazardous substances and wastes.	Aids in identifying the anticipated health and safety hazards associated with any project	40 CFR 300 Site Safety Plan Health and Safety Plan
REMOVAL SITE EVALUATION	DOE 5480.1B	Establishes the environmental protection safety and health programs for DOE operations.		40 CFR 300 Removal Site Evaluation
NESHAPS AIR PERMIT	Executive Order 12088	Federal compliance with pollution control standards which establish regulations and procedures for Federal agencies to comply with environmental legislation and regulation.		Clean Air Act OEPA
PERMIT TO INSTALL/ PERMIT TO OPERATE	Executive Order 12088	Identifies the need for approved permits identifying the expected emissions that may be seen from the facility.		

Fig. 8. DOE Order/EPA Equivalents, Cont'd.

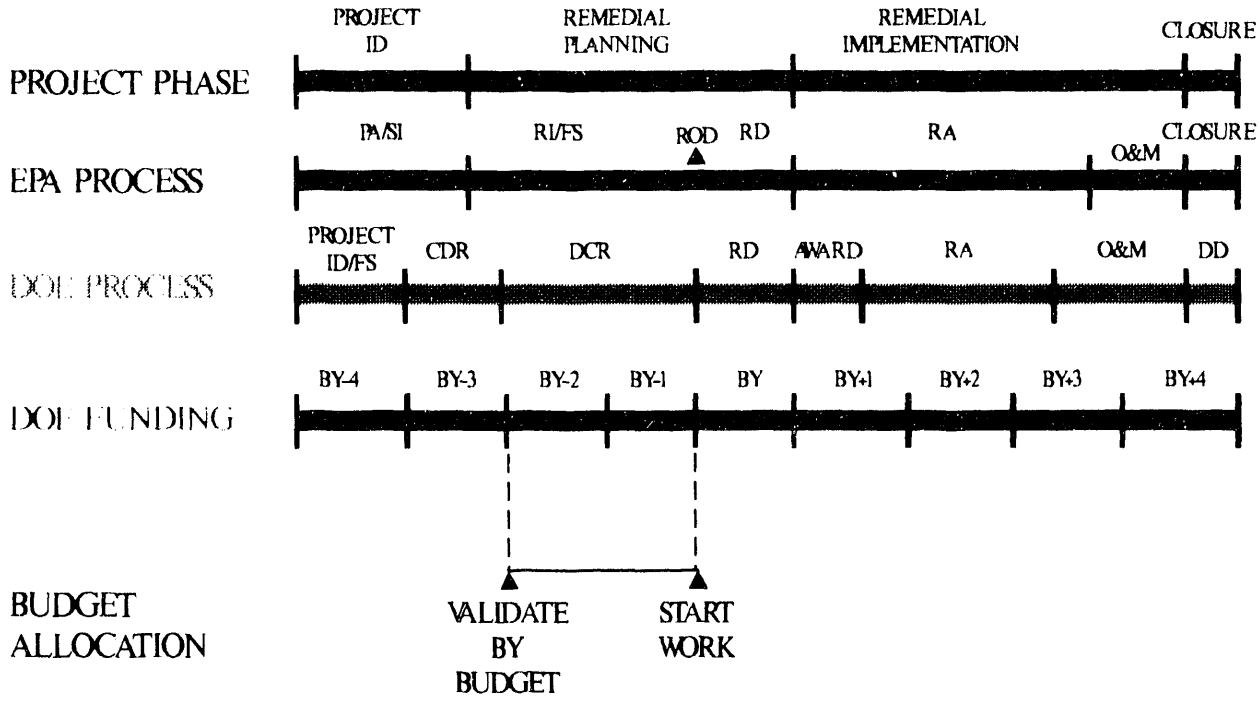


Fig. 9. Traditional schedule.

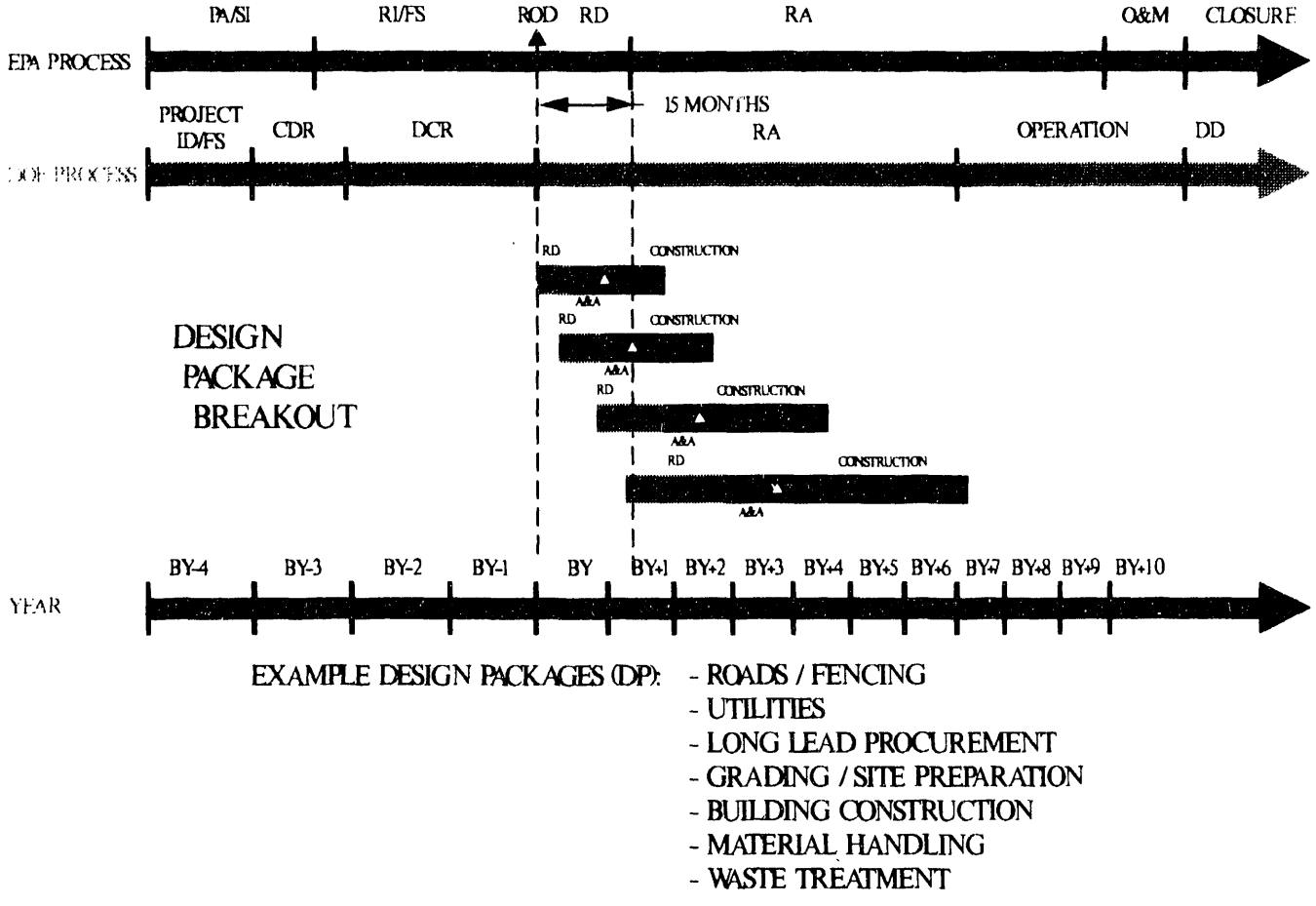


Fig. 10. Innovative schedule.

HANFORD WASTE TANK SAFETY ISSUES: A PROGRAM OVERVIEW

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ABSTRACT

This paper presents an overview of the potential high-activity waste safety issues in the 177 underground radioactive waste storage tanks at the Hanford Site. Also, included is a discussion of the strategy and plans to remedy hazardous conditions and remove other deficiencies related to the operation of the tanks. A three-pronged multimillion dollar integrated program has been initiated that (1) assesses and, on an as needed basis, defines remediation and/or mitigation actions to allow interim stabilization of high risk waste tanks; (2) upgrades existing facilities and instrumentation to meet current nuclear facility operations standards; and (3) addresses and upgrades the conduct of operations. For tanks that are considered at risk, extensive management controls presently are employed to ensure that the tanks continue to be maintained in a safe manner. In addition, comprehensive monitoring, characterization and applied research, and engineering efforts have been initiated to support resolution of safety issues. A key element of the Westinghouse Hanford Company effort is preventing future problems associated with creating potentially incompatible wastes as part of waste management activities associated with the planned disposal of the wastes in these storage tanks. Such efforts also will provide the basis for safe near future remediation of tanks and define and maintain the envelope of safety to support the ultimate disposal of all high-activity waste in Hanford Site tanks.

INTRODUCTION

This paper lists the 23 safety issues related to storing high-activity mixed tank waste at the Hanford Site. A summary discussion of seven of the safety issues follows. This paper serves as an introduction to the Environmental Restoration 1991 conferences special session "Hanford Tank Operations and Safety Issues." Initiatives are underway for evaluating the technical issues leading to solving waste tank safety issues. Initially, high priority efforts being focused on are the hydrogen and ferrocyanide tanks because they represent unreviewed safety questions. The logic underlying the Waste Tank Safety, Operations and Remediation Program at the Hanford Site will be presented.

BACKGROUND

The radioactive waste stored in Hanford Site underground tanks has come from (1) three different processes for recovering plutonium and uranium from approximately 100,000 metric tons of uranium of fuel; (2) from three different processes that recovered radionuclides from the waste; (3) from miscellaneous other sources such as laboratories and reactor decontamination solutions; and (4) from production and waste management operations. The wastes were neutralized before entering the storage tanks and, over the years, the wastes have been concentrated as a result of water evaporation. The major chemicals in the tanks include sodium nitrate/nitrite, sodium hydroxide, sodium aluminate, and sodium phosphate. Also, there are large amounts of organics. The waste tank radionuclide inventory is approximately 210 million curies, and is stored in single-shell and double-shell tanks.

Between 1943 and 1964, 149 single-shell tanks (total capacity 94-million gallons) were built for storing liquid radioactive wastes at the Hanford Site. These single-shell tanks consist of reinforced concrete with a carbon-steel liner. Single-shell tank capacities range from 208 cubic meters (55,000 gallons) to 3,785 cubic meters (1 million gallons). Today, the tanks hold about 168,205 cubic meters (37 million gallons) of liquids and solids from a variety of reprocessing and waste processing activities No wastes have been added to any of these tanks since November 1980. Sixty-six of the single-shell tanks have either leaked or are suspected to have leaked.

Between 1968 and 1986, 28 double-shell tanks were built for storing liquid radioactive wastes at the Hanford Site. The double-shell tanks consist of a carbon-steel tank within a steel-lined concrete tank. The double-shell tanks have a nominal capacity of 3,785 cubic meters (1 million gallons). The total capacity of the double-shell tanks is about 113,562 cubic meters (30-million gallons). The double-shell tanks were placed into service beginning in 1973. They presently contain about 104,560 cubic meters (23 million gallons) of liquid radioactive waste. The double-shell tanks have a built-in leak detection capability: none of the double-shell tanks have leaked.

In 1968, a program to remove pumpable liquids from single-shell tanks was started to prevent or diminish future impacts from possible leaks. Pumpable interstitial liquid and supernatant wastes are being removed from single-shell tanks and transferred to double-shell tanks. The remaining 51 tanks are scheduled to be pumped by September 1996. Not all liquid can be pumped from the single-shell tanks because some liquid is bound interstitially in the tank solids and the remainder drains too slowly to pump effectively.

The tanks and the instrumentation and equipment associated with the tanks reflect the engineering practices of the times that the tanks were built or installed. The more stringent application of nuclear facility standards, by the Department of Energy, to waste management facilities will require an extensive upgrade program, as well as the construction of new facilities. Additional double-shell tank capacity also is needed to accommodate potential mitigation/remediation actions associated with higher risk tanks, and to support pretreatment activities associated with the disposal of existing double-shell tank wastes.

Concerned about waste tank safety at the Hanford Site, Congressman Wyden (Oregon) introduced an amendment to the *National Defense Authorization Act for Fiscal Year 1991*, Public Law 101-510, Section 3137. The amendment requires

that the secretary of the U.S. Department of Energy report to the U.S. Congress on actions taken to promote high-level radioactive waste tank safety at the Hanford Site. In compliance with Public Law 101-510, a report was written (DOE 1991) that also addresses the secretary's timetable for resolving outstanding safety issues at the Hanford Site. The report addresses the identified safety issues, and describes the planned studies and remediation actions. In addition, the report presents a schedule for resolving the safety issues. Table I contains the list of Hanford Waste Tank Safety Issues.

The four Priority 1 issues and three of the Priority 2 issues are discussed in the following sections.

STRATEGY FOR RESOLVING SAFETY ISSUES

Resolving all safety issues will take many years, and as the tanks receive further evaluation it is anticipated that more issues may be identified. A Waste Tank Safety Program has been established to conduct this work and a series of charts have been developed to describe the program logic. Detailed plans also are being developed for each of the major activities. Program logic charts, which show relationships of the major activities and the steps necessary to resolve the issues, were developed. Based on new information, improvements will be made in the logic as the program proceeds.

The Waste Tank Safety Program is summarized in Fig. 1. The major activities shown are: evaluation, remediation/mitigation, verification and upgrades. The 23 potential safety issues have been divided into 3 priorities to aid further evaluation, in response to Public Law 101-501 by the U.S. Department of Energy. The four Priority 1 tanks that have been selected for accelerated evaluation are introduced in the following section. Three of the Priority 1 tanks will be discussed in greater detail in later papers in this session. Three other Priority 2 issues that play a pivotal role in ensuring the success of the accelerated evaluation program, or in ensuring safe operation also are described in following sections.

Evaluation will determine that some tanks require remediation/mitigation to close the safety concern (such as

TABLE I

Hanford Site Waste Tank Safety Issues

Safety Issues Description	Number of tanks DST	SST	Total
Priority 1			
1. Flammable gas generation in Tank 241-SY-101 and other tanks	5	18	23
2. Potential explosive mixtures of ferrocyanide in tanks	--	24	24
3. Potential organic-nitrate reactions in tanks	--	8	8
4. Continued cooling required for high-heat generation in Tank 241-C-106	--	1	1
Priority 2			
1. Insufficient tank contents characterization to support evaluations	All	All	177
2. Inadequate safety documentation	All	All	177
3. Tank safe operating life	All	All	177
4. DST space requirements	All	All	177
5. Upgrading of operations, equipment, and facilities			
a. Improvement in conduct of operations	All	All	177
b. Lack of plant-essential drawings	All	All	177
c. Maintenance and upgrades of tank farm facilities and equipment	All	All	177
d. Instrument upgrades in SST and DSTs	All	All	177
e. Tank toxic vapor releases	All	All	177
f. Leaking S-302-A catch	tank	383	86
g. Inadequate single-shell tank leak-detection systems	--	All	149
h. SST emergency pumping	--	17	17
i. Response to a leaking DST	All	--	28
Priority 3			
1. SST sealing to prevent intrusions	--	All	149
2. DST safety upgrades	All	All	All
a. Transfer line concrete encasement integrity and secondary containment compliance	All	All	All
b. AZ Tank Farm ventilation line	2	--	2
c. Excessive hydroxide consumption in Tank 241-AN-107	1	--	1
d. Improved leak detection in DSTs	All	00	28
e. Intertank ventilation connections	All	19	47

DST = double-shell tank.
SST = single-shell tank.

tanks 241-SY-101 and 241-C-106) while the evaluation of other tanks may determine that there is not a safety issue. For those tanks requiring remediation or mitigation, this activity includes collecting data, developing the remediation method, and installing and conducting the remediation.

Tank safety verification is a parallel, long-term activity that includes an in-depth review of the physical condition, as well as contents of the tanks. The end result is documented verification of each tank's capability to safely store waste until the waste can be disposed of.

The tank farm upgrades activity provides a broad range of improvements that have safety implications; such as improved configuration control and conduct of operations, improved maintenance, new instrumentation, upgraded equipment and facilities, and upgraded safety documentation. These upgrades are needed to close some of the safety issues as well as enable the tank farms to be operated to today's standards.

Successful completion of the Waste Tank Safety Project will ensure that wastes are safely stored until the Waste Disposal Program(s) can be carried out.

PRIORITY 1 SAFETY ISSUES

This section provides an overview of the four Priority 1 safety issues associated with single-shell and double-shell tanks and their potential impact on pretreatment before disposal. Issues of concern to potential treatment strategies include cyclic hydrogen (flammable gas mixture) release, ferrocyanide accumulation, the presence of organic chemicals mixed with nitrate-nitrite salts, and the requirement to add cooling water to single-shell Tank 241-C-106.

Safety issues are the present focus of the Waste Tank Safety Program whose task is to ensure the safety of the single-shell tank and double-shell tank systems until appropriate treatment and disposal of tank contents can take place. To ensure interim safety, extensive management and technical controls are employed to ensure that safety issues related to tanks will continue to be maintained in a safe manner. In addition, there is an ongoing requirement (established by the Department of Energy) for a broad-based peer review of all planning and safety documentation by high-level groups established by the U.S. Department of Energy-Headquarters. Approval of all actions relating to the flammable gas and ferrocyanide tanks by U.S. Department of Energy-Headquarters, before all intrusive acts, is required also.

The hazardous characteristics of the existing wastes, leading to identification and control, were estimated on the basis of general information from the chemical literature, expert peer judgement, and limited historical and actual sampling data. Mitigating factors, which would serve to reduce risk, such as moisture content, presence of inert diluents (e.g., sodium carbonate, sodium aluminate, and/or sodium phosphate), and conditions that could lead to a lack of reactivity of the wastes were purposely understated.

Scenarios of significant concern associated with waste in tanks include the following.

- The potential for ignition of flammable gases such as hydrogen-air, hydrogen-nitrous oxide and or air-organic vapor mixtures.

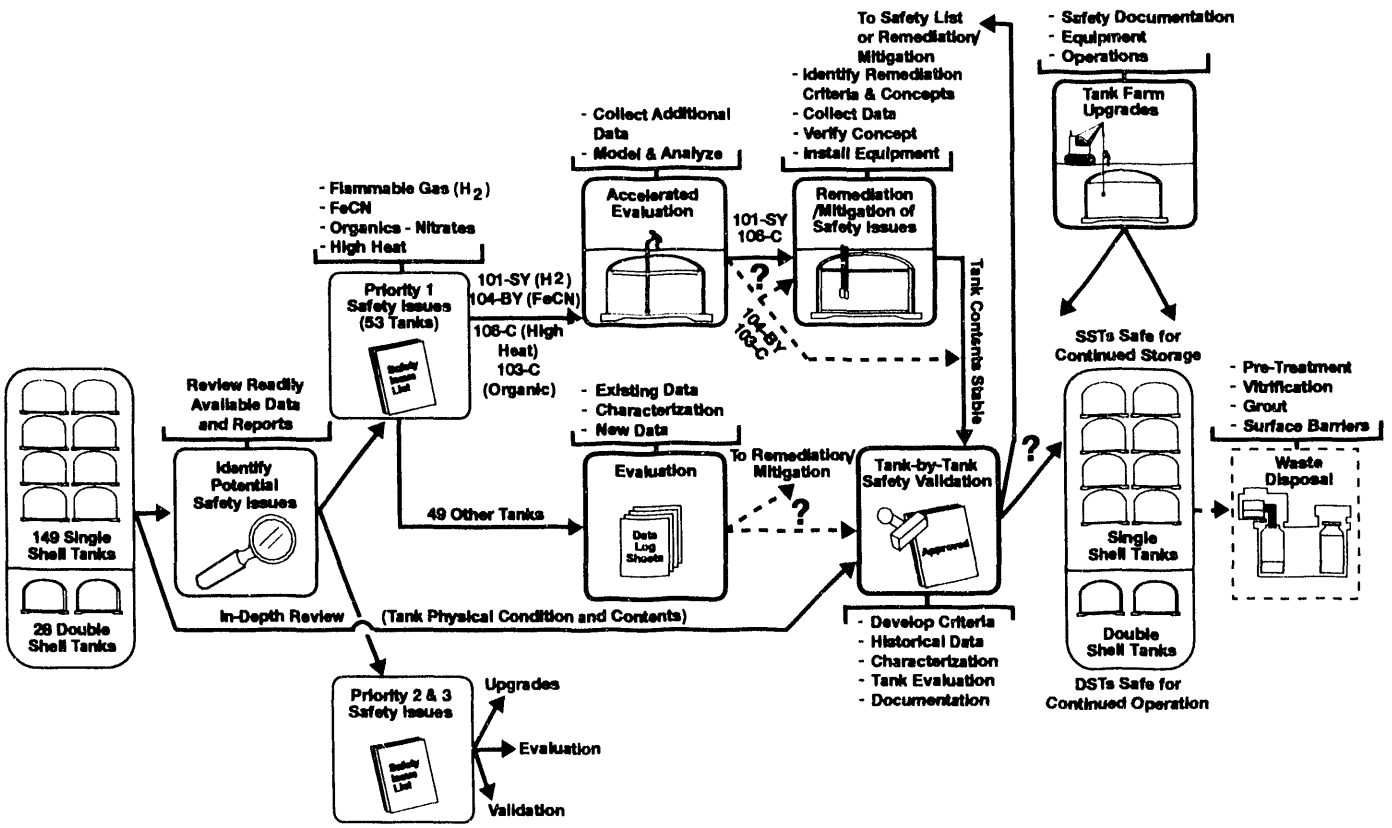


Fig. 1. Waste tank safety program.

- The potential for secondary ignition of organic-air and/or organic-nitrate mixtures initiated by the burning of flammable gases.
- The potential for ignition of organic-nitrate and/or ferrocyanide-nitrate mixtures initiated by the radiolytic or chemical heating of dry salt cake or by localized heating.
- The potential for a leak from a tank causing release of contaminants into the environment while having to meet a requirement to add cooling water to that tank to maintain its structural integrity.

Administrative and technical controls associated with the conduct of operations are in place to restrict activities that could cause undesirable exothermic reactions. For example, pumping of interstitial liquid from ferrocyanide tanks has been stopped to maintain present moisture levels (e.g., to maintain present thermal conductivity and heat capacities). Nonsparking tools and use of electrical bonding techniques on instrumentation are used around hydrogen tanks. So-called "normal" activities for tanks at issue are limited to surveillance. Special safety analysis documents, which are extensively peer reviewed, are prepared for all work inside the tank.

In addition, comprehensive monitoring, characterization, and applied research efforts have been initiated to support resolution of issues and to prevent creation of future problems associated with potentially incompatible wastes or actions related to the planned treatment and disposal of the wastes in these storage tanks. Such efforts also will provide the basis for safe near future remediation of tanks and define the envelope of safety to support the disposal of all high-activity waste in Hanford Site tanks. A review of these and other safety issues was presented recently at the Waste Management 1991 Conference (Babad 1991).

Flammable Gas Generating Tanks

Some of the double- and single-shell tanks generate, store, and periodically appear to release significant quantities of flammable gas, primarily mixtures of hydrogen and nitrous oxide. If a spark were to be present, this gas mixture could ignite and burn; thus, potentially causing filters in the vent system to fail resulting with a spread of contamination.

Hydrogen gas generation in Tank 241-SY-101 is a top priority waste tank safety issue at the Hanford Site because average peak concentrations above the lower flammability limit for hydrogen occur periodically. Such venting of gases is expected to keep reoccurring until some form of remediation is taken. In addition, it is likely that a greater-than-lower flammability limit for concentration sometimes exists within the waste. In the unlikely event an ignition source was to be present during these periods, a hydrogen burn or explosion could occur with a possible release of nuclear waste to onsite and offsite personnel.

There are 22 other tanks also suspected of potentially containing smaller accumulations of hydrogen. However, there is a significant difference in severity of behavior between those tanks and Tank 241-SY-101. Evidence of venting, surface level behavior, and knowledge of the other tank contents suggests a much lower likelihood of potentially dangerous gas concentrations in these other tanks.

Potentially Explosive Mixture of Ferrocyanide in Tanks

Twenty-four tanks contain insoluble ferrocyanide salts in quantities greater than 1,000 gram/moles mixed in a sodium nitrate/sodium nitrite matrix. If subjected to high temperatures, these materials could become explosive. However, there is a low probability for any heating mechanism to occur.

Ferrocyanide tanks were identified as a safety issue because it is not known whether concentrations and distribution of ferrocyanide and nitrate-nitrite materials in the tanks would allow an uncontrolled exothermic reaction or explosion if tank contents were allowed to heat up. Although the measured tank temperatures [57°C (135°F)] are far below the temperature [285°C (545°F)] required to cause an exothermic reaction, the consequences of an event could be at a level potentially exceeding the safety envelope defined in the Environmental Impact Statement (DOE 1987; GAO 1990).

A recent review of the practice of drying out single-shell tanks to avoid potential leakage of radioactive and hazardous materials into the soil disclosed that additional analysis of this practice is needed for tanks containing ferrocyanide. For tanks that contain large quantities of ignitable materials (tanks containing ferrocyanide and organics), pumping has been discontinued until additional safety evaluations of liquid removal can be completed.

Potential Organic-Nitrate Reactions in Tanks

Eight tanks contain organic chemicals at a concentrations believed to be potentially hazardous. Concentrations of organics that may be present in some tanks could cause an exothermic reaction given a sufficient driving force, such as high temperatures. However, the difference between ignition temperatures and actual tank temperatures measured, as discussed previously for the ferrocyanide tanks, is so large that the probability of such a reaction is considered to be very low. The tank temperatures in the organic tanks do not exceed 65°C (149°F).

The postulated high concentrations of organic compounds have been inferred (from tank transfer, flow sheet records, and limited analytical data) in eight single-shell tanks. Many organic chemicals, if present in concentrations above 10 dry weight percent (sodium acetate equivalent), have the potential to react with nitrate-nitrites constituents at temperatures above 220°C (392°F) in an exothermic manner. The consequences of the postulated reaction are about the same as that postulated for a secondary crust ignition after ignition of hydrogen in a tank. Although work on this issue is just beginning, consideration of hazards associated with heating nitrate-nitrite mixtures containing organic materials is an integral part of both the hydrogen and ferrocyanide tank efforts. Because the concentrations of organic materials in the listed single-shell tanks and their chemical identity are not accurately known at present, a tank sampling program has been planned to provide more information on the contents of these tanks and to serve as a basis for laboratory testing and safety evaluations.

Evaluation of the records related to material transfers to the remaining single-shell tanks and double-shell tanks continues, and may uncover additional tanks that meet the organic concentration requirements, placing them on "watch list" status.

Continued Cooling Required for High-Heat Generation in Tank 241-C-106

One single-shell tank requires periodic addition of water to maintain its temperature within the permissible limits determined by structural considerations. Single-shell Tank 241-C-106 (530,000 gallon capacity), has been used for radioactive waste storage since mid-1947 and currently contains about 250,000 gallons of waste. During the late 1960s, a program to recover strontium and cesium from aging stored waste in the A and AX Tank Farms was started at the Hanford Site. Sludge washing/decanting steps in this process inadvertently transferred heat-generating strontium-rich sludge to Tank 241-C-106.

Tank 241-C-106 generates enough heat that periodically water is added to prevent overheating. Continued cooling by adding water is required to prevent exceeding tank operating limits; thereby, possibly causing structural damage to Tank 241-C-106. This tank is currently considered to be sound. If the current methods of cooling Tank 241-C-106 are stopped, the sludge will heat to temperatures greater than established tank limits and may cause tank structural problems. This type of behavior is an anomaly among the single-shell tanks. In the event of a leak, the need for adding cooling water to the tank would remain. Because cooling water is needed to keep the tank within operating limits, existing interstitial liquid could not be pumped from the tank, which is the usual practice.

EXAMPLES OF PRIORITY 2 SAFETY ISSUES

Insufficient Tank Contents Characterization to Support Evaluations

For many tanks, there are sufficient uncertainties in tank chemistry, a possible source of a yet unidentified hazard. Based on flow sheet considerations, the probability of additional hazardous chemical combinations occurring is believed to be low. The nature of the chemicals used in past chemical processing, the waste management operations leading to the waste in the tanks, and the alkaline condition of the tanks appears to limit the range of new possibilities. The actual composition and distribution of chemicals in most tanks is not well characterized. Process records suggest that most tanks contain appreciable oxidants (mostly sodium nitrate and sodium nitrite) and some tanks contain flammable or potentially explosive materials. This situation creates a need for enhanced characterization data to support safety analysis and the definition of the risk.

In general, knowledge of the contents of the single-shell tanks and double-shell tanks is necessary to ensure appropriate safety precautions and preventative measures are taken in operating the tank farms. Characterization is required to assess the flammable and/or explosive potential and the chemical and radiological hazards that may be present in the tanks for continued storage and final disposal. For operating tanks, it is imperative to know what is in the tank and how that waste will interact with other wastes before they are mixed. A multi-programmatically funded detailed characterization program of the contents of Hanford Site high-activity waste tanks is underway.

Upgrading of Operations, Equipment and Facilities (Monitoring and Control Systems)

Many of the waste tank farm facilities are old, degraded, and unreliable. For example, the electrical distribution equipment needs upgrades to provide a reliable source of power as well as backup power. Ventilation systems are wearing out and require high maintenance, which results in outages that are longer than desirable. Instrumentation, such as liquid-level gauges, leak-detection systems in process pits, and radiation monitors require high maintenance and are out of service or fail often. Spare parts for older equipment are unavailable. In addition, many of the waste tank farm facilities do not meet current design requirements. One example would include the lack of redundant high-efficiency particulate air filtration in many facility ventilation systems.

A major upgrade (repair and/or replace) effort is required to return existing equipment to an acceptable condition, as well as bringing all equipment and facilities into compliance with current regulatory requirements. The instrumentation to monitor and control tank temperature or to detect the presence of flammable gases is old, and needs to be updated to current waste management design requirements.

Tank Safe Operating Life

The single-shell tanks at the Hanford Site have exceeded their original operating life and the early double-shell tanks are fast approaching their operating life (20 years). However, all these tanks will be required to contain chemical and radioactive materials beyond their suggested design lives (50 years), under present operational and disposal plans. About half of the single-shell tanks already have leaked or are presumed leakers. No double-shell tank containment liner has leaked to date, but original corrosion specifications would suggest that the possibility exists that a liner could start leaking before disposal operations are completed. Thus, a determination of the safe operating life of the single- and double-shell tanks needs to be made to assess their ability to safely store wastes until waste disposal decisions are implemented (estimated to be 25-30 years)

The condition of the single-shell tank concrete structure was evaluated in the late 1970s and early 1980s, to determine structural conditions. At that time, it was concluded that the single-shell tank concrete structure was adequate to support the disposal plans, although the tanks could not be expected to contain any liquid materials. In the 1970s and 1980s, it was expected that the single-shell tanks were to be disposed of by the late 1990s. The cleanup of the single-shell tanks is now scheduled to be completed by the year 2018 (Ecology et al. 1990).

The single-shell tanks were designed using industry standard codes in the 1940s and 1950s. The ability of the single-shell tanks to safely store solid waste contents, particularly the ability to withstand natural forces and the added stresses due to contained waste forms and planned remediation activities, will be reevaluated.

The double-shell tanks at the Hanford Site may need to remain operational past the year 2030 to support site cleanup, including the disposal of single-shell tank wastes. The double-shell tanks were designed in the 1960s, 1970s, and 1980s to existing design codes and standards. The condition of the

tanks will be reviewed to determine their capacity to support the extended cleanup mission.

SUMMARY

Evaluating the safety issues identified previously, defining appropriate remedial action to correct these safety concerns, and implementing facilities upgrades to bring facilities associated with the aging waste tanks closer to modern nuclear standards is being actively pursued at the highest possible priority. Risk to the operating staff, the Hanford Site environment, and to the general public appears to be low and is being reaffirmed. Work is underway to both quantify the risk and to take appropriate corrective actions to support continued safe storage of the waste as well as the eventual permanent disposal of Hanford's single-shell tanks and double-shell tanks.

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THE PATH TO GAINING A DEFENSIBLE UNDERSTANDING OF "WATCH LIST" TANK RISK AND INTERIM STABILIZATION NEEDS

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ABSTRACT

The "watch list" waste tanks at the Hanford Site in Washington state are those that the Secretary of the Department of Energy reports upon to the Congress because of the unresolved safety question. As such, they are subject to intense surveillance and an enhanced list of controls and safety procedures. The objective of the Waste Tank Safety Program is to mitigate the safety concerns with respect to these tanks, thereby removing them from the "watch list." The essential step in this process is the development of a defensible position that reduce the risk of these tanks to an acceptable level. An integrated research and development (R&D) program is believed to be the most cost-effective means of achieving the information required to mitigate the safety concern and to resolve the safety issues. This program uses chemical and physical modeling studies of synthetic waste, is substantiated with limited field data and radioactive samples from a tank, and uses numerical modeling to extrapolate results to actual tank-scale operations.

INTRODUCTION

Radioactive wastes from defense operations have accumulated in underground tanks at the Hanford Site since the early 1940s. At present, there are 177 such waste-storage tanks. Their dimensions are 75 ft. in di., and capacities range from 500,000 to approximately 1,000,000 gal. The 149 single-shell tanks (SST) consist of a concrete tank structure with a carbon steel lining up to a height above the maximum liquid level. Of the newer tanks, 28 are double-shell tanks (DST) in which a double lining, with an intervening annular gap, is constructed within the concrete form.

Over the intervening years, to reduce the need for additional tanks, the original wastes were further treated, concentrated, and rerouted into the tanks in such a way that any original segregation has not been consistently maintained. Recent reviews of past practices have identified a number of safety issues concerning the present state of some of these tanks (1). This has been discussed in the initial paper of this session (2). The Priority 1 safety issues are briefly stated as follows:

1. Twenty Three of the SSTs and DSTs contain wastes that generate a flammable gas that poses a potential hazard. The gas is believed to be generated as the result of the radiolytic and thermal chemical reactions taking place within the tanks. As the result of the ventilation of the tanks, the concentration of flammable components is well below the lower flammable limit in the freeboard of most of these tanks. However, in a number of the tanks, it is evident that the generated gas is partially held back within the contents of the tank and episodically released. During these events, the concentration in the freeboard may exceed the flammability limit for a short period of time until the released gas mixes with the continuous flow of ventilation air above the tank.
2. The contents in 24 of the SSTs contain varying amounts of ferrocyanides as the result of processing steps taken in 1950 to scavenge the cesium fission product in the waste and thus reduce the waste tank requirements. It is very likely that these same tanks also contain significant quantities of sodium nitrate/nitrite. Sufficient concentrations of ferrocyanides, intimately mixed with an oxidant such as sodium nitrate and heated to an initiation temperature can be shown to explode. Although there are indications that conditions exist within any of these tanks to match the above criteria, as yet there is insufficient evidence to eliminate this as a concern.
3. Eight of the tanks contain organic constituents that might possibly react with oxidizing materials (e.g., sodium nitrate) to produce vigorous exothermic reactions of uncertain magnitude, if the contents reached the initiating temperature of such reactions. The last accident in the Soviet Union at their Kyshtym fuel reprocessing site, which recently became known in western technological circles (3), has heightened the concern for such possibilities.
4. One tank contains sufficient heat generating constituents (i.e., un-decayed fission products) that passive cooling (from conduction to the surrounding ground and evaporation into the ventilation air) is insufficient to prevent exceeding the operating temperature limits of the tank structure. This tank is actively cooled by the periodic addition of water to maintain the evaporative cooling process.

The "watch list" tanks are those that have one (or more) of these safety issues. As such they are subject to intense surveillance and an enhanced list of controls and safety procedures. (e.g., sampling, additions, or withdrawals to or from these tanks). The objective of the Waste Tank Safety Program is to mitigate the safety issues with respect to these tanks, thereby removing them from the "watch list." It will allow normal and safe operations in preparation for eventual

* Pacific Northwest Laboratory is operated by Battelle Memorial Institute for the U.S. Department of Energy under contract DE-AC06-76RLO 1830.

permanent disposal of the waste (i.e., permanent environmental remediation of the site). The essential step in this process is the development of a defensible position that reduces the risk of these tanks to an acceptable level. This, in turn, requires an integrated research and development program to provide the necessary depth of understanding of the operating situation in the tanks to establish that defensible position. The significance of integrating the scope and direction of the science and technology support will be illustrated in this paper.

STEPS TO RESOLUTION OF SAFETY ISSUES

To develop a "defensible position" for removing a tank from the "watch list" requires the following generic steps.

1. Establish the source and nature of the problem in sufficient depth and certainty.
2. Establish the requirements for mitigation or remediation (i.e., stabilization of the tanks to eliminate safety concerns.
3. Evaluate alternative mitigation/remediation methods and select one if specific mitigation is deemed necessary.
4. Demonstrate the selected mitigation/remediation concept (e.g., small-scale model that can confidently be scaled up to tank operations.
5. Implement the mitigation/remediation concept.
6. Evaluate the performance relative to the safety issue.

For each of the Priority 1 situations, these steps would involve a different set of activities but for each situation the need to establish the nature of the problem requires in depth understanding of the chemical and physical nature of the tank as a system.

In one or more of the Priority 1 situations, the selected mitigation remediation scheme might be to leave the tank "as is." To arrive at this decision, one must develop a defensible position that the present situation does not actually constitute a safety hazard.

Other possible options for mitigation/remediation might include the following:

1. Mix, or homogenize tank contents: It may be possible to demonstrate conclusively that if the contents were homogeneous, the safety issue would be eliminated because of dilution of reactive constituents into the rest of the material in the tank. Mixing may prevent the establishment of an unstable situation within the tanks, that could lead to the episodic release of flammable gases in some of the tanks.
2. Alter the chemical or physical state within the tank: Heating or adding sonic energy to the tanks, that produce flammable gas may eliminate the holdup and episodic release of gas from these tanks. Continuous release of the flammable gases could probably be accommodated safely by the ventilation systems. Possibly, a chemical agent could be added to (and mixed into) the tanks to intervene in the chemical reaction(s) that generated the flammable gas.
3. Selective retrieval and alter the chemical composition: Possibly, removal of particular constituents may eliminate the source of the safety issue (e.g. removal of the fission products that may be a dominant factor in the generation of flammable gas in several of the tanks).

COMPLEXITY OF THE PROBLEM

The resolution of the safety issues for these tanks is a difficult task because of the complexity of the chemical, physical, and operational environments in the tanks.

Chemically, the contents of the tanks are not well characterized because of the many different waste streams that have been added to each tank during the 45 years of operation at the Hanford Site. In any particular tank one may encounter significant concentrations of up to 16 different ion species which are the process chemicals form the various reprocessing flowsheets used over the years and the corrosion products form the process vessels. Organic solvent extraction agents and complexants may be present, as well as their decomposition products (from interactions with the highly radioactive fission products and the strong caustic environment.) Fission products in trace concentration are also present, as well as uranium and plutonium in very low concentrations. However, it should be noted that there is no foreseen potential for a nuclear criticality situation in any of these waste tanks. Possibly 80% of the elements in the periodic table could be present in the total of the waste storage tanks in quantities that could influence the local nature of chemical reactions. Since most of these wastes have been concentrated to the maximum level permitted for pumping, all of the tanks contain settled solids, and the liquid phase is generally saturated at the existing temperature in the tanks.

The physical complexity is manifested as liquid and solid phases with wide-ranging characteristics. The solid phase may be present as a slurry, which may exhibit non-Newtonian flow behavior, or as a rock-hard solid that may be very nonuniform in composition and characteristics (because it was introduced into the tank as a saturated slurry at different times and from different sources). Some of the tanks contain very little water which was intentionally removed by pumping out free liquid to reduce the risk of release to the soil from leaking tanks.

The operational environment imposes a number of severe restrictions to mitigation efforts. For example, there is a high-radiation field (200 to 5,000 rad/h) in all of the tanks. In some, there is the present concern about possible explosive reactions if the initiating temperature is reached starting an exothermic reaction. In the SST tanks, there are restrictions about adding water because the tanks are single-shell constructed and have or will leak in the future.

INTEGRATED RESEARCH IN SUPPORT OF THE FLAMMABLE GAS-GENERATING TANKS

As an illustration of both the need and the structure of an integrated research program in support of waste tank safety, the science and technology support of the flammable gas-generating tanks will be described.

Tank 101-SY represents the most serious safety issue of the Priority 1 category because of the frequency and magnitude of the episodic release of a flammable gas mixture from this tank. The schematic drawing, Fig. 1, shows the suspected

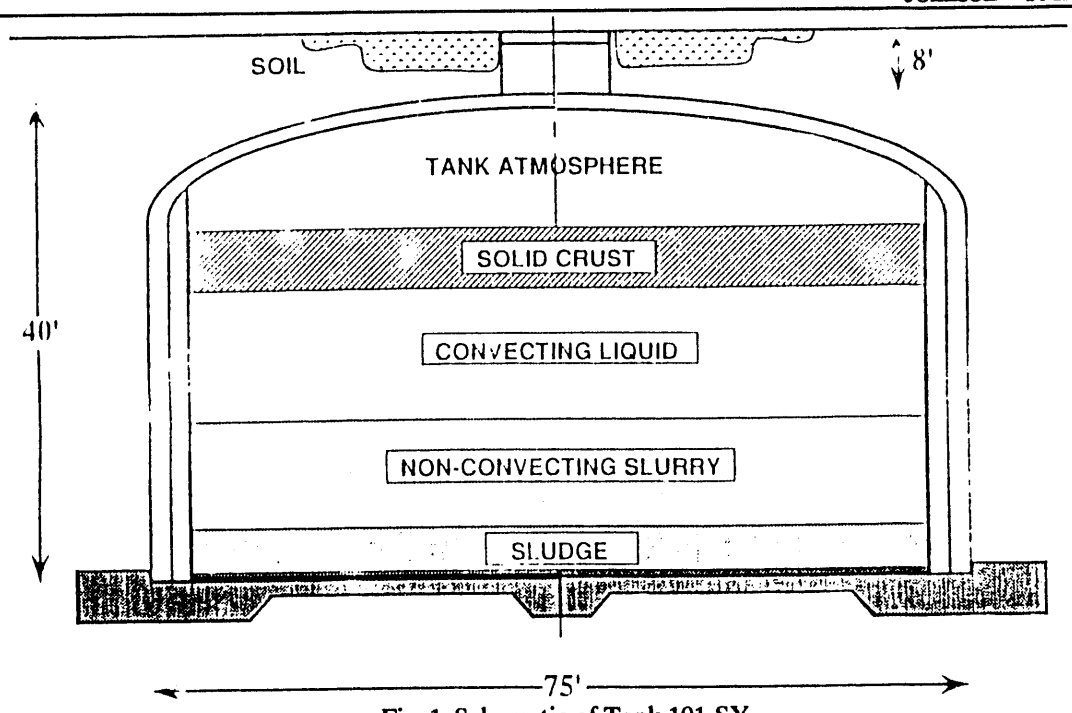


Fig. 1. Schematic of Tank 101-SY.

nature of the tank contents. The region identified as the nonconvecting layer is believed to be the location where a portion of the generated gas is trapped. The postulate behavior of the tank during the course of one cycle of the episodic release of this trapped gas is as follows, beginning just after a gas release.

- The tank's two principal layers, the convecting and nonconvecting layers, are partially or completely mixed. This is the result of the (postulated) rollover of the tank contents once the nonconvecting layer has become sufficiently unstable to breakup and rise to the top of the tank (below the crust).
- The suspended solids settle and reform the denser nonconvecting layer, which is highly viscous due to the high solids content.
- Gas is generated throughout the tank; that within the convecting layer escapes continuously; that within the nonconvecting (slurry) layer is trapped (possibly the result of a hydrophobic surface on the particles).
- The trapped gas swells the slurry zone and raises the crust. This zone is somewhat cohesive (the explanation is unclear at present) and consequently it can become less dense than the over-laying convective zone.
- The instability of the buoyancy of the slurry zone eventually results in a "turn-over," with the slurry zone splitting up into smaller segments and rising to the top. The gas trapped within the slurry is partially (or entirely) released. This constitutes the episodic gas release. During the process, the tank becomes partially (or completely) mixed, and the cycle repeats.

The integrated research program must have the following four elements to provide sufficient information on which to base a mitigation scheme.

1. Field data from the tanks - These provide an initial picture of the characteristics of the system and (later) substantiate the modeling studies.
2. Chemical studies with synthetic wastes - These results will thoroughly characterize the chemical system, identify the existing and potential reactions and reaction rates that may take place, and provide a basis to evaluate the probable level of hazard that may exist. These studies are performed with synthetic waste because of the much greater cost and time required to carry out these studies on actual waste from the tank.
3. Physical modeling of the system - The results will provide a thorough understanding of the physical parameters of the system and demonstrate any proposed mitigation/remediation concept.
4. Mathematical modeling - The model(s) will provide insight into the scale up of the proposed mitigation/remediation concept. The mathematical modeling will first be developed to the extent of substantiating the behavior of the physical model and then be used to predict its full scale performance. This approach is more cost effective than testing the mitigation/remediation concept at (near) full scale. It also provides a means of investigating configuration options without the need of trying them all out at the pilot scale.

These four elements are clearly identified in the program in support of the flammable gas-generating tanks.

Field data indicated that the composition of the gas generated within the tank consists roughly of equal parts of hydrogen, nitrous oxide, and nitrogen. This composition is believed to be within the explosive limits of hydrogen in the presence of an oxidant (nitrous oxide) so that mixing is not required to create a potential hazard. The reason for the gas generation could initially only be surmised from the operations history of the tank, shown in Fig. 2. It was believed to be related to the presence of organic complexants that were

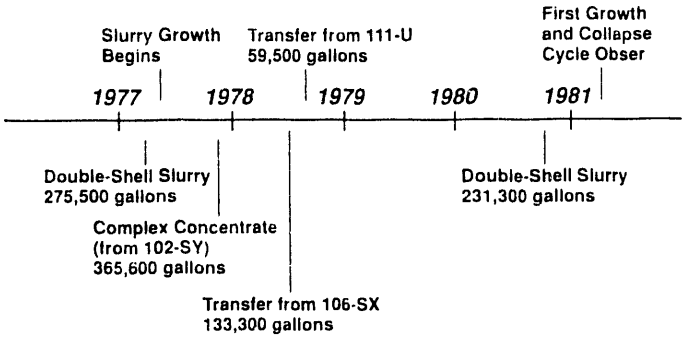


Fig. 2. History of Tank 101-SY.

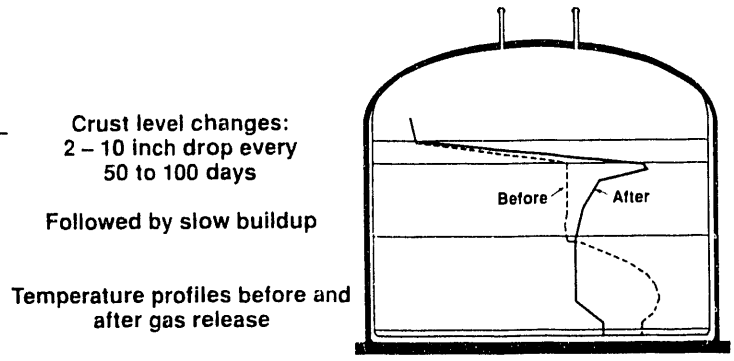


Fig. 4. Evidence of episodic gas release.

included in the last batch of waste to be added to the tank shortly before the periodic release of gas was noted. Figure 3 provides the approximate composition of the tank as deduced from the fill history and early grab samples from the tank.

Evidence of the episodic gas release was obtained from three sources of field data; the constantly changing liquid surface level, the somewhat dramatic change in temperature throughout the tank just after the "turn-over event." Figure 4 illustrates the latter. At the time of an episodic release, the crust level may drop from 2 to 10 in.

The studies of synthetic wastes have centered on gaining knowledge to answer such questions as:

- What is in the tank?
- Why is gas generated? What are the reactants and reactions involved, and what are the products?
- What situations will increase or decrease the generation rate?
- What is the role of the crust that formed on the tank?

The actual tasks undertaken to provide these answers include:

- Fundamental studies using synthetic waste of radiolytic gas generation at the Argonne National Laboratory (ANL)

Component	Concentration	MT
NaOH	3.22 M	549
$NaAlO_2$	1.90	662
$NaNO_2$	3.28	964
$NaNO_3$	4.23	1,530
Na_2CO_3	0.62	280
Na_2SO_4	0.12	72
Na_2PO_4	0.19	136
TOC	26.24 (g/l)	112
Pu	713 (g)	
Sr	2.187×10^{11} (μCi)	
Cs	3.10×10^{12} (μCi)	
H_2O	594,600 (gal)	2,251

Fig. 3. Initial composition of Tank 101-SY.

- Fundamental studies using synthetic waste of thermal-chemical gas generation; at the Georgia Institute of Technology
- Studies of combined radiolytic and thermal-chemical reactions that generate gas and a study of the mechanism for crust growth, at the Pacific Northwest Laboratories (PNL)
- Studies of gas generation from actual tank waste samples; by the Westinghouse Hanford Company (WHC)
- Development of methods for determining the organic constituents in the waste and their decomposition products; at PNL.

The cost and time required to carry on these studies with actual waste samples would be far greater than studies that use synthetic wastes, which are substantiated with actual samples from the tank.

Physical modeling with synthetic waste mixture is being conducted to respond to questions such as:

- Can one demonstrate the retention and episodic release of gas in the slurry zone?
- Can one show how to reduce or eliminate the episodic release of gas?

A number of mitigation/remediation schemes are being considered. They can be categorized as either preventing the retention of the gas (so that it is continuously released at rates that do not result in a hazardous concentration in the tank at any time), or eliminating gas generation.

Retention can possibly be eliminated either by altering the nature of the slurry (possibly through heating, diluting, or adding a surfactant) or by mechanically disengaging the bubbles from the slurry zone, (i.e., mixing by ultrasonic energy, jet mixing, or by some type of mechanical mixing).

Eliminating gas generation appears to be more difficult and would seem to require removing one of the reactants (or intermediate reaction species) or somehow changing the conditions for gas generation. Perhaps nitrogen disbursed through the slurry zone could be added to change the equilibrium gas composition.

The physical modeling tasks, in place to provide sufficient information on which to base a selection for a mitigation scheme, involve studies of the gas retention and release phenomena in synthetic wastes. With the generation of gas (primarily hydrogen) these phenomena are simulated by an

auxiliary source independent of either radiolytic or these phenomena are normal thermal-chemical reaction in the synthetic waste. The extent of mixing required to keep the slurry zone from forming and retaining gas will be determined, and various forms of mixing will be modeled.

Numerical modeling, primarily of the circulating flow encountered during mixing, is being developed. It will match the physical modeling results, and will then be used to predict the intensity of turbulence and circulation patterns that one would encounter in the full-size tanks. On the basis of the result of the pilot-scale model, numerical modeling would predict the possibility of satisfactory performance in the waste tank. We are working with a system for which the overriding phenomena governing the critical function of preventing retention of gas bubbles upon the slurry solid particles is unknown. Therefore, numerical modeling is believed to be the most cost effective and certain way of developing a "defensible position" for mitigation when fitted to pilot-scale results and then extended to a prototypic tank.

SUMMARY

An integrated R&D program, using chemical and physical modeling studies of synthetic waste, substantiated with limited field data and radioactive samples from the tanks, and using numerical modeling to extrapolate results to actual tank-scale operations, is believed to be the most cost-effective means of achieving the information required to mitigate/remediate the safety issue and to remove these tanks from the "watch list."

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EVALUATION OF TANKS THAT RELEASE FLAMMABLE GASES

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ABSTRACT

Of the 177 high-level waste tanks on the Hanford Site, 23 tanks have been identified as having a potential to generate and release flammable gases. Efforts were initiated in 1990 to ensure safe operation of the tanks, to conduct a characterization of the waste, and to develop approaches for mitigating the release of flammable gases. The focus of the efforts has been on Tank 241-SY-101 because it has been shown to be the most active tank for the release of gases. This tank vents gases about every 100 days and the major components have been determined to be hydrogen, nitrous oxide and nitrogen. In some cases the venting has resulted in mixtures that have been above the lower flammability limit. Laboratory studies are underway to determine the chemical and radiolytic mechanisms for the production of the various gases. It is believed that a major source for the gases comes from the degradation products of the chelating agents used in the original waste processing steps, as well as radiolysis. Analysis and modeling of the behavior of Tank 241-SY-101 has shown that the gases are retained in the lower portion of the tank, presumably due to adherence to small crystalline particles. The buildup of the gases produces a density and temperature instability causing the tank contents to eventually "roll-over" thereby, releasing the gases. Initial concerns about a secondary crust burn initiated by ignition of the combustible gases in the air space above the waste have been partially allayed. The new data obtained from waste sampling and characterization, synthetic waste studies, and from recent modeling are discussed and a preliminary overview mechanism for tank behavior introduced.

INTRODUCTION

Flammable gas generation in Tank 241-SY-101 and in other waste tanks at the Hanford Site is a top priority waste tank safety issue at the Hanford Site because the tank periodically vents gas at average peak concentrations above the lower flammability limit (LFL) for hydrogen. Such venting of gases is expected to keep reoccurring until some form of remediation is taken. In addition, it is likely that a greater-than-lower flammability limit concentration exists at times within the waste and at the point of release into the tank air space. In the unlikely event an ignition source were present during these periods, a hydrogen burn or explosion could occur with a possible release of nuclear waste to onsite and offsite personnel.

The hazardous characteristics of the existing wastes, leading to their identification and control, were estimated on the basis of general information from the chemical literature, expert peer judgement, and limited historical and actual sampling data. Mitigating factors such as moisture content, presence of inert diluents (e.g., sodium carbonate, sodium aluminate, and/or sodium phosphate), and conditions that could lead to a lack of reactivity of the wastes were purposely understated.

Scenarios of significant concern associated with waste in these flammable gas tanks include the following.

- The potential for ignition of flammable gases such as hydrogen-air and/or hydrogen-nitrous oxide.
- The potential for secondary ignition of organic-nitrate mixtures on the crust initiated by the burning of flammable gases or mechanical in-tank energy source.

Administrative and technical controls are in place to restrict activities that could cause undesirable exothermic reactions. Because of this cyclic behavior, the Westinghouse Hanford Company limits intrusions into the tank to a 20- to 30-day "window of safety" that starts immediately after a gas release event (to assume work is done when hydrogen inventory is low). The length of the window varies depending on whether the intrusion penetrates into the waste (20 days) or restricts activity to the tank air space (30 days). Nonsparking tools and use of electrical bonding and grounding techniques are used. So-called "normal" activities for tanks at issue are limited to surveillance. Special safety analysis documents prepared for all work inside the tank are extensively peer reviewed and require U.S. Department of Energy (DOE) approval.

BACKGROUND

Although there are 22 other tanks also suspected of potentially containing smaller accumulations of hydrogen or other flammable gases, this paper will focus only on Tank 241-SY-101. There is a significant difference in severity between Tank 241-SY-101 and the other 22 tanks. Evidence of venting, surface level behavior, and knowledge of the other tank contents suggests a much lower likelihood of potentially dangerous gas concentrations in these other tanks.

This paper will center on Tank 241-SY-101 because it is currently the focus of efforts to understand and ultimately remediate the problem.

Tank 241-SY-101 finished construction in 1976. The first waste put into the tank was from the first double-shell slurry campaign using the 242-S Evaporator in 1977. Double-shell slurry is the thickest material that the evaporators can produce. One hundred inches of this material was pumped into Tank 241-SY-101.

From 1977 to 1980, the tank received complexed concentrate waste. Complexed concentrate waste was placed in the tank at three different times (Table I shows the filling history). A total of 203 inches of complexed concentrate waste was placed on top of the heavier double-shell slurry. Complexed concentrate is a waste from the cesium/strontium recovery process in B-Plant. It is rich in complexants such as ethylenediaminetetraacetic acid (EDTA), N-(hydroxyethyl)-ethylenediaminetriacetic acid (HEDTA), citric acid and

TABLE I

Tank 241-SY-101 Contents

Tank Fill Chronology	Gallons	
April 1977	274,000	Double-shell slurry[a]
November 1977	365,000	Complexed concentrate[b]
June 1978	131,000	106-SX Complexed concentrate
August 1978	60,000	111-U Complexed concentrate
November 1980	230,000	Double-shell slurry
September 1984-May 1988	8,000	Water
Total	1,068,000	

[a]Double-shell slurry is a concentrated waste produced by the evaporator that is high in hydroxide, nitrate, and aluminate concentration.

[b]Complexed concentrate is an evaporator product similar to double-shell slurry (though not as concentrated) that also contains significant organic complexant concentrations.

hydroxyacetic acid. These soluble organics were concentrated with the waste stream to a high total organic carbon (TOC).

The last material put into Tank 241-SY-101 was another campaign of double-shell slurry in the fall of 1980. About 84 inches were put into the tank to bring the final volume to 387 inches. The average estimated composition of Tank 241-SY-101 is provided in Table II.

The volume of waste in Tank 241-SY-101 was first noticed to increase in 1977 when the first double-shell slurry was put into the tank. This phenomenon was called slurry growth. After the last double-shell slurry campaign, the waste continued to grow and then dropped several inches during a vent, or a so called "burp". This cyclic growth and subsequent drop has continued.

Figure 1 shows how the surface level of the tank has cycled during the past several years. Water and air lancing was used for a number of years in an attempt to control the burps in the tank. Lancing was stopped in 1989 when the surface level reached 423 inches. This was high enough to be of some concern in this tank because it reached the maximum allowed by structural analysis. Since that time, the surface has trended downward with more regular burp cycles.

The pressure in the vapor space generally showed an increase during a burp event. This was an indication of gas being released. Laboratory work on the slurry growth phenomena also produced gas and indicated that hydrogen was a major component of the slurry growth gas. Since early 1990, there has been an ongoing vapor sampling effort. The results of this sampling suggest the gas composition shown in Table III.

In addition to these noncondensable gases, there has been, at times, a strong indication for ammonia in the slurry grown gas along with water vapor. It should be pointed out that the nitrous oxide is a good oxidizer and that mixtures of hydrogen and nitrous oxide are flammable at concentrations of hydrogen greater than 3 volume percent (LFL).

The temperature profile in the tank changes shape during a burp. Before a burp, the profile shows higher temperatures in the lower part of the tank with essentially constant temperatures in the upper part of the tank. Figure 2 also illustrates the vertical distribution of the tank contents and the temperature profiles associated with the October 24, 1990 vent cycle. Tank 241-SY-101 contains about 50 inches of crust floating on a convective layer of mostly liquid waste. The convective layer sits on top of an approximately 150-inch layer of settled solids that is essentially nonconvective in fluid behavior. At the bottom of the tank, there appears to be a layer of compacted solids.

After a burp, the profile straightens out so that the tank has essentially constant temperature. This temperature change has occurred on every burp. Also shown on the figure

TABLE II

Tank 241-101-SY Total Composition

Component	Concentration
NaOH	3.22 M
$NaAlO_2$	1.90 M
$NaNO_2$	3.28 M
$NaNO_3$	4.23 M
Na_2CO_3	.62 M
Na_2SO_4	.12 M
Na_3PO_4	.19 M
Pu	713 (g)
Sr	2.187×11^{11} (μCi)
Cs	3.10×10^{12} (μCi)
TOC	26.24 (g/l)
H_2O	594,600 (gal)

Note: The concentrations are based on a present average tank height of 408 inches.

TABLE III

Periodic Release of Gases

Event date	Number of days since last event	Change in surface level, in.	Peak pressure, in (WG)	Peak H_2 conc., %
January 1990	109	-7.7	-	-
April 19, 1990	110	-8.3	+0.1	3.5
August 5, 1990	109	-5.2	-1.96	1.2
October 24, 1990	80	-10.3	+2.3	4.7
February 13, 1991	110	-5.0	-2.0	0.04
May 16, 1991	92	-7.0	+0.25	0.5

Average gas composition: 38% H_2, 32% N_2O, 30% N_2.

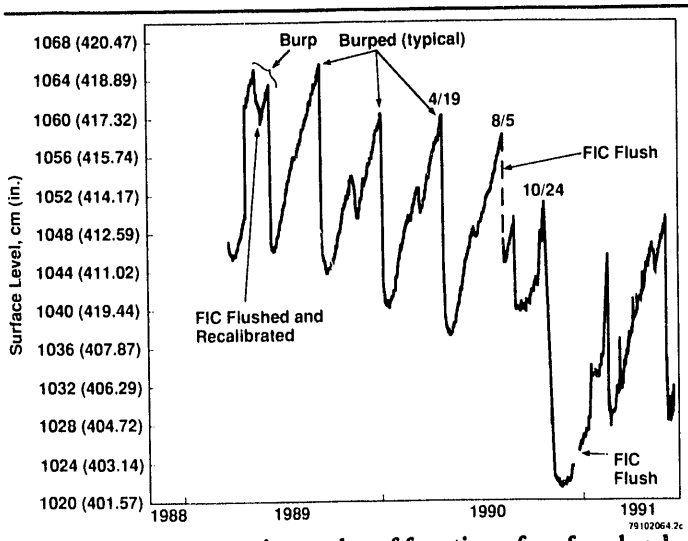


Fig. 1. Recent gas venting cycles of function of surface level in Tank 241-SY-101.

is the position of the 22 segments of the core sample taken after the May 1991 burp.

The Flammable Gas Program

Five double-shell tanks and 18 single-shell tanks have been identified as having a significant potential for flammable gas accumulation, entrapment below the crust layer, and periodic gas releases. The presence of a simultaneous flammable gas mixture and ignition source pose the potential for a burn and could lead to an increased risk of the release of radioactive waste. Of a lower potential risk is an unfiltered release of radioactivity to the environment from overpressurizing the ventilation system during a periodic gas venting. The most active waste tank, Tank 241-SY-101, has released during several of its venting periods, concentrations of hydrogen that for a short period of time exceeded the amount (LFL) necessary to support combustion. During these releases, overpressurizations have been measured without resulting in any contamination spread or breakdown of the high-efficiency particulate air filters. The venting of gases is expected to reoccur periodically until some form of mitigation/remediation is taken. Operational restrictions have been imposed for the 23 waste tanks to reduce the potential for sparks and ignition sources.

The worst postulated consequence is a hydrogen burn that could ignite the waste crust (if it is indeed flammable), leading to larger releases of radioactive waste. This is believed to have a low probability of occurring because there are no known ignition sources in the tanks and temperatures are well below those required to initiate postulated reactions in the crust. In addition, initial crust samples have shown a low total organic carbon (TOC) and moisture above 20 percent indicating a crust burn is not possible.

Several options are being considered to mitigate/remediate the flammable gas issue: (1) dilute and circulate the waste in situ, (2) transfer a portion of the waste to other double-shell tanks and then dilute and circulate it in the affected tanks, (3) increase ventilation to remove gases faster, (4) stir and/or mix to release gas bubbles, (5) heat or use ultrasonic devices to release trapped gas bubbles or add chemicals or heat to destroy the organics, the latter being small portions of waste.

It may take several years to develop and install new instrumentation, obtain and characterize in-tank core samples, and complete *National Environmental Policy Act of 1969* documentation on the proposed remedial actions. Remedial actions to eliminate accumulation and/or generation of flammable gas mixtures may require major ventilation modifications, additional double-shell tank space for diluting the waste, or sophisticated waste treatment processes to be developed, engineered, constructed, and operated for remediation of all 23 high-level radioactive waste tanks that accumulate flammable gases. Meanwhile, near-term efforts are directed towards emergency preparedness planning and redirecting the cyclic releases of flammable gas mixtures to continue lower concentration releases by ultrasonic nucleation, stirring, dilution, transferring or some other method so that the gases generated within the waste tank will be continuously released at concentrations within safe limits.

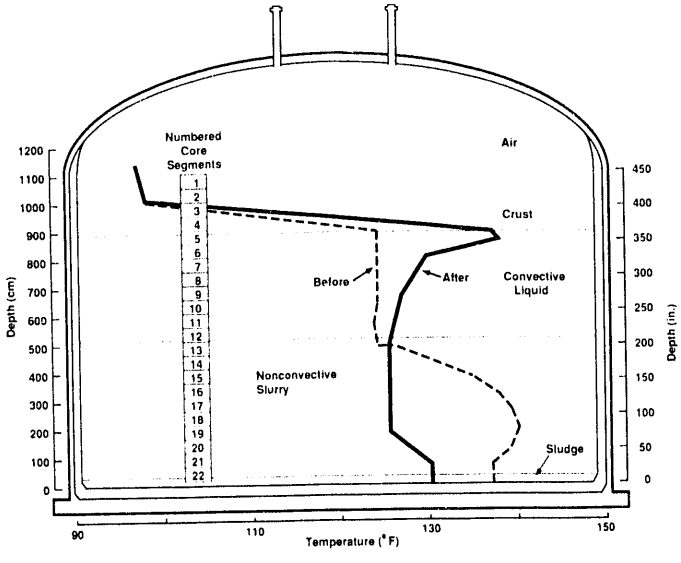


Fig. 2. Vertical Distribution of the tank contents and the temperature profiles associated with the October 24, 1990 vent cycle.

Studies of Tank Waste

Waste has been stored in tanks since the start of the Hanford Project. The waste has been kept caustic to protect the ferritic or carbon-steel tanks. The caustic waste precipitates a sludge that falls to the bottom of the tank. This sludge is heavy in iron hydroxides and oxides. To minimize the volume of waste in the tank, evaporators are used to concentrate the waste. Salts precipitate from this concentrated waste. The settled salts are termed salt cake and are composed mainly of sodium nitrate and sodium nitrite. Sodium carbonate also precipitates and tends to float and form crusts on the concentrated waste. The fluid remaining is concentrated in hydroxide, nitrate, nitrite, and aluminum.

Photos taken inside the tank several years ago indicate that the entire surface of the waste is covered by a crust. Recent color and black and white videos indicate chunks of floating solids and open areas of wet, mushy areas. The presence of the crust has some safety implications as discussed later in this report. Some crust was retrieved to test for safety concerns by removing equipment from the tank that had contacted the crust. Three different locations in the tank were sampled this way. Specially designed samplers were used to recover samples at a later date. Both sampling activities were limited to only the surface material. The crust from the various locations inside the tank were different physically, but all

showed that the crust is moist with little organic carbon (Table IV). Studies of crust energetics showed that it could react exothermically at high temperatures (> 220°C), but there was sufficient moisture in tank crust samples to quench the reaction.

TABLE IV

Crust Sample Results

Moisture	16 to 41%
Organics	< 2%
Weight loss due to exotherm	4 to 9%*

*Represents loss of volatile materials during decomposition of the organics.

Summary of Gas Monitoring Data

The vapor space has been monitored to varying degrees for approximately 1 1/2 years. Currently there are probes in the tank that measure hydrogen (electrochemical cells), composition by mass spectrometry, and pressure. The ventilation line out of the tank also has devices to measure hydrogen concentration (thermal conductivity meter), two gas chromotagraphs, a cryogenic trap for organic vapors flow, temperature, and relative humidity.

Figure 1 illustrated the cyclic behavior and the rise and fall of the tank crust surface of Tank 241-SY-101. Episodic vent cycles have ranged from 42 to 110 days (most recently averaging 100 days). Each drop in surface level, while gas is venting, takes from a few hours to a few days to reach surface level equilibrium. Information from the most recent and more heavily instrumented events were shown in Table III. From these measurements, the nominal composition of the gas released by the waste is given also in Table III.

Figures 3 and 4 provide some typical gas evolution data from a recent burp. The figures illustrate the release rate and composition of the gasses evolved during a burp.

Figure 3 shows the pressure and hydrogen concentration at the vent header. The pressure increase indicates a very sudden gas release. However, the hydrogen concentration does not peak until nearly an hour later. This is because of the large dome space in the tank, which equalizes and dampens the hydrogen concentration spike.

Hydrogen concentration is shown in Fig. 4. The two curves that peak highest are from the sample probe near the surface of the crust. The other curve is from the vessel vent line. The sample port near the crust shows a higher concentration and a sharper peak. This is indicative of being nearer to the release point.

Nitrous oxide is also a major component of the gas released. The ratio of nitrous oxide to hydrogen has been constant from burp to burp. Also, it was observed that nitrous oxide becomes a larger part of the gas released after the main release. It is believed that this is because nitrous oxide, which is relatively soluble, is being released from the solution after the bulk of the hydrogen is gone.

Ammonia gas is smelled sometimes during a burp; therefore, an organic vapor monitor has been mounted on the tank farm stack. An organic vapor monitor is not specific for ammonia, but ammonia does register on the organic vapor monitor.

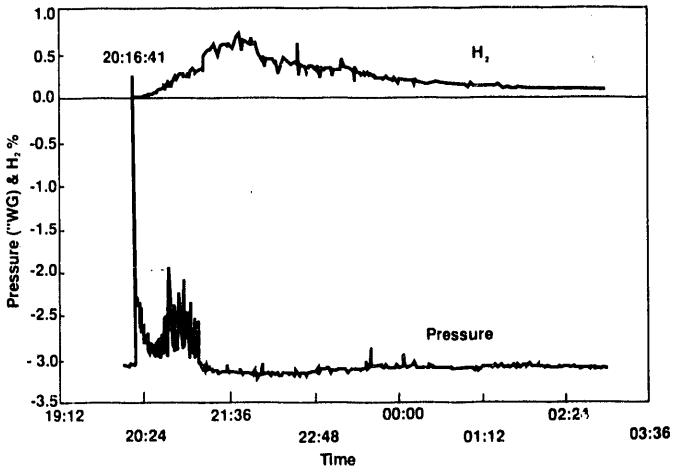


Fig. 3. Pressure and Hydrogen profiles May 1991 gas release event.

Possible Mechanisms of Tank Behavior

A number of hypotheses have been proposed to explain the mechanisms of gas creation, but more information from characterization, modeling, and laboratory simulation studies is needed to fully understand the chemical and physical process before development of a plan to mitigate the tank hazards. Work is in progress by Westinghouse Hanford Company, Argonne National Laboratory, the Georgia Institute of Technology, and Pacific Northwest Laboratory to determine the exact mechanism of gas generation and release. Because the cause of the cycle is not yet known, cyclic hydrogen generation and release is an unreviewed safety question.

Based on analysis of the off-gas stream, a mixture of hydrogen, nitrous oxide, and nitrogen gas appears to form as the product of radiolysis and/or the chemical decomposition of the organic chemicals in Tank 241-SY-101. Insight into tank chemistry and the processes associated with gas generation requires the information be obtained by taking a full core sample of the tanks contents. The first core sample was taken in May 1991 and is not yet fully analyzed. According to the current hypothesis, tank gases appear to be formed continuously in the whole tank, but appear to be stored preferentially in the nonconvective slurry layer in the bottom, settled solids portion, of the tank. The storage phenomenon creates a supersaturated "solution" of gas in the tank. Unknown instabilities trigger a thermal roll-over, releasing the stored gas.

The temperature profile change gives insight to what is the mechanism that causes the periodic burps. There seems to be a chemical reaction, assisted by radiation affects, that generate the gas. The gas-trapping mechanisms appears to be a result of hydraulic and physical methods. Figure 5 provides a discussion of the postulated burp mechanism.

Before a burp, the bottom part of the tank shows a profile that has a maximum temperature with lower temperatures at the top and bottom. This is a classic shape temperature profile for a self heating heat material. The indications are that the bottom layer has a high volume fraction of solid particles. The radioactive decay heats the bottom layer uniformly, but the heat can flow from both the bottom and top of the layer. Hence, those areas are cooler than the center of the layer.

Above this layer is a layer that has a uniform temperature. This is an indication of a fluid convective heat transfer zone. Heat generated in this zone, and heat transferred to this zone from below, is the force that moves the fluid by convection.

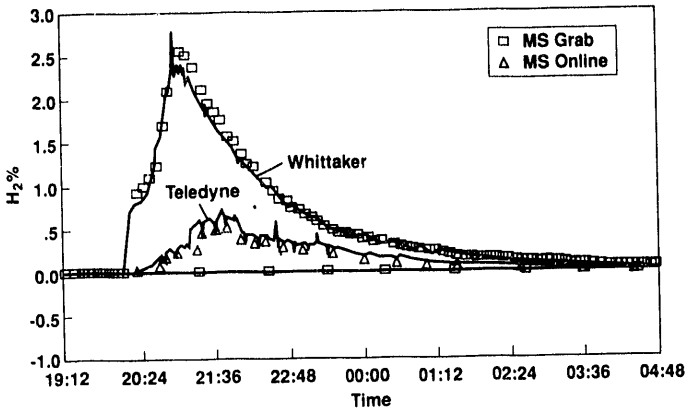


Fig. 4. Hydrogen release profile May 1991 gas release event.

The convection mixes the layer that keeps the temperature uniform.

After a burp the temperature profile is commonly flat. This indicates that a part or the entire tank has been stirred up. Also, this indicates a partial or full "roll-over" in the tank. Indeed, when the temperatures are studied closer, it is common to see the hot material from the bottom raise to the top and lodge there for some time.

While other mechanisms have been proposed this roll-over has stood up under scrutiny and explains the observations seen. Figure 5 shows a schematic of what is believed to be happening.

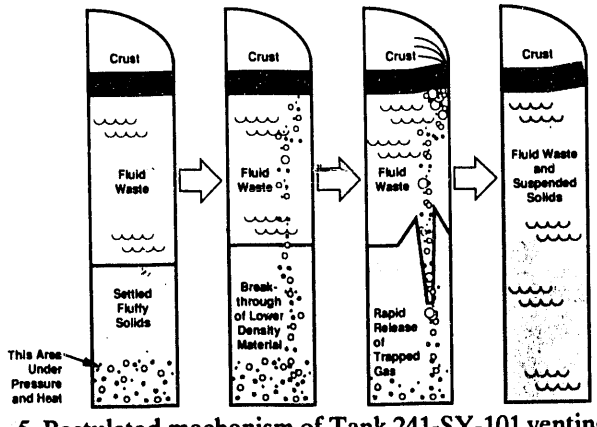


Fig. 5. Postulated mechanism of Tank 241-SY-101 venting.

The chemical reaction (involving the organics and assisted by the radiation) is producing gas throughout the tank. In the convective layer, the motion of the fluid brings the gas generated in the layer to the surface, where the gas can be released. This does not allow the gas to accumulate in the fluid layer. However, in the lower nonconvective layer, the waste does not move. The gas formed in this layer is trapped and cannot escape.

This lower nonconvective layer becomes less dense as a result of the accumulated gas. Several things happen when the temperature rises. The warmer temperature causes the accumulated gas to expand further, thus decreasing the density. The increased temperature decreases the viscosity of the material. Some of the solid material redissolves in the warmer fluid. The rate of chemical reaction also may increase.

Finally, the lower level reaches a critical density and becomes buoyant. This causes instability and the lower region rolls-over to the top region. When this happens, the hydrostatic head decreases and the pressure on the accumulated gas drops, and the bubbles expand. This further increases the buoyancy. The gas releases when it gets to the surface.

Eventually, enough of the accumulated gas is released that the solids can settle out. The conductive layer forms on the bottom again and the cycle starts over again.

The current thought is that the crust is not a barrier to gas. The crust is estimated to be several feet thick and floats on top of the fluid. During a burp, the force of the roll-over is strong enough to physically disrupt the crust and allows the gas to escape.

Crust Burn Analysis

The primary risks associated with Tank 241-SY-101 and related tanks result from a potential for hydrogen gas ignition, with or without a secondary ignition of the crust. Secondary crust ignition depends on the magnitude and duration of a hydrogen burn, and the characteristics of the crust. The following four factors could prevent such a crust burn:

- The presence of only limited quantities or concentrations of combustible gases in the dome space
- The presence of significant quantities of moisture in the crust
- The absence of large quantities of organics in the crust
- The presence of large quantities of noncombustible (inert) material such as sodium carbonate, sodium sulfate, and inorganic aluminum salts and oxides in the crust.

An assessment of the prospects for a secondary chemical reaction initiated by a hydrogen burn accident in waste Tank 241-SY-101 was recently completed by Westinghouse Hanford Company. The results of this study indicate that a hydrogen burn in Tank 241-SY-101 would not result in the ignition of the crust. Surface projections with thin cross-sections might burn off, but this analysis concludes that a self-sustaining reaction in the crust would not occur. These conclusions are based on crust reaction properties derived from synthetic crust. The synthetic crust was shown to be more reactive than actual crust, but the number of crust samples available at this time is limited. The higher reaction energy observed in laboratory crust, relative to tank crust, contributes to a margin for accommodating more reactive surface crust should that condition be found in future tank sampling activities.

As stated earlier, the principal constituents of the crust are sodium nitrate and sodium nitrite, which make up 50 to 60 percent of the crust. The principal additional constituents that affect crust burn potential are total organic carbon (TOC) content and moisture level in the crust. The reaction exotherms are related to the former and the endotherms are associated mainly (but not entirely) with the latter property. Crust properties have been measured in both synthetic and actual crust and, in general, actual crust appears to be less reactive. This is attributed to the partial reaction of the carbon that has occurred over the years of residence in the tank.

Two levels of organic carbon in synthetic crust have been used to characterize the energetics of the crust thermal reactions. The chemical analysis of the first batch of crust indicated a total organic carbon of 1.2 percent. A second batch of synthetic crust was formulated to contain 3.2 percent organic carbon, but found to contain 3.4 percent. As expected, the

higher carbon crust is significantly more energetic as shown in Table V. The maximum self-heat rate is obtained from adiabatic calorimeter tests conducted by Fauske and Associates (FAI) and is a measure of the rate of energy release. The self-heating ΔT, obtained from the same tests, is a measure of the total energy release from the sample.

The adiabatic calorimetry data are presented in a form that facilitates extraction of temperature-dependent energy release rate parameters (Arrhenius parameters) for use as a chemical energy generation term in the transient crust heat-up calculations.

Results from adiabatic calorimetry indicated that the temperature at which the self-heat rate becomes significant, occurs at a lower temperature in the low carbon sample than in the high carbon crust. For example, the low carbon crust reached a self-heat rate of 10°C/min at 200°C, which was not reached until the temperature reached was 290°C for the high carbon crust. Both types of crust have been considered in the burn analyses.

The differential scanning calorimeter (DSC) tests conducted at Westinghouse Hanford Company indicate the presence of distinct energy absorbing endotherms before the net positive energy release phase. Based on characteristic water of hydration for some of the inert compounds in the crust, most notably Na_2Al0_3 and Na_2C0_3, it is believed that most of the energy involved in the endotherms is due to water loss from the sample. Decomposition of organic compounds also may be involved in the endothermic reactions. However, if the endothermic weight loss observed in the thermogravimetric analysis (TGA) is all considered to be water, the ratio of observed energy absorption to calculated energy absorption is 0.97; thus, water is shown to be a good model for the release. In the crust heat transfer calculations, water was assumed to be released linearly between 40 and 120°C. For those cases where wet crust was considered, the crust was assumed to contain 10 percent moisture, the minimum observed in the November crust surface sampling.

There are indications that the reactions in the synthetic crust are significantly more energetic than actual crust, based on crust samples retrieved to date. This is shown in Table VI. This information suggests that released energy estimates from the synthetic crust are conservative. The reason for the energy deficit in actual crust can, in part, be attributed to partial reaction of the TOC in the crust owing to years of exposure to oxidation and radiolytic reactions.

Comparisons between synthetic and actual crust are qualified by the lack of a statistical sample base at this time.

TABLE V

Synthetic Crust Reaction Parameters

	Low carbon	High carbon
Total organic carbon (wt%)	1.2	3.4
Maximum self-heat rate (°C/min)	500	6,000
Self-heating ΔT (°C)	280	550

TABLE VI

Exotherms for Actual and Synthetic Crust

Sample	TOC %	Exotherms cal/g-dry
Manual tape	2.3	83
FIC gauge	1.6	50
Sludge weight solids (wet)	1.6	83
Sludge weight solids (dry)	2.0	56
Sludge weight loose solids	2.2	92
DSC synthetic crust	1.2	92
Adiabatic calorimetric synthetic crust	1.2	91
Adiabatic calorimetric synthetic crust	3.4	148

TOC = Total organic carbon

Confidence in crust behavior predictions is expected to increase as the tank sampling program progresses.

SUMMARY

While the probability of flammable gas ignition or crust burn is very low, the level of risk from such an event remains unacceptable. Therefore, after initial, but detailed characterization of the contents of Tank 241-SY-101 (and other tanks that undergo cyclic venting) steps to mitigate and or remediate the tanks will be evaluated and ultimately implemented. The characterization efforts are being paralleled by the studies to support remediation, so that an understanding of the root cause can be developed to avoid creating cyclically venting tanks in the future.

FERROCYANIDE-CONTAINING WASTE TANKS: FERROCYANIDE CHEMISTRY AND REACTIVITY

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ABSTRACT

During the 1950's ferrocyanide and nitrate bearing wastes were added to the Hanford radioactive waste tanks as a result of a need to increase the amount of free tank space. To provide additional tank space, the aqueous wastes were decontaminated by coprecipitating the radiocesium with other alkali nickel ferrocyanides and disposing of the decontaminated liquids separately. In recent years a concern has arisen because of the potential explosive reactions of ferrocyanides with nitrates and the nitrate radiolytic degradation product nitrite. Because of this concern the Department of Energy (DOE) and the Hanford site have established a program to insure continued safe operation of the Hanford radioactive waste storage tanks containing ferrocyanides.

This paper discusses briefly the history of the ferrocyanide wastes and the four basis components of the program with special emphasis on the chemical reactivity and explosivity research and development studies. These studies with synthetic ferrocyanide bearing wastes indicate that reactions begin at temperatures >200°C and that reactions within these wastes are not initiated by mechanical impact, friction, and low energy electrical spark but are initiated by a very high energy spark.

SUMMARY

During the 1950s, additional high-level radioactive waste tank space was needed at the Hanford Site to accommodate increased production and processing of defense materials. To meet this need, the radiocesium scavenging process using ferrocyanide precipitation was developed and implemented at the Hanford Site. There were two principal flowsheets used to remove the radiocesium from the nitrate containing aqueous wastes. These were the In-Plant and In-Farm scavenging flowsheets.

In the In-Plant scavenging flowsheet, acidified wastes from the Bismuth Phosphate Process were scavenged. These wastes contained large quantities of dissolved solids. When these acidified wastes were neutralized with sodium hydroxide, the dissolved solids precipitated, possibly diluting the precipitated ferrocyanide solids.

In the In-Farm flowsheet, the aqueous supernates were scavenged. The wastes were already basic, thus the principal dissolved solids were sodium nitrate and its radiolytic degradation product, sodium nitrite. The resulting wastes produced by this flowsheet were ferrocyanides with an interstitial solution of approximately 4 to 6 M nitrate and nitrite.

During the late 1950s, experiments showed that alkali transition metal ferrocyanide solids mixed with nitrate exploded when dried and heated. Since that time, concern has arisen that the ferrocyanide wastes stored in the waste tanks could represent a reaction or explosion hazard. This concern resulted in the storage of those ferrocyanide wastes in tanks with more than 1000 gmoles of ferrocyanide being declared an Unresolved Safety Question (USQ).

Because of the concern about the storage of ferrocyanide wastes in the Hanford tanks, the Hanford Site has begun a program to resolve the safety concerns regarding these wastes. The program consists of four basic components: 1) ensuring proper tank monitoring, 2) waste characterization, 3) computer modelling and analysis, and 4) research and development. This paper briefly reports on the chemistry studies that have been performed to understand the conditions under which mixtures of ferrocyanides, nitrates, and nitrites are explosive.

Chemical analyses of precipitates, prepared using the In-Farm scavenging flowsheet, indicate that non-stoichiometric sodium nickel ferrocyanide was formed. Chemical analyses are not yet complete on the precipitates prepared using the In-Plant scavenging flowsheet.

To better understand the effects of various potential waste constituents on the explosivity of the mixtures of interest, we made thermodynamic calculations to estimate the amount of a specific material required to prevent thermal runaway. These calculations indicate that with a stoichiometric amount of sodium nitrate as the oxidant (1.6 g/ g sodium nickel ferrocyanide), about 3 g of water would be required to prevent the waste temperature from reaching 200°C. An exothermic reaction has not been observed at this low a temperature at neither the Pacific Northwest Laboratory (PNL) nor at the Los Alamos National Laboratory (LANL).

Analyses using small-scale time-to-explosion (TTX) tests, differential scanning calorimetry (DSC), and scanning thermogravimetry (STG) indicate that settled and dried solids prepared using the In-Farm scavenging flowsheet have thermal reactivity and explosivity behavior similar to solids prepared using the same recipe, washed twice with water, dried, and mixed with equimolar sodium nitrate and nitrite. In contrast, the homogenized, dried, synthetic wastes prepared using the In-Plant scavenging flowsheet did not explode in the TTX testing nor was there much evidence of exothermic behavior or weight loss.

In our TTX test using about 40 mg of sample, the minimum explosion temperature observed for the sodium nickel ferrocyanide observed was about 305°C. In our DSC and STG analyses, the lowest reaction temperature was about 230°C. These temperatures are significantly higher than the measured current tank temperatures and suggest that current tank temperatures will not induce thermal runaway.

Also of concern is the sensitivity of the ferrocyanide and oxidant mixture to nonthermal initiating events. Tests at LANL indicated that a near-stoichiometric mixture of cesium nickel ferrocyanide and equimolar sodium nitrate and nitrite was not sensitive to mechanical impact, friction, or spark equivalent to the static discharge from a human. The laboratory at Los Alamos did find that a high energy spark could initiate the reaction; LANL believes that the initiation was likely due to thermal effects from the high energy spark.

The chemical and sensitivity studies began in 1988, and continued studies are planned to determine the reactivity of synthetic ferrocyanides prepared using variations of the two primary flowsheets and of aged ferrocyanide wastes. Aging studies will include work to determine the effect of radiation, and exposure to solutions having pH higher or lower than the flowsheets. We will also be performing studies of the reaction mechanism, kinetics, aqueous oxidation reactions, and we will pursue additional sensitivity tests.

INTRODUCTION

Radioactive waste from defense operations has accumulated in underground waste tanks at the Hanford Site in Washington state since the early 1940's. During the 1950's additional tank space was required to support the defense mission. To obtain this additional storage volume within a short period of time and without constructing additional storage tanks, Hanford Site scientists developed a process to scavenge radiocesium from tank waste liquids. In implementing this process, approximately 140 metric tons of ferrocyanide were added to 24 single shell tanks (SST).

Ferrocyanide is a stable complex of ferrous ion and cyanide that is considered nontoxic because it does not dissociate in aqueous solutions. However, in the presence of oxidizing materials, such as nitrates and nitrites, ferrocyanide can be made to explode if heated to temperatures above 285°C or if exposed to an electrical spark of sufficient energy. The explosive nature of ferrocyanide in the presence of an oxidizer has been known for decades, but the conditions under which the compound can undergo an uncontrolled exothermic reaction have not been thoroughly studied. Because the radiocesium scavenging process involved precipitating ferrocyanide from solutions containing nitrate and nitrite, it is possible that an intimate mixture of ferrocyanides and nitrates and nitrites exists in parts of some of the SSTs.

Since the mid 1980's efforts have been underway to evaluate the potential for a ferrocyanide explosion in the Hanford Site SSTs (Burger 1984; Burger and Scheele 1988; Burger and Scheele 1991). In 1987, the environmental impact statement (EIS), "Final Impact Statement - Disposal of Hanford Defense High-Level, Transuranic and Tank Waste," (DOE 1987) was issued. The EIS projected that the bounding "worst case" accident in a ferrocyanide tank would be an explosion resulting in a subsequent short-term radiation dose to the public of 200 mrem.

A recently reported General Accounting Office study (Peach 1990) postulates a greater "worst-case" accident with independently calculated doses one to two orders of magnitude greater than the 1987 EIS (DOE 1987). A special Hanford Site Ferrocyanide Task Team was commissioned in September 1990 to address all issues involving the ferrocyanide tanks, including the consequences of a potential accident. On October 9, 1990, Secretary of Energy Admiral James D. Watkins announced (DOE 1990) that a supplemental EIS would be prepared that would contain an updated analysis of safety questions (including the possibility for a ferrocyanide explosion) for the Hanford Site SSTs.

Using process knowledge and transfer records, an evaluation process that is still ongoing, 24 tanks have been identified at the Hanford Site as containing 1,000 gmole (465 lb) or more of ferrocyanide as the $Fe(CN)_6$-4 species. In October 1990, the ferrocyanide issue was declared an "Unreviewed Safety Question" (USQ) because the safety envelope for these tanks may no longer be bounded by the existing safety analysis report (WHC 1986). As a consequence, work in and around any of the ferrocyanide tanks requires detailed planning with the preparation of supporting safety and environmental documentation and approval by the U.S. Department of Energy (DOE) top management. These restrictions are required for safety, and greatly increase the time to complete work or install equipment in the tanks.

There are essentially four components within the Ferrocyanide Safety Program dealing with the resolution of the USQ. Tank monitoring is the first component. This activity involves the maintenance, development, and deployment of instrumentation for the continuous monitoring of the tank contents to insure that an unsafe condition does not arise. The computer modeling and analysis of existing tank data is the second program component. This effort allows the predictive calculations of, for example, the existence of hot spots within the waste and the concentrations of the dome-space gases. The third program component is the characterization of the waste by use of actual tank samples. This activity focuses on the chemical analysis of gas space, surface, and core samples from the ferrocyanide waste. Research and development is the fourth program component. The objective of this activity is to understand the potentially hazardous reactions of precipitated ferrocyanides and their aging products in the presence of SST wastes.

This report will focus on the research and development component and related studies of the Ferrocyanide Safety Program. This work supports the determination of whether, and under what conditions, a hazard may exist and will help determine required tank monitoring activities for safe operations of ferrocyanide tanks. An important outcome of this study will be to develop information to allow the selection of remediation strategies for ferrocyanide-containing tanks.

DESCRIPTION OF THE FERROCYANIDE SCAVENGING OPERATIONS

The wastes treated with the cesium scavenging process resulted from the bismuth phosphate and uranium recovery processes. The two primary flowsheets used for the scavenging process treated the acidic U Plant waste (In-Plant flowsheet) and the already basic U Plant waste (In-Farm flowsheet) stored in the tanks. This section gives a detailed description of these processes.

THE BISMUTH PHOSPHATE AND URANIUM RECOVERY PROCESSES

The bismuth phosphate process used in B Plant and T Plant was a plutonium recovery/purification process that did not recover uranium from its waste streams. The extraction waste, called metal waste (MW), contained the uranium and approximately 90% of the fission products. The MW was stored in underground waste tanks in the 200 Areas. In addition, first decontamination cycle (IC) waste was stored in 200 Area underground waste tanks separate from those containing MW. IC waste contained approximately 10% of the fission products.

The U Plant was built as a third bismuth phosphate plant, but was never used as such. To recover uranium from the MW, U Plant was converted to a solvent extraction uranium recovery (UR) plant. The alkaline MW solution was sluiced from the underground waste tanks, acidified, and transferred to the UR plant for processing. The UR plant waste was then neutralized with caustic and returned to the underground waste tanks.

The UR process (also called the TBP process since tributyl phosphate [TBP] was the active solvent extractant), began operation in November 1952. While the process efficiently recovered uranium from the sluiced, acidified MW, the overall process generated almost 2 gal of waste to be stored for every gallon of stored MW processed. Methods to reduce the volume of stored waste were studied and resulted in the development and implementation of the ferrocyanide scavenging process. In addition to the ferrocyanide scavenging process, the 242-B and 242-T tank farm evaporators had been placed in operation in 1951 to reduce stored waste volumes (Anderson 1990).

SCAVENGING PROGRAM OBJECTIVE

The principle, medium-lived fission products in the MW were ^{90}Sr (half life 28.6 yr) and ^{137}Cs (half life 30.2 yr). The objective of the ferrocyanide scavenging process was to remove the soluble, long-lived fission product, ^{137}Cs, from the UR and IC wastes as a precipitate; ^{90}Sr was already essentially insoluble in the neutralized UR waste. Removal of the cesium thus permitted disposal of the supernate to the ground, reducing the stored waste volume in the tanks.

SCAVENGING PROCESS FLOWSHEET DESCRIPTION

There were two principle scavenging flowsheets used to decontaminate aqueous wastes. The radiocesium In-Plant scavenging process consisted of adding $Fe(CN)^4$ ion to the acid waste, adjusting the waste pH to 9 ± 1, and then adding an equal molar amount of Ni^{+2} ion to produce a $Cs_2NiFe(CN)_6$ precipitate and/or carry the cesium along with other nickel ferrocyanide precipitates such as $Ni_2Fe(CN)_6$ and $Na_2NiFe(CN)_6$. The major ferrocyanide precipitate was not, and still is not identified. Since the major metal ion in the waste was sodium, the likely major precipitate was $Na_2NiFe(CN)_6$.

The ferrocyanide scavenging flowsheet was tested in U Plant in October 1953 (Abrams 1956). Both ferrocyanide [as $K_4Fe(CN)_6$] and nickel [as $NiSO_4$] were added to a concentration of 0.005 M. The treated waste (530,000 gal) was routed to Tank T-101 for settling. Control of pH during the first half of the plant test was poor, so only approximately half (255,000 gal) of the settled supernate was cribbed in December 1953. Production scavenging of the UR wastes began in late September 1954. At that time there was a total of approximately 21.2 Mgal of unscavenged UR waste in the tank farms. Approximately 13.1 Mgal of waste was located in the 200 East Area, and approximately 7.9 Mgal was in the 200 West Area (Stedwell 1957). The initial production flowsheet consisted of adding $K_4Fe(CN)_6$ to a concentration of 0.005 M to the acid waste, adjusting the pH of the waste to 9 ± 1, and then adding $NiSO_4$ to 0.005 M. In some campaigns, the pH adjusted waste was partially concentrated before adding the $NiSO_4$ (Abrams 1956).

Flowsheet changes made in the U Plant scavenging operation included: (Abrams 1956)

- replacing $K_4Fe(CN)_6$ with $Na_4Fe(CN)_6$ (April 18, 1955)
- testing and routinely adding $Ca(NO_3)_2$ to 0.016 M to improve strontium decontamination (April 21, 1955)
- testing and adding $Sr(NO_3)_2$ to 0.004 M as required, to replace $Ca(NO_3)_2$ for improved ^{90}Sr decontamination as the $Sr(NO_3)_2$ was available (August 1955)
- testing and routinely adding $Fe(CN)^4$ and Ni^{+2} to 0.0025 M instead of 0.005 M (August 1955 test, November 1955 routine)
- adding Na_2HPO_4 to wastes that were low in PO^3 ion concentration to aid ^{90}Sr retention in soil (January 1956).

PROCESSING IN THE 200 EAST AREA

The In-Plant scavenged UR waste was routed to a settling tank in the BY Tank Farm in 200 East Area (usually BY-106, -107, -108, or -110) at a rate up to approximately 50,000 gal/day. When a tank filled, the waste stream was changed to another settling tank. Each filled tank was allowed to settle for a minimum of 7 days before sampling. Aqueous scavenged waste was then sampled at several incremental depths and analyzed for ^{90}Sr, ^{137}Cs, total ß, total α, and PO_4-3. If the ^{137}Cs and ^{90}Sr were within limits, the supernate was then pumped to a crib or trench via a floating suction pump. From every 50,000 gal of supernate cribbed, grab samples of the supernate were taken from the discharge line and routinely composited and analyzed for the previously mentioned components. Other analyses were performed intermittently. In June 1955, the sampling procedure was changed; grab samples were collected for every 100,000 gal cribbed.

A continuous gamma monitor was mounted on the pump discharge line. The pump was to be shut off when a sudden increase in the monitor signal indicated the tank sludge level had been reached (Clukey 1955). During this process period, accumulated sludge in the various settling tanks was periodically transferred to tanks BY-104 or -105. The sludge volume was expected to be 7% to 10% of the treated supernate volume (Sloat 1954, Carpenter 1954). The UR wastes were scavenged throughout the remainder of the Metal Waste Recovery program. The last scavenged waste from U Plant was received in the 200 East Area in June 1957.

Beginning in May 1955, unscavenged UR waste already stored in 200 East Area tanks was routed to the 244-CR vault for scavenging using the In-Farm flowsheet. The pH was adjusted with HNO_3 and/or NaOH to pH 9.3 ± 0.7, and

$Fe(CN)_6$-4 and Ni^{+2} ion were added (generally to 0.005 M each). If laboratory analysis of the feed tank indicated additional ^{90}Sr decontamination was necessary, calcium nitrate was also added (Sloat 1955). The scavenged waste was then routed to another tank for settling, sampling, and decantation to a crib. Note that this procedure may have left much of the original, alkaline-insoluble solids [e.g., $Fe(OH)_3$] produced from neutralizing the UR waste in the original UR waste storage tanks. The primary settling tanks for this "In-Farm scavenged" waste were C-108, -109, -111, and -112. The sludge volume expected from the In-Farm scavenging was 10% of the treated supernate volume. In-Farm scavenging was completed in December 1957.

The original process plans called for cribbing the scavenged supernate. However, in 1956 it was found that ^{60}Co in the supernate would migrate to the ground water and exceed allowable limits. Considerable effort was expended trying to develop a cobalt scavenging procedure while disposal to ground was halted. In October 1956, a decision was made to dispose the high ^{60}Co wastes to ground on a specific retention basis. The BC trenches and cribs were built for specific retention disposal of the scavenged supernate. A ^{60}Co scavenging flowsheet was used on some In-Farm scavenging campaigns. This flowsheet involved adding Na_2S to 0.003 M in the waste after adjusting the pH to 8.5 to 9.2, and then proceeding with $Na_4Fe(CN)_6$ and $NiSO_4$ additions.

PROCESSING IN THE 200 WEST AREA

During this same period, In-Farm scavenging of the unscavenged UR waste stored in the 200 West Area was also planned. Both a project for chemical addition facilities at the 242-T Evaporator and various laboratory studies were completed. However, no In-Farm scavenging in 200 West Area was performed. Examination of records for waste disposed to ground for both 200 East and 200 West areas does not show ground disposal in 200 West Area of any scavenged wastes other than those noted in this report. The records for 200 West Area scavenged waste include the U Plant test in late 1953 when the treated waste was routed to T-101 and the In-Plant scavenging of IC T Plant wastes, which were subsequently routed to tanks TY-101, -103, and -104. Six batches, totaling 2.93 Mgal of scavenged supernate, were disposed to the TY cribs.

During the T Plant test, $K_4Fe(CN)_6$ was added to the acid waste to a concentration of 0.005 M, the pH was adjusted to 9 ± 1, and $NiSO_4$ was added to 0.005 M. Coating waste was to be combined with the scavenged waste either in T Plant or in the underground waste tanks. Further, 750,000 gal of IC wastes were to be scavenged in the initial plant test (Schmidt, Stedwell 1954). Later information indicated that incorporation of the coating waste into the IC scavenged waste gave poor ^{90}Sr decontamination, so the two waste types were segregated (Anderson 1990). Routine scavenging of T Plant IC wastes started on December 31, 1954, and continued until T Plant was shut down in March 1956. The effective reduction in waste volume, as discharged from the building, was approximately 88% (Anderson 1990). It should be noted that the IC waste contained less than 10% of the fission products ^{137}Cs and ^{90}Sr in the original charge, since the MW contained 90% of these products.

FERROCYANIDE CHEMISTRY AND REACTIONS

The Metal Cyanide Complexes

Nearly all the d-transition metals form cyanide complexes in a wide range of metal-ligand ratios and in a variety of structures (configurations) that include linear, triangular, square, octahedral, and dodecahedral geometries. The hexacyano-iron complexes are probably the best known, having been studied for well over 200 years (American Cyanamid 1953). An assortment of structures has been suggested over the years; but the octahedral configuration proposed by Werner and supported by Pauling (1939) has been accepted. The electronic structures have been described in detail by Chadwick and Sharpe (1966) and Sharpe (1976). Most of the higher complexes are very stable with respect to dissociation, and those of iron are no exception. The triple-bonded CN^- is covalently bonded to the metal, normally through the C atom. Back donation of electrons strengthens the M-C (M = metal) bond but slightly weakens the C-N bond. Sille'n and Martell (1964) list stability constants for the CN^- complexes of most metals. The CN^- ligand is nonlabile in the hexacyano iron complexes.

The present discussion will be concerned primarily with the ferrocyanides and emphasize the solid transition metal salts involving nickel. Pyrolysis of the sodium and potassium ferrocyanide salts in air at 400°C, or slightly higher, effects a mixture of products including the cyanate salt, nitrogen, carbon, and, at high temperatures, some free alkali metal. Pyrolysis in oxygen yields similar products with the additional product sodium carbonate (American Cyanamid 1953).

We did not find any information for the thermal decomposition of alkali metal nickel ferrocyanides, but Wirta and Koski (1957) found the thermal decomposition of cesium zinc ferrocyanide to be exothermic. Experiments at Pacific Northwest Laboratory (PNL)* using differential scanning calorimetry (DSC) and scanning thermogravimetric analyses (STG) suggest that complete oxidation to nitrogen and CO_2 or carbonates may occur by about 500°C, although the products have not been confirmed. Differential scanning calorimetry tests performed on cesium nickel ferrocyanide indicate a reaction starting at about 230°C to 260°C, with a maximum in the exotherm at about 305°C to 330°C (Burger and Scheele 1990). Preliminary data for the sodium nickel ferrocyanides and ferricyanides suggest that the oxidation reaction may start at a temperature below 200°C. Hepworth, McClanahan, and Moore (1957) observed decomposition beginning at 480°C for the analogous di-cesium zinc compound.

PROBABLE TANK PRECIPITATES

Mixed ferrocyanide salts containing alkali metal and transition metal cations often have nonstoichiometric compositions. That this is especially true for the nickel salts is evident from the review of Loos-Neskovic et al. (1984, 1989). Thus, the composition of the precipitates depends on the relative solution concentrations, the order of addition of the reagents,

* Pacific Northwest Laboratory is operated by Battelle memorial Institute for the U.S. Department of Energy under contract DE-AC06-76RLO 1830.

probably the pH, the temperature, and, of course, the individual solubilities. For the alkali metal nickel ferrocyanides, the order of decreasing solubility and apparent reactivity is increasing atomic number. The solubility of di-nickel ferrocyanide is reported to be $2.0 \cdot 10^{-5}$ g Ni/L (Tananaev, Gluchkova, and Seifer 1956). No information on the sodium nickel salts has been found in the literature.

Considering the above reactivity and solubility factors and the compositions of the waste tanks, the precipitates that originally formed in the waste treatment process would logically have included $Na_2NiFe(CN)_6$, $Ni_2Fe(CN)_6$, small amounts of $K_2NiFe(CN)_6$ and $Cs_2NiFe(CN)_6$, and large amounts of a mixed salt, $Na_xNi_y[Fe(CN)_6]_z$ where $4z = x + 2y$. The preparations that have been examined have contained 2 to 4 moles of water per mole of ferrocyanide.

The prediction that sodium nickel ferrocyanide would be the principle precipitated form is due to the fact that the waste tank solutions, to which the nickel and ferrocyanide ions were added to 0.005 M were 3 to 6 M sodium nitrate/nitrite. There are no solubility data to confirm this hypothesis. Attempts have been made to prepare these various forms in PNL laboratories, and a variety of tests have been carried out on the products. Preliminary tests show that a sodium nickel ferrocyanide is the predominant form.

The solid nickel complexes are inert to most reagents. Sulfuric acid heated to fuming readily dissolves the solids. A large excess of EDTA will also dissolve the compounds. For metal analysis, the most convenient approach is to heat the samples in air at 800°C and dissolve the resulting oxides in HCl.

The precipitates are very fine and nearly impossible to filter. Washing with water tends to produce colloids. The precipitates formed may occlude salts present in the solution.

POSSIBLE REACTIONS IN WASTE TANKS

Cyanides are strong reductants and are known to react explosively with nitrates, nitrites, chromates, and other strong oxidants. Hepworth, McClanahan, and Moore (1957) describe the explosive behavior of cesium zinc ferrocyanide when attempts were made to dry samples that were wet with nitrate solutions. Other observations placed the explosion threshold temperature of the material in contact with sodium nitrate at 375°C (Cooper 1957). If solid nitrates were heated with the dry compound, explosions accompanied by dense white fumes were observed.

The explosive reaction of molten sodium nitrate and sodium cyanide is noted by Sax (1957) and by the National Board of Fire Underwriters (1950). An Austrian explosives patent is based on mixtures of nitrites and cyanides or ferrocyanides (Eiter, Vogl, and Michl 1954).

During the past three years, numerous explosive tests have been carried out using milligram quantities of cyanide compounds, including those expected to exist in Hanford process tanks. While not defining the actual reactions that take place, these tests, along with scanning calorimetry and gravimetry measurements, do provide much information on the nature of these reactions. Preliminary data have been presented in interim reports (Burger and Scheele 1988; 1990).

The energetics of the oxidation of these compounds can be estimated from the enthalpies of formation of the reactants and products. No data were found for the nickel hexacyanoferrates. Based on both enthalpies and free energies of formation of a variety of complex cyanides (Wagman et al. 1982; Barin 1989), values of $\Delta H_f = +200$ kJ for di-nickel ferrocyanide and zero for the sodium nickel ferrocyanide were assumed. These values are uncertain to at least 200 kJ.

Six moles of nitrate or 10 moles of nitrite is required for the complete oxidation of 1 mole of ferrocyanide to N_2 and CO_2. The products of the reaction with either nitrate or nitrite salts may include N_2, CO_2, CO, NO, Na_2O, NaOH, Na_2CO_3, NiO, FeO, and traces of carbon and other compounds. The product NaOH assumes some water is present. The calculated energy release is highly sensitive to the products formed, as shown in Table I. If a sizable fraction of the carbon goes to CO, or if appreciable oxides of nitrogen form, the energy is greatly reduced. On the other hand, a change from one ferrocyanide salt to another results in a much smaller change.

Some comment regarding the sodium salt is necessary. On the basis of stability, the carbonate product should predominate up to about 1827°C, at which point decomposition to the oxide becomes appreciable. Above about 1927°C, the decomposition of the oxide itself becomes important. However, if water vapor is present, sodium hydroxide becomes the most stable sodium form above about 1727°C. At this temperature, sodium hydroxide is in the vapor form. Thus, without knowing the final temperature and the components in the reactive mixture, a single reaction cannot be specified. Secondly, there is no reason to expect that equilibrium is reached among the products formed.

TABLE I

Calculated Energy Release for Oxidation of Some Cyanides and Ferrocyanides

Compound	Oxidant	Products[a]	Energy, kJ
$Na_2NiFe(CN)_6$	$NaNO_3$	Na_2CO_3, CO_2, N_2	-3012
"	"	Na_2O, CO_2, N_2	-1722
"	"	Na_2O, CO, N_2	-240
"	"	Na_2CO_3, Na_2O, NO	+230
"	$NaNO_2$	Na_2CO_3, N_2	-3708
$Ni_2Fe(CN)6$	$NaNO_3$	Na_2CO_3, CO_2, N_2	-2880
"	$NaNO_2$	Na_2CO_3, CO_2, N_2	-3480
NaCN	$NaNO_3$	Na_2CO_3, N_2	-3450

(a) Other products are FeO and NiO

Based on a typical nitrate-nitrite ratio in the waste tanks, a reasonable value for the maximum energy released is about 3300 kJ/mol of ferrocyanide or 3.7 kJ/g of a stoichiometric mixture of sodium nickel ferrocyanide and a 50/50 mol% mix of sodium nitrate/sodium nitrite.

REACTIVITY MEASUREMENTS

Chemical reactivity measurements taken at PNL have included small-scale explosive testing and thermal analysis of ferrocyanide-nitrate/nitrite mixtures. In addition, sensitivity evaluation testing of a near-stoichiometric mix of cesium nickel ferrocyanide and 50/50 mol% sodium nitrate-nitrite was conducted by the Los Alamos National Laboratory (LANL) (Cady et al. 1989). The materials used were ground to < 200 mesh. The 50/50 mol% sodium nitrate / sodium

nitrite was melted, cooled, and ground using a marble mortar and pestle.

Time-to-Explosion Testing

The time-to-explosion (TTX) test is similar to the standard test Henkin and McGill (1952) used to evaluate explosives. The TTX data were obtained at PNL by inserting 40- to 50-mg samples of cyanide compound mixed with oxidant into a heated metal block. The samples were contained in 5-mm. dia. thin wall (nmr) tubes. The times and nature of the explosions (or other reactions) were recorded. Figure 1 exhibits a typical data set, and Table II lists pertinent data obtained from these tests. The following comments summarize the results:

- Sodium nickel ferrocyanides and ferricyanides or ferrocyanides with a high nickel content were more reactive than cesium nickel ferrocyanide.
- Reactions involving nitrites were more vigorous than those with nitrates alone.
- The brisance (shattering effect) increased with nitrite concentration, temperature, and quantity of material, the reaction often resulting in a sharp explosion that pulverizes the tube.
- Heating at temperatures below the minimum measured explosion temperature often produced some NO and/or NO_2 gas in a mild reaction. If the mixture was then placed in a block at high temperature, an explosion sometimes still occurred.
- The maximum explosive behavior was probably with near-stoichiometric mixes, but large excesses of either the ferrocyanide or the oxidant may still produce explosions. The experimental dilution limits have not yet been determined.
- In preliminary tests, the addition of sodium EDTA increased the explosivity and reduced the minimum observed reaction temperature as does nickel hydroxide, and to a lesser extent ferric hydroxide. Small amounts of sodium hydroxide or tributyl phosphate had a negligible effect.
- Attempts to treat the data kinetically were inconclusive.
- The explosive tests were not always reproducible with respect to either time or temperature. This is characteristic of explosive reactions.
- Samples of dried, settled solids prepared by using the In-Farm process flowsheet produced explosions when heated (no added nitrate or nitrite). A sample of dried, settled precipitate prepared using the In-Plant flowsheet (using dilute ferrocyanide, 0.0025M) did not explode.
- The violence of the observed reactions leaves no doubt that an explosion will result if a mix of ferrocyanides and nitrate or nitrite salts is rapidly heated. However, it is possible that slow heating may produce slower and less exothermic reactions.

Figure 1 presents the TTX data for the In-Farm settled and unwashed sample compared with another sample that was centrifuged, water-washed to remove soluble salts, and then mixed with a stoichiometric amount of sodium nitrate/nitrite. As shown in Fig. 1, the settled material carried enough nitrate/nitrite to cause explosion.

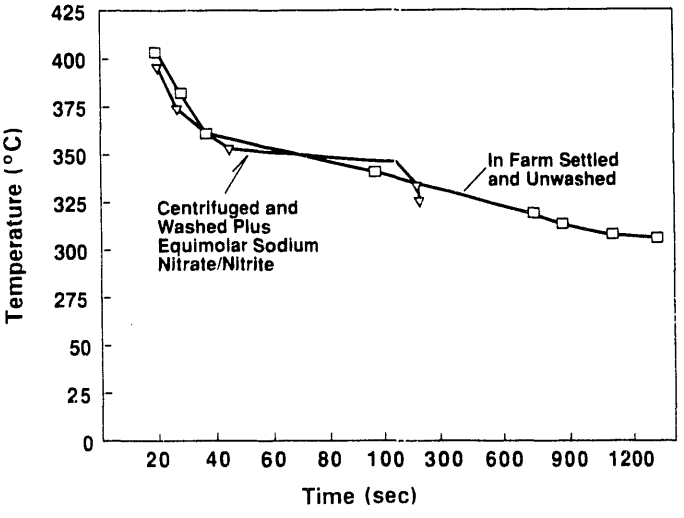


Fig. 1. A Typical TTX Plot. This is an example of a laboratory preparation of sodium nickel ferrocyanide using In-Farm process flowsheet.

TABLE II

Time-to-Explosion Data for Small Samples

Compound	Oxidant	t, s at 360°C	Minimum Estimated Explosion Temp, °C
$Cs_2NiFe(CN)_6$[a]	(Na,K)NO3	15	310±10
"	(Na,K)NO2	33	300±5
"	Na(NO3,NO2)	50	340±10
"	" + 5%Ni(OH)2	18	300±5
"	" + 5%EDTA	8	280±5
KCN $Na(NO_3,NO_2)$		240	350±20
$Na_2NiFe(CN)_6$[a]	"	27	330±10
$Ni_2Fe(CN)_6$[b]	"	10	280±10
$NaNiFe(CN)_6$ [c]	"	13	300±10

[a] The Na/Ni ratio is uncertain.
[b] Although high in Ni, the compound still contains some alkali metal ions.
[c] Ferricyanide compound.

Thermal Measurements

Using both DSC and STG, thermal measurements were taken of the CN compounds alone and with mixtures of nitrate and nitrite salts in air and in N_2. Typical results are shown in Figs. 2 and 3. Figure 2 represents the behavior of a sodium nickel ferrocyanide sample mixed with a stoichiometric mix of sodium nitrate/nitrite. Figure 3 illustrates the results of using dried solids from the In-Farm flowsheet material.

Typical laboratory preparations have a variable nickel-sodium ratio. Salient features of the DSC plots are the temperature at the beginning of the exothermic reaction, the temperature at the exotherm maximum, and the general complexity (multiple peaks) of the exotherms. The multiple peaks suggest that a complex (stepwise) reaction may be occurring.

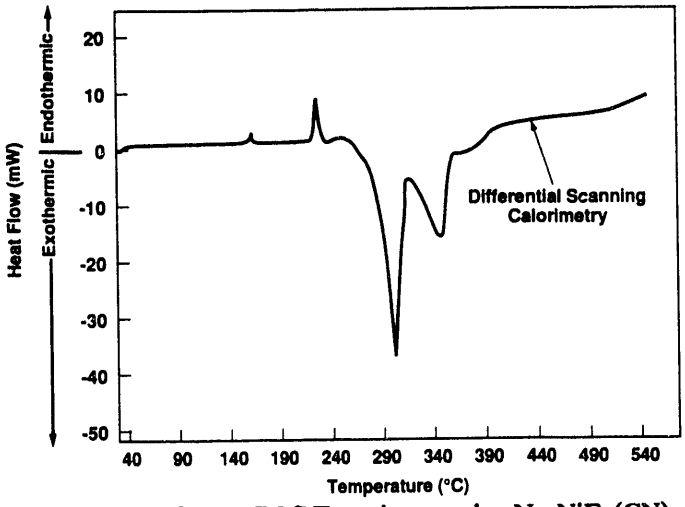


Fig. 2. Results from a DSC Experiment using $Na_2NiFe(CN)_6$ with $NaNO_3/NaNO_2$ oxidant.

In-Farm Flowsheet Settled and Dried Solids in N_2

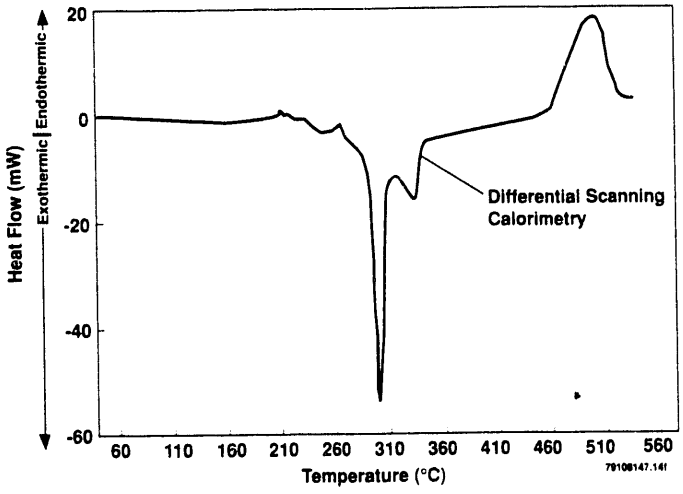


Fig. 3. Results from a DSC experiment using In-Farm settled and dried solids in N_2.

The enthalpies for the reactions may be computed from the areas of the exothermic peaks and serve a comparative purpose, but are generally not quantitatively reliable. The thermal analysis work is ongoing but to date, the results can be summarized as follows:

- The nickel complexes reacted at lower temperatures than alkali metal cyanides or alkali ferrocyanides.
- The minimum temperature at which an exotherm was first noted was in the vicinity of 220°C. The maximum exotherm appeared in the range from about 280°C to 320°C.
- The reaction achieved with a typical mixed nitrate/nitrite salt was complex and showed multiple exothermic peaks. The reaction achieved with nitrate salts varied somewhat with the cation and may have shown single or multiple peaks. The reaction with nitrites was much faster and normally showed a single sharp peak at about 260°C to 300°C.
- Some evidence of a reaction beginning at lower temperatures, between 180°C and 230°C, was obscured by endotherms characteristic of the oxidant.
- At the present time, no interpretation can be given to the specific reaction steps responsible for the different exotherms.

The complex structure of the DSC thermograms implies that the oxidation reactions are not simple. Some knowledge of the reaction mechanisms and the kinetic parameters of significant steps is necessary before the explosive reactions can be identified. Several experiments are underway to provide some of this information.

Figure 4 is a typical STG plot and shows the behavior of sodium nickel ferrocyanide when heated with the nitrate/nitrite mixture. After the initial weight loss due to water, two major mass losses, along with several minor losses, are suggested. The behavior of the In-Farm settled solids is compared in Fig. 5. Reaction product analysis would provide a more detailed interpretation.

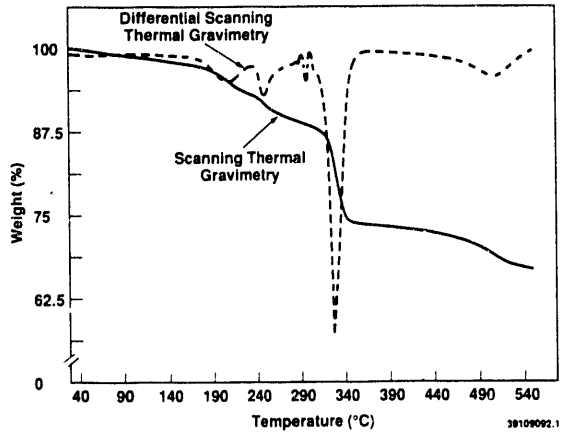


Fig. 4. Results from a Scanning thermometric experiment using $Na_2NiFe(CN)_6$ with $NaNO_3/NaNO_2$.

In-Farm Flowsheet Settled and Dried Solids in N_2

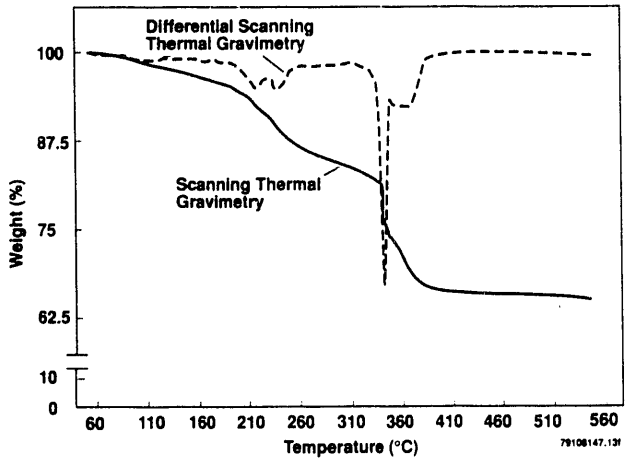


Fig. 5. Results from a Scanning Thermometric Experiment using In-Farm Settled Solids.

The LANL thermal analysis data obtained (Cady et al. 1989) from a mixture of cesium nickel ferrocyanide and sodium nitrate/nitrite generally support the above reactivity conclusions. In addition, it was found that a mixture of $Cs_2NiFe(CN)_6$ and sodium nitrate/nitrite was insensitive to mechanical shock, friction, or electric spark as defined by standard sensitivity tests for explosive materials.

Catalysts and Initiators

Explosive reactions are often influenced by catalysts. A few potential catalysts have been tested at PNL. The choice was governed by the materials expected to be present in the waste tanks. The TTX tests and DSC tests were conducted with 5 mol% of $Ni(OH)_2$, FeO(OH), NaOH, TBP, and Na_4EDTA. The latter two compounds may act as initiators by reacting independently with the oxidants. Sample reactivity was markedly increased by the addition of nickel and EDTA compounds and slightly increased by the iron compound. Further tests are being performed.

Diluents

Diluents are expected to play an extremely important role in the reaction mix. They may change the thermal conductivity of the mixture, thus influencing the propagation of the reaction; they may change the rates of bi-molecular reaction steps; and most importantly, they introduce an additional heat capacity that will control the temperature rise during an adiabatic process. Diluents likely to be present in the pertinent waste tanks include water, excess sodium nitrate and nitrite, aluminates, and a variable mix of lesser components such as silicates, sulfates, phosphates, carbonates, and metal ions such as iron and bismuth.

Using heat capacity data and an assumption that the oxidation reaction is 80% efficient, we have calculated the quantity of water, excess sodium nitrate, and a model diluent (sodium aluminate) that would prevent propagation of the exothermic reaction. These data are presented in Table III.

Water is the best diluent because its vaporization enthalpy is large. While free water is easily lost, chemically bound water, such as in hydrates or in zeolytic materials, may remain until temperatures of 150°C to 200°C are attained. The enthalpy of fusion of sodium nitrate aids in preventing a temperature rise in the vicinity of 300°C. A thermal runaway reaction is precluded if sufficient diluent is present.

In the simplified models used in Table III calculations, all solid state transitions were ignored including the decomposition of hydrates. However, the hydrate decomposition was approximated in the water vaporization term.

Results from the TTX tests indicate that explosions occur with wide variations in the ferrocyanide-oxidant ratio, but the limits have not been determined.

TABLE III

Quantity of Diluent Required to Prevent Propagation of Ferrocyanide Oxidation (g diluent/g ferrocyanide)[a]

	Mass of Diluent Required, g		
Reaction Temperature, °C	307[b]	250	200
ΔH (80% of Theoretical), kJ	7966	8071	8146
H_2O	2.7 (2.4)	2.9 (2.59)	3.0 (2.7)
$NaNO_3$	9.4 (8.3)	16.8 (14.9)	23.7 (21.3)
$NaAlO_2$	27.9 (24.6)	38.5 (34.3)	60.8 (54.5)

[a] Reaction mix is 1.0 g $Na_2NiFe(CN)_6$ + 1.61 g $NaNO_3$. Values in ( ) assume each ferrocyanide molecule retains 4 molecules of water.

[b] Calculation at 307°C assumes that runaway reaction requires melting of $NaNO_3$. Heat of fusion of $NaNO_3$ is not included in calculations at other temperatures.

RADIOLYSIS

As discussed in an early ferrocyanide report (Burger 1984), the uncomplexed cyanide ion is rapidly destroyed under radiolysis conditions in aqueous solution. Considerable data are available: Touhill et al. 1969; Ogura et al. 1972; Behar 1974; Bielski and Allen 1977; Liaw and Woodbridge 1977; Draganic, Draganic, and Niketic 1977; and Shen-chu, Shao -hua, and Ji-lan 1981. Products include CNO^-, NH_3, $CHONH_2$, and smaller amounts of $HCOO^-$, CO_2, urea, and probably N_2. Results from this radiolysis study indicate G values (molecules decomposed per 100 eV of energy absorbed) as high as 6. Stable products are expected to be cyanate ion, CO_2, and N_2.

In the presence or absence of oxygen, the ferrocyanide ion is easily oxidized to ferricyanide by radiolysis. In deoxygenated systems, the reverse reaction can also occur (Denaro and Jayson 1972). The oxidation of ferrocyanide to ferricyanide in the absence of oxygen was first demonstrated by Fricke and Hart (1935) where $G(H_2)$ was found to be 0.45.

Only brief preliminary experiments have been reported on the radiolytic stability of solid ferrocyanides (Martin, Burger, and Morgan 1985). Results from these experiments suggest that the solid compounds are likely to be very stable with respect to radiolytic decomposition. Any mechanism for decomposition is, therefore, likely to be through the aqueous phase. The major radiolytic products of water and their approximate yields (G values) at high pH are: OH, 2.9; H_2O_2, 0.8; H_2, 0.4; H, 0.6; e^-_{aq}, 3.0 (Denaro and Jayson 1972). The first two products are oxidizing, and the latter three are reducing. Subsequent reactions produce oxygen (from H_2O_2) and additional hydrogen (from the hydrated electron). Equilibria with OH^- at the high pH will produce additional ionic species: O^-, HO_2-, and O_2-. The radiolytic decomposition of nitrate ion, producing both nitrite ion and oxygen, may add to the oxidative nature of the solution.

Although the amount of cyanide or ferrocyanide in solution is expected to be extremely small, the effectiveness of radiolytic oxidation reactions with the very low solubility of the ultimate product, $Fe(OH)_3$, provides a possible path to the radiolytic destruction of ferrocyanide precipitates in the high pH environment.

CONCLUSIONS

The complexing constant for hexacyano-iron complexes, both Fe(II) and Fe(III), are exceptionally large. The derived transition metal salts or double salts containing alkali metal ions are only slightly soluble. The various nickel compounds examined in this study, i.e., those predicted to have been formed in the Hanford waste scavenging program, are typical examples. In spite of their relative stability towards most reagents under ambient conditions, they are all thermodynamically unstable towards oxidation and react exothermically with oxidants such as nitrate or nitrite salts when heated to temperatures in excess of 200°C.

These oxidation reactions are very complex and poorly understood. Further research is required on the mechanisms of the several steps in the reactions as well as on the effects of catalyst and diluents. For example, when a mixture of ferrocyanide and nitrate or nitrite is heated, a reaction typically

begins at about 240°C, but may occur well below 200°C in the presence of catalysts or organic compounds that may act as initiators.

The peak reaction rate may occur in the vicinity of 320°C. The energy released is highly dependent on the course of the reaction. Complete oxidation yields about 3300±20% J/mol. Milligram quantities of a ferrocyanide nitrate/nitrite mix tend to explode over a wide range of temperatures, typically starting at about 280°C.

Both the cyanide and hexacyano-iron complexes are reported to be unstable to radiolysis in aqueous solution, but preliminary measurements show the solid compounds appear to be resistant. However, no quantitative data exist. Very slow, long term destruction of the cyanide precipitates may occur through aqueous processes.

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HIGH ORGANIC CONTAINING TANKS - ASSESSING THE HAZARD POTENTIAL

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ABSTRACT

Eight Hanford Site tanks contain organic chemicals at concentrations believed to be greater than 10 mole percent sodium acetate equivalent mixed with the oxidizing salts sodium nitrate/sodium nitrite. Also, three of the hydrogen and ferrocyanide tanks appear on the organic tank list. Concentrations of organics that may be present in some tanks could cause an exothermic reaction given a sufficient driving force, such as high temperatures. However, the difference between ignition temperatures and actual tank temperatures measured is so large that the probability of such a reaction is considered very low. The consequences of the postulated reaction are about the same as the scenarios for an explosion in a "burping" hydrogen tank. Although work on this issue is just beginning, consideration of hazards associated with heating nitrate-nitrite mixtures containing organic materials is an integral part of both the hydrogen and ferrocyanide tank efforts.

High concentrations of organic compounds have been inferred (from tank transfer, flow sheet records, and limited analytical data) in eight single-shell tanks. Many organic chemicals, if present in concentrations above 10 dry weight percent (sodium acetate equivalent), have the potential to react with nitrate-nitrites constituents at temperatures above 200°C (392°F) in an exothermic manner. The concentrations of organic materials in the listed single-shell tanks, and their chemical identity, is not accurately known at present. A tank sampling program has been planned to provide more information on the contents of these tanks and to serve as a basis for laboratory testing and safety evaluations.

Evaluation of records relating to material transfers to the remaining single-shell tanks and double-shell tanks continues. If additional tanks are identified that meet the organic concentration requirements, the tanks will then be added to the organic tank list.

BACKGROUND

Since the early 1940s, radioactive wastes from defense operations have been accumulating at the Hanford Site in underground waste tanks. Presently, there are 177 waste storage tanks at the Hanford Site, of which 149 are single-shell tanks and the remainder are double-shell tanks.

During the years of tank farms facilities operation, wastes have been systematically distributed among the tanks. In this process, two of the objectives were to segregate different types of wastes and to reduce the need for additional tanks. The known major constituents of the wastes are sodium nitrate, sodium nitrite, silicates, aluminates, hydroxides, phosphates, sulfates, carbonates, organics, ferrocyanides, uranium, copper, and calcium in addition to the fission products present from the processing of irradiated fuel.

The presence of organic chemicals in Hanford Site waste storage tanks became an issue for reevaluation as a consequence of the U.S.S.R. releasing more information (1) on the explosion of a waste tank, on September 29, 1957, in Kyshtym, U.S.S.R. The U.S.S.R. tank exploded because a mixture of oxidizing salts with organic chemical wastes was allowed to self heat to an explosion initiation temperature. The principal constituents in the tank that were the cause of this incident were sodium nitrate and sodium nitrite mixed with sodium acetate. There appears to be no similarity in waste composition between the Kyshtym tank to any of the Hanford Site tanks.

In the past, the potential for danger from reactions in organic constituents stored in the waste tanks has been studied at the Hanford Site. For example, in April 1976 a paper was published describing combustion studies with sodium nitrate (2). However, in keeping with the concerns at that time, this report was directed more towards the oxidative power of sodium nitrate than to the reactivity sensitivity of specific tank waste mixtures.

Renewed concern as a result of knowledge gained about the Kyshtym incident prompted a new study at the Hanford Site in 1989. This study included a series of 26 preliminary tests that examined the reactivity of waste tank acetate mixtures. The results were used to define an upper limit for an acceptable concentration of total organic carbon constituents in the wastes. The limit was defined as "10 percent organic equivalent weight to sodium acetate," which corresponds to approximately 3.0 percent "total organic carbon." Results of this study and process engineering knowledge of tank contents form the current basis for identifying tanks for the organic program. Presently, there are eight tanks listed on the organic programs, but further studies may add or subtract tanks from the list.

Process knowledge was needed to identify tanks for the organic program because of limitations in the historical records. In the past, records were generally maintained most accurately for radioactive constituents. At that time, the future need for detailed chemical constituent information was not anticipated.

Organic materials entered the tank waste streams in many forms and from a variety of processes. Such materials included solvents [e.g., NPH (normal paraffin hydrocarbon), hexone, and carbon tetrachloride], complexing agents [EDTA (ethylenediaminetetraacetic acid) and HEDTA (N-(hydroxyethyl)-ethylenediaminetriacetic acid], reagents for solvent actinide and fission product extraction, buffering or denitrification reagents (e.g., citric acid and sugar), and general laboratory reagents.

Tanks in the organic program may be subject to a number of operating restrictions to minimize the possibility of an unsafe event occurring. The following is a listing of activities that can be restricted for an organic tank:

- Waste transfers in and out of tanks
- Waste core sampling
- In-tank photography
- Work in primary tank air space or on the associated ventilation/exhaust systems
- Work in tank annulus or on associated annulus peripheral equipment
- Work in the vicinity of the tank or exhaust systems.

The Organic Tank Safety program covers a wide range of activities that include (1) characterization of the tank wastes, (2) an evaluation of the current criteria for listing tanks in the program, and (3) testing using simulated waste mixtures as well as corrective actions to the tank contents, if required. The program objective is to resolve safety issues associated with the tanks. Program closure is achieved when contents of all of the tanks are satisfactorily mitigated, remediated, or are determined to be readily amenable to interim stabilization before remediation or disposal.

Table I provides a listing of the eight organic tanks in the program.

The tanks are listed because of the possibility of organic chemicals being present in quantities sufficient to sustain a reaction that may result in a potential for release of high-level waste due to uncontrolled increases in the temperature or pressure of the tank contents.

PROGRAM SCOPE AND OBJECTIVES

The overall scope of work for the program is to resolve the known safety and technical issues associated with the eight organic waste tanks. Resolution of these issues will lead to safe disposition of the tank contents either by mitigation, remediation, or interim stabilization until final disposal. Activities associated with issue resolution include, but are not limited to, short and long term safety assessments, management and control of tank storage operations, collection and analysis of tank historical information as well as characterization and testing of tank waste samples.

The principal objective of the program is centered on ensuring that safety, using safety evaluation techniques, for each listed tank. These evaluations will determine whether or not the tank contents are currently being stored safely. If it is determined that tank contents are not stored safely, then necessary remediation or mitigation action will be taken to ensure safe storage. In addition to the principal objective, the organic program also will review the results of characterization of other single-shell tanks to ensure that they do not pose a risk because of their organic contents. The single-shell tanks presently are being characterized under the environmental restoration/remediation action program. The object of the review will be to provide ensurance that tanks meet the criteria for safe interim storage of organic containing nitrite-nitrate wastes.

The work activity sequences associated with the program are depicted in the Organic Tank Program Logic Chart (Fig. 1). Figure 1 depicts the relationships between the major program activities. It shows that two routes exist to achieve program closure. The direct route would be to discover a means of processing the tank contents that allows for safe storage without the activities covered by the Organic Tank Safety program.

Evaluation of the Tank Listing Criteria

The first activity is to complete a comprehensive determination of the safety limits of organic waste constituents in the tanks. Completion of this task will allow for verification, through an operations safety review, of the existing criteria or its revision to a new standard. Achieving this objective also will allow for an evaluation of the maximum safe operating temperatures for the eight organic watch list tanks as well as other tanks that may be discovered to violate the operations safety review.

Reactivity Testing of Simulated Waste Mixtures

Simulated waste mixture testing will be done to define safe concentration limits for the variety of organic materials that may be in the wastes. Determinations of concentration effects on mixtures reactivities will be performed using waste samples that approximate the tank contents. The samples will be gram quantities synthetic mixtures of organic chemicals that are the known major organic waste constituents with the oxidizing salts and diluents. Constituents used in test mixtures may not be limited to chemicals identified as present in large quantities in the waste tanks. Waste constituents that could act as catalysts or reaction initiators also will be tested.

Choices of the reference organics will be made based on available analytical data, process engineering knowledge, and chemical technical opinion. The initial test mixtures will be

TABLE I

Organic Waste Tanks

Tank	Tank capacity kilogallons	Waste volume percent of tank capacity	Temperature fahrenheit	Waste heat load Btu/H
241-B-103	500	20	60	< 10,000
241-C-103	500	40	131	18,000
241-S-102	750	100	109	11,900
241-SX-106	1,000	85	115	< < 40,000
241-TX-105	750	85	103	20,000
241-TX-118	750	50	75	4,900
241-U-106	500	60	84	6,500
241-U-107	500	100	81	13,800

simple ones, of few components, followed by more complex mixtures to be tested for catalytic effects. The testing program will proceed by evaluating dilute to more concentrated organic-containing mixtures. The organic chemical components will be progressively increased in concentration, until pre-established safety values of the test parameters are reached. At this point, the safety limit for concentrations of the organic mixtures will be determined.

Compositions of the simulated waste mixtures will be corrected, as needed, when more information becomes available from tank waste characterizations. Such new information will be used to replace process engineering knowledge that served in the initial criteria for identifying watch list tanks.

Characterization and Testing of Samples Obtained From the Waste Tanks

Waste samples obtained from the tanks will be chemically characterized and tested for reactivity and shock sensitivity. Table II tabulates the information to be obtained. Such information will act as an aid for identifying mixture compositions that will be candidates for "scale-up" testing.

Test results of actual waste can be used to evaluate the degree of risk that can be associated with continued storage of organic containing waste in the tanks. This will be done after the waste samples had been sufficiently analyzed for constituent concentrations. The waste characterization results also will act as reference information in the design of mitigation, remediation or interim stabilization processes. Determination of chemical and physical properties to assess waste behavior will be a key factor in performing issue closure.

"Scale-Up" Testing using Simulated Wastes

Performing "scale-up" testing using larger (kilogram) quantities of materials is essential to determine the affects of increased mass on the hazard potential of waste mixtures. Testing will be performed with simulated wastes, where possible, to avoid the difficulties of handling radioactive materials under test conditions. Scale-up testing will determine more accurately if a dangerous mixture in a specific tank could heat up and, if not controlled, reach an exothermic reaction initiation temperature that leads to a runaway condition. It will be necessary to take into consideration the tank environment of the waste mixture in performing the testing. This will require

TABLE II

Waste Characterization

Chemical analysis to determine concentrations of:

- organic constituents
- oxidizing salts
- diluents
- potential catalysts
- and reaction initiators.

A determination of the spatial distributions in the tanks of the organic waste constituents and other constituents that may interact with them.

Determinations of physical chemical parameters:

- reaction initiation temperatures
- reaction enthalpies
- reaction propagation rates.

Estimates of sensitivities to reaction triggering phenomena:

- electrostatic discharges
- physical shock waves (impacts)
- friction
- radiation, nuclear and electromagnetic
- crystal energy relaxations.

Effect of temperature on triggering mechanisms

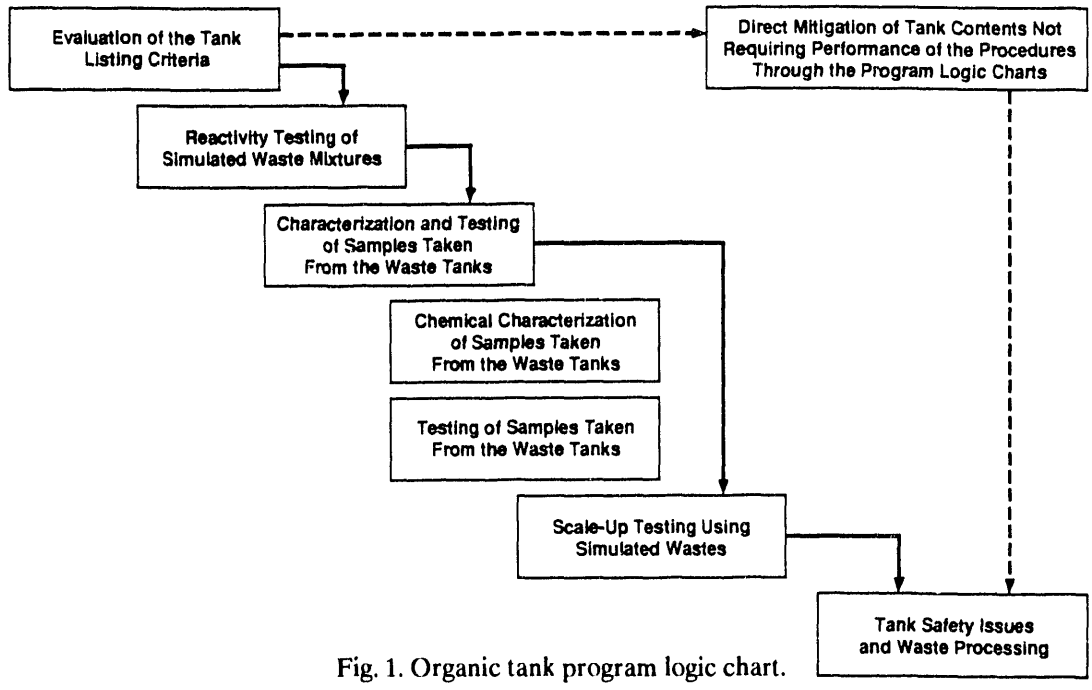


Fig. 1. Organic tank program logic chart.

knowledge of the heat capacities and thermal conductivities of the waste and associated tank materials.

Tank Safety Issues and Waste Processing

Tank safety issues and waste processing includes actions found necessary for interim stabilization of the organic containing tanks. Such actions may require mitigation or remediation of the safety issue associated with a given tank contents before final waste disposal. Completion of this final objective for any of the listed tanks achieves program closure for that tank. Mitigation or remediation will not be required for tanks that are determined to be in a safe condition during the course of performing the program activities.

Literature Reviews

During the course of the program, reviews of existing literature and other information will be made on the following subjects:

- Reviews of tank history
- Reviews of the literature to determine how the waste composition can change as a function of time
- Reviews of the literature for leads on runaway reactions involving nitrate or nitrite systems
- Evaluation of the literature to assess the potential for processes that would concentrate the organics in the tanks
- Reviews of the literature to facilitate the development of chemical assay methods specific to different organic species
- Reviews of existing waste chemistry information for mitigation and remediation processes.

SUMMARY

The Organic Tank Program is one in which safety issues are being evaluated that are associated with storage of organic wastes in Hanford Site tanks. Currently, a listing of eight tanks are on the program tank listing. These tanks have extra safety precautions imposed on operational activities performed in and around the tank. The imminent danger from the tanks is considered to be very low because of the low maintenance temperatures of the tanks. However, an explosion of a waste tank in the U.S.S.R. has prompted a reevaluation of the tank safety for all tanks containing organic wastes.

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OPERATING WATCH LIST TANKS: A STUDY IN CONTROL

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ABSTRACT

The paper will present the controls and processes by which Westinghouse Hanford Company manages the characterization and maintenance of tanks that are considered unresolved safety questions. Cultural as well as management changes will be discussed. First, processes by which safe and disciplined actions around potentially hazardous high-activity Hanford waste tanks can be instilled in our work force will be examined. Our success in changing our work practices will be discussed in tangible terms. Second, the dual challenge of upgrading personnel skills while addressing the upgrades for antiquated equipment and control systems with limited financial growth will be examined. This represents one of the primary management challenges of the Waste Tank Operations organization. Reorganization of groups to improve plant maintenance efficiencies, their tracking and prioritization will be addressed. This includes the establishment of unique internal review committee of line managers and operators to prioritize maintenance activities. Finally a means of enhancing the ability of plant forces to respond to anomalies in monitoring data or other tank related event will be discussed. The innovative use of a "Joint Test Group" structure (e.g., on call teams of representatives from all affected and authorizing organizations) to assure that all activities on "watch list tanks" in the Tank Farm remain within the defined safety envelope will be discussed.

OPERATING WATCH LIST TANKS: A STUDY IN CONTROL

The facilities and operations of the Waste Tank Safety, Operations, and Remediation Division (WT) are located in the 200 East and 200 West Areas of the Hanford Nuclear Reservation and include 149 single-shell tanks (SST), 28 double-shell tanks (DST); waste transfer facilities such as interconnecting pipelines, pits, and catch tanks; and surveillance systems and support equipment. In addition to the waste tanks, the Tank Farms Project is responsible for operation of one evaporator-crystallizer, one waste unloading facility, and various support facilities.

In 1990, Section 3137 of Public Law 101-510 (commonly referred to as the Wyden Bill) identified 23 potential safety issues after reviewing tank farm facilities, operations, anomalies and investigations (Public Law 101-510, 1990). These issues range from episodic flammable gas releases to aging facilities. The 23 potential safety issues were categorized as Priority 1, 2, and 3 issues. The prioritization process identified four Priority 1 safety issues, thirteen Priority 2 safety issues, and six Priority 3 safety issues.

The four Priority 1 safety issues were found to affect 53 Hanford waste tanks (48 SSTs and 5 DSTs) now known as Watch List Tanks. These 53 tanks are undergoing extensive scrutiny through inspection, analysis, and documentation review to identify the full scope of the potential safety issues and the most effective methods for stabilization and mitigation/remediation of the potential threat to safety (Babad et al. 1991, Cash and Thurman, 1991, and Hill and Babad 1991).

The remaining 124 Hanford waste tanks (101 SSTs and 23 DSTs) are affected by one or more of the nineteen Priority 2 and 3 safety issues. These safety issues will be closed by upgrading Tank Farm equipment and documentation, further evaluation and remediation, or simply providing positive verification of current information.

The Tank Farms Project has been identified as the lead organization for fifteen of the nineteen Priority 2 and 3 safety issues (Gasper and Reep 1991). To be resolved, these safety issues require continuous operational monitoring or administrative and physical upgrades.

Priority 2 and 3 Safety Issues for Tank Farms Project Lead

- Inadequate safety documentation
- Maintenance and upgrade of tank farm facilities and equipment
- Inadequate SST leak detection systems
- Instrument upgrades in SSTs and DSTs
- SST emergency pumping
- Leaking S-302-A Catch Tank
- Tank toxic vapor releases
- Improvement in conduct of operations
- Lack of plant essential drawings
- DST space requirements
- Response to a leaking DST
- Transfer line concrete encasement integrity and secondary containment compliance
- AZ Tank Farm ventilation line
- Sealing of SSTs to prevent intrusions
- Improved leak detection in DSTs.

The Waste Tank Safety organization is identified as the lead organization for the remaining four priority 2 and 3 safety issues because these issues require some evaluation and analysis before mitigation/remediation can begin (Gasper and Reep, 1991).

Priority 2 and 3 Safety Issues for Waste Tank Safety Lead

- Insufficient tank contents characterization to support evaluation
- Tank safe operating life
- Excessive hydroxide consumption in Tank 107-AN
- Intertank ventilation nnections.

The Wyden bill (Public Law 101-510, Section 3137, 1990) also identified specific requirements for management of the affected tanks. These requirements include continuous monitoring of the tanks to detect a release of excessive temperature or pressure and developing action plans to respond to excessive temperature or pressure or a release. This bill also required that no additions be made to the affected tanks without the Secretary of Energy's prior approval and that the Secretary of Energy submit a report to Congress on the actions taken to promote tank safety.

The Westinghouse Hanford Company (Westinghouse Hanford) immediately stopped high level waste transfers to the watch list tanks by physically isolating transfer lines into SSTs and ensuring that DSTs transfer lines are 'Locked and Tagged' out of service. Once the watch list tanks were isolated, Westinghouse Hanford began a parallel path of developing action plans and reorganizing the division.

Action plans have been developed to address abnormal conditions in tanks that contain flammable gasses (Thurman 1991), and abnormal conditions in tanks containing ferrocyanide (Cash and Thurman). These action plans identify planned responses to potential abnormal events in all of the watch list tanks. Action strategies currently are being developed to address responses to excessive temperature and pressure in high heat tanks and abnormal conditions in tanks with high organic content or high hydroxide ion concentration.

In order to change the day-to-day operation of the Tank Farms and simultaneously address the difficult technical issues raised by the 23 safety issues, the Waste Tank Safety, Operations, and Remediation Division (WT) was formed from the organizations that previously had been providing direct and indirect support to the Tank Farms.

The WT technical structure was set up functionally to address the specific technical questions raised by the 23 safety issues. The technical organizations are composed primarily of engineers, scientists, and technicians assigned to tasks associated with mitigation/remediation of specific safety threats.

The WT operational structure was set up as a project with dedicated and matrixed engineering, operations, maintenance, health physics, quality assurance, safety, and training support. This new operational structure was critical to gaining control of all Tank Farms work scope. By being able to work with dedicated resources, priorities can be set internally, the project is assured of having personnel consistency from one Tank Farm task to the next, and the management team can rely on the numbers and types of resources to apply to any given task.

In addition to establishing the Tank Farms organization as project, a Joint Test Group (JTG) was initiated to provide centralized management of test operations in the Tank Farms (Fig. 1). Resolution of the 23 identified safety issues will require substantial testing and sampling of all 177 of the Hanford waste tanks. The JTG will act as a project within the project to assure readiness, proper integration, and performance of activities as delineated in testing and operations plans.

The JTG matrix includes both internal and external organizations under one test director to coordinate technical and programmatic needs from Westinghouse Hanford organizations, Department of Energy Field Offices Richland, Department of Energy-Headquarters, and any other interested parties. The JTG concept of managing Tank Farms testing has

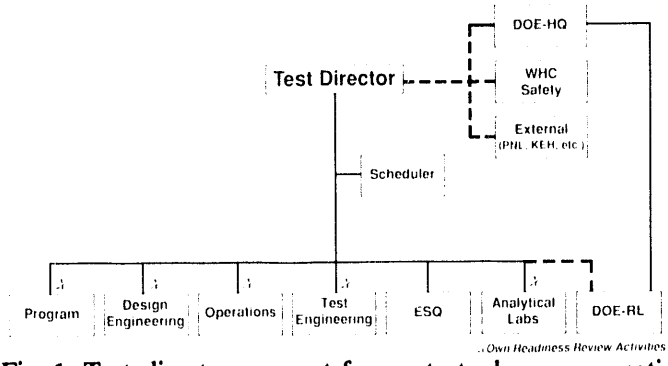


Fig. 1. Test director concept for waste tank programmatic activities.

been successfully demonstrated on the Tank 101-SY safety windows and is being used to begin testing in ferrocyanide tanks.

Both administrative and physical upgrades are necessary to bring the Hanford Site waste tanks into complete control for mitigation/remediation. The administrative upgrades to date have been directed at organizational and cultural changes through direct involvement of individual contributors with the WT management team. These changes have ben introduced through initiatives such as the Operations Advisory Council (OAC) and extensive training for the operational, maintenance, and engineering staffs.

The OAC (Fig. 2) was created to identify, plan, and take corrective actions to improve Tank Farms operations. The OAC is composed of non-management personnel (both bargaining units and staff) who are chartered to identify problem areas and empowered to fix the problems. OAC accomplishments to date include:

- Developing a $144 K PRICE proposal (Cost saving initiative) for eliminating redundant training.
- Acquiring an emergency response vehicle for the 200 West area.
- Revising the Industrial Safety Manual (WHC-CM-4-3, Vol. 3).
- Reducing the number of Engineering Change Notices required to repair equipment.
- Involving Health Physics Technicians in radiological and safety planning to reduce number of suspended work packages.
- Replacing A and AN Tank Farms vent pit ladders to reduce potential industrial safety hazard.

Physical upgrades to date have been focused on instrumentation upgrades on tank 101-SY during the safety windows to better understand the hydrogen gas generation taking

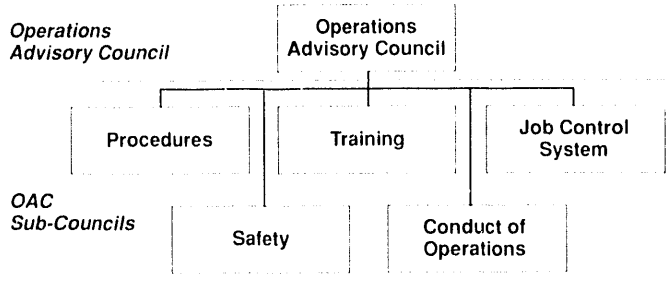


Fig. 2. Operations Advisory Council Chart.

place in the tank. Future physical upgrades will concentrate on Instrumentation & Control systems, Configuration Control systems, Major Maintenance, Capital Equipment, and Contamination Zone Reduction (Henderson 1991). Physical upgrades to the Tank Farms facilities have been planned to support controlled, responsible operation of the Tank Farms through to site closure.

As the organizational and cultural changes introduced over the past year become a way of doing business in the Tank Farms and the physical upgrades give the Tank Farms staff the necessary tools to work with, operation of the Hanford Site waste tanks will be brought under control and the 23 identified safety issues will be resolved. As the safety issues are resolved work can be focused on final remediation of the wastes stored in the Hanford Site waste tanks and eventual closure of the Hanford Site.

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EXTENDED TANK USE ANALYSIS

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ABSTRACT

The single-shell tanks at the Hanford Site were originally designed for "temporary" use. The newer double-shell tanks were designed for 50 years of use. A number of single-shell tanks failed their original design criteria to contain liquid waste soon after they were constructed. These single-shell and double-shell tanks now will be required to contain semi-solid high-activity waste well beyond their design lives. It must be determined that the waste contained in these tanks will remain stable for up to an additional 30 years of storage. This paper describes the challenge of demonstrating that the tanks that have exceeded or will exceed their design lifetime can safely store high-level waste until planned disposal actions are taken. Considerations will include structural and chemical analyses.

INTRODUCTION

The bulk of the single-shell waste tanks at the Hanford Site were built in the 1940's and early 1950's. The oldest of the more modern double-shell tanks (DST) were built in 1968. The waste contained in the tanks will remain in the tanks for some time. The date set in the Tri-Party Agreement (1) for disposal of the DST wastes is the year 2018. Depending on decisions related to disposal of waste in older single-shell tanks (SST), the DSTs could be used for staging SST waste and may be used for more than 50 years.

How a structure is determined to be acceptable for long-term storage and what acceptance criteria must be used will be addressed by a waste tank structural analysis program over the next 5 years.

Figure 1 shows the waste tank timeline and the requirements, codes, and seismic criteria in place at the time. Tables I and II provide additional details. All of the tanks on the Hanford Site were built before the advent of the recent seismic criteria (2). Most tanks have received some type of structural analysis, usually a post-construction evaluation.

Figure 2 is a logic diagram showing the steps necessary to evaluate the structure of the tanks. The first step (and one of the more difficult steps) is to determine what is "acceptable." It is difficult to determine what is acceptable for a 46-year-old facility that was built before modern quality control methods were in place and that presently does not contain liquids yet still contains very hazardous wastes. The old data and analyses must be reviewed, inspection requirements defined to obtain necessary in situ properties, and historic and projected loads and acceptance criteria determined.

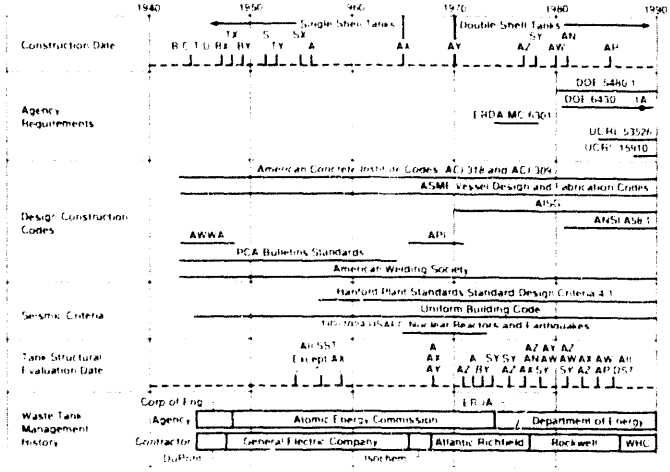


Fig. 1. Hanford waste tank design and construction timeline.

It is difficult to obtain the old operating and construction data. A number of SSTs have been exposed to elevated temperatures above the original design specification values. Earlier analyses indicated that thermal loads, especially temperature cycling, had the most impact on the tank structure. An extensive review of past thermal history records was completed in the early 1980's. Information on waste tank temperatures prior to 1974 was not documented or stored in a consistent and retrievable manner; hence, much thermal data are now irretrievably lost. The data that were recovered are now formally documented (3). No data prior to 1952 are available. Significant data prior to 1974 was obtained only for 4 of the 12 SST farms (241-S, -SX, -A, and -AX). The other (older) SST farms primarily received waste resulting from the bismuth-phosphate process. The process produced more dilute, low heat-generating waste with resultant tank temperatures at or below 200°F; maximum temperatures ranged from 120 F to 140°F. Since 1974, tank temperature data have been collected and stored using the Computer Automated Surveillance System for all DSTs and 68 of the 149 SSTs.

The records showed that only five SSTs had waste (not necessarily the concrete) that exceeded 350°F. These SSTs include the following.

SST	Maximum temperature	Present leak status
241-A-101	399°F	Sound (no leak detected to date)
241-A-106	594°F	Sound
241-A-104	430°F	Leaker
241-A-102	420°F	Sound
241-SX-107	390°F	Leaker

Tank 241-A-106 reached the highest temperature; in addition, it was at the very elevated temperatures the longest and was exposed to a number of temperature cycles. Other SSTs have been exposed to temperatures between 250 and 350°F. The effects of the temperature on the tanks were studied in the early 1980's (4,5). The studies included extensive laboratory simulations (6), analytical modeling, and physical

TABLE I

Single-Shell Tank Design Data

Tank/farm constr. completion 241	Project number	Hanford spec.	Steel liner tank (ASTM)	Steel design code	Reinforced concrete			Welding spec.	Rebar spec. (ASTM)	Seismic criteria
					Spec.	Prop.(ksi)*				
						f'c	fy			
B\C\T\U/1944	9536	HWS-1946	A7-39	AWA	PCA joint committee	3.0	40.0		A-15-39	
BX/1947			A7-39	AWA		3.0			A15-39	
TX/1948	C-163	HWS-3061	A285-46	AWA/API-ASME		3.0			A15-39	
BY/1949	C-271	HWS-3783	A283-46T or A285-46	ASME VIII '46	ACI-613 '44	3.0	33.0		A15-39 or A16-35	
S/1951	C-187-D	HWS-4038	A283-46T			3.0	40.0		A15-39	
TY/1952	C-148	HWS-4696 HWS-4585	A283-49T	ASME VIII '46		3.0			A15-39	
SX/1954	CA-539	HWS-4957	A283-52T	----------	---------	3.0	40.0		A15-50T	
A/1955	CA-513-1A	HWS-5614 HWS-4799-S	A283-52T A285-52AT	----------	---------	3.0	40.0		A15-50T	
AX/1964	CAC-945	HWS-8237 HWS-4798-S	A201 GR. A	ASME VIII '62	---------	3.0	40.0		A15-58T	UBC Zone 2

*All properties are "nominal" values.
ACI = American Concrete Association.
API = American Petroleum Institute.
ASME = American Society of Mechanical Engineers.
ASTM = American Society of Testing and Materials.
HWS = Hanford Works Specification.
PCA = Portland Cement Association.
UBC = Uniform Building Code.

TABLE II

Double-Shell Tank Design Data

Tank/farm constr. completion 241	Project number	Hanford spec.	Steel liner tank (ASTM)	Steel design code	Reinforced concrete			Welding spec.	Rebar spec. (ASTM)	Seismic criteria
					Spec.	Prop.(ksi)**				
						f'c	fy			
AY/1970	IAP-614	HWS-7789 HWS-7791	A515-65 GR. 60	ASME VIII DIV 2 '65	ACI-318 '63	3.0	60.0		A432	UBC '67
AZ/1977	HAP-647	HWS-8982 HWS-8985	A516-73 GR. 60	ASME '68	ACI-318 '63	3.0	60.0		A615 '68	.25G (H) .17G (V) TID-7024
SY/1978	B-101	B-101-C1, C2,C3,P5	A516-65 GR. 65	ASME '71	ACI-318 '71	4.5 3.0*	60.0	AWS D12.1	A615 '72	SDC 4.1 TID-7024
AW/1980	B-120	B-120-D1, C1 to C7	A537-75 CLI GR. 50	ASME VIII DIV 2	ACI-318 '71	5.0 4.5 FDN.	60.0	AWS D12.1	A615 '76A	SDC 4.1 .25G (H) .17G (V) TID-7024
AN/1981	B-130	B-130-D1, C1 to C7	A537-75 CL 1	ASME VIII '71	ACI-318 '71	5.0	60.0	AWS D12.1 '75	A615 '76A	SDC 4.1 .25G (H) .17G (V) TID-7024
AP/1986	B-340	B-340-D1, C1 to C7, C9	A537 CL 1	ASME VIII DIV 2 '80	ACI-349 '76 ACI-318 FDN.	5.0	60.0	AWS D1.4 '79	A615 '81A	SDC 4.1 Rev. 7 .25G (H) .17G (V) TID-7024

*Basemat concrete.
**All properties are "nominal" value.
ACI = American Concrete Association.
ASME = American Society of Mechanical Engineers.
AWS = American Welding Society.
HWS = Hanford Works Specification.

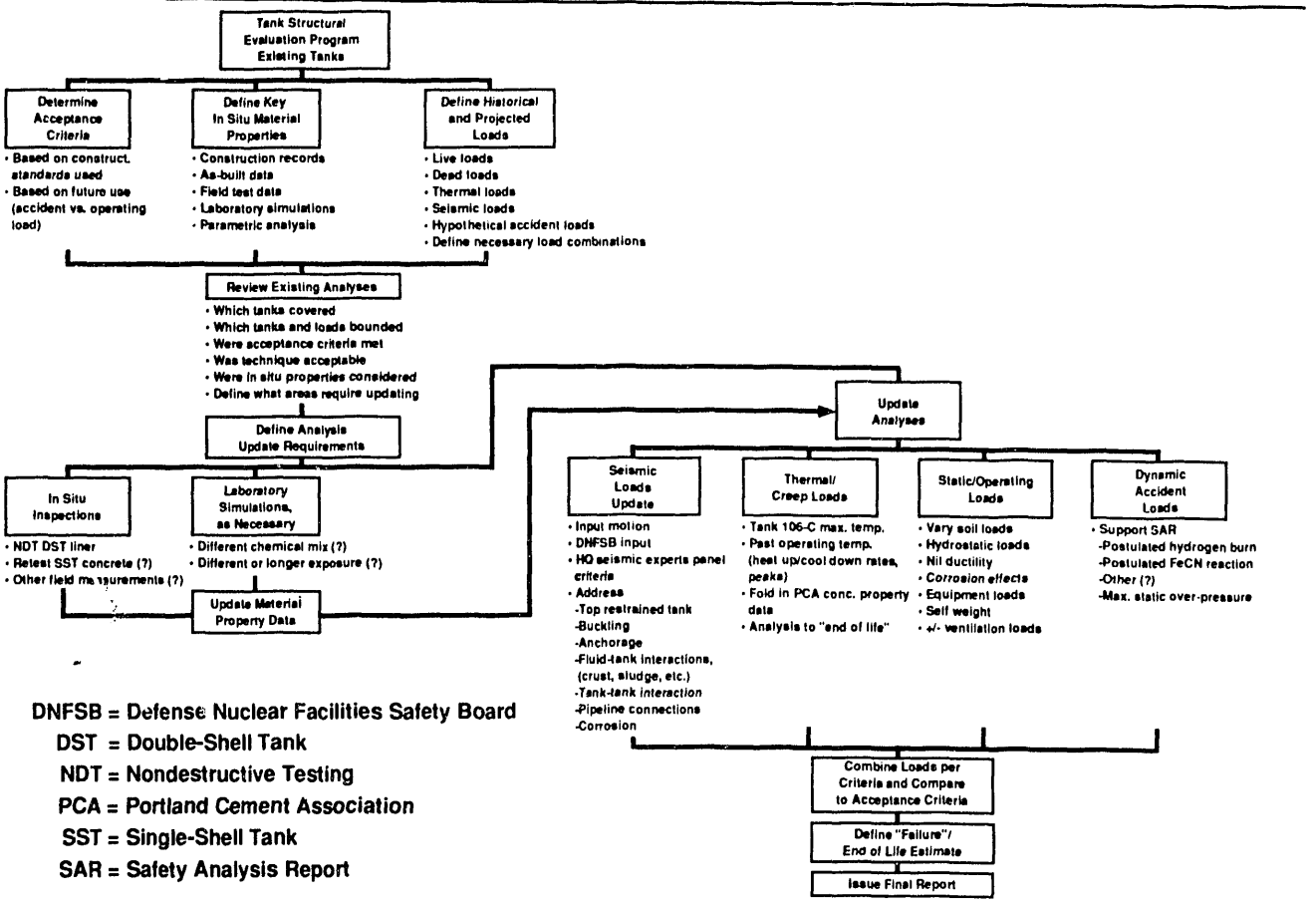


Fig. 2. Flow chart of tank structural evaluation activities.

sampling of tank concrete. Results, particularly from the sampling, indicated that the effects of temperature were not as great as the earlier computer simulations had indicated. It was also noted that the construction variations (i.e., different pour mixes of concrete) appeared to mask any changes in concrete material property that may have occurred because of temperature. The reviews concluded that there appeared to be no evidence of long-term impacts to the waste tanks because of the short-term temperature peaks in the 1950's and 1960's.

Seven design analysis reports and available backup data pertaining to one SST farm and three DST farms were recently subjected to an in-depth peer review. These reports addressed the as-designed tank configuration but did not address the in situ conditions and potential effects on tank integrity and concluded that the historical analyses represented state-of-the-art methods generally used at the time of the reports. The loading conditions adhered to the current national codes and standards. Because state-of-the-art techniques and knowledge of structures have improved over the last 5 to 10 years, the work is not complete. However, the analyses indicate that a reasonable amount of time can be taken to evaluate material properties, ensure proper future loads, and decide upon criteria before incurring inordinate computer costs for numerical modeling.

Determining the present in situ material properties is the highest priority because this can be a long lead item, particularly if special equipment or procedures are required. The concrete properties of the haunch, wall, and footing area of the SST (Fig. 3) will require special attention. A sample of the haunch, wall, and footing of a SST was taken in the early 1980's, and the results were compared to laboratory simulations and other concrete samples. At that time, variations between construction pours appeared to mask the effects of any temperature or waste exposure.

The Resource Conservation and Recovery Act of 1976 (RCRA) (7) includes extensive inspection requirements for DSTs. It is likely that additional requirements will not be needed; this will be formally evaluated in fiscal year 1991. Parametric studies are being performed to guide the inspection requirements by determining the areas and material properties of interest and defining the approximate accuracy needed. Aspects will include, but will not be limited to, weld

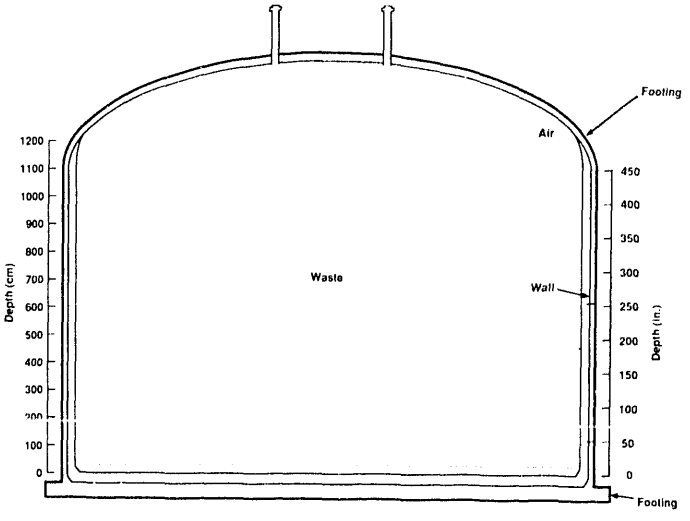


Fig. 3. Typical tank cross section.

inspections for potential cracking, liner general thickness, concrete properties, and rebar bonding.

Defining the past and present structural and thermal loads and the acceptance criteria is another initial key requirement. The projected loads will be relatively straightforward, but as previously mentioned, earlier loads may have to be approximated. The acceptance criteria will require more attention. The modern criteria used to determine acceptability of a new design are based on modern construction and quality control techniques and may not be appropriate or acceptable for tanks built in the 1940's and 1950's. Also for DSTs one criteria of "failure" is the inability to hold liquids. Of the 149 SSTs, 66 have already leaked. The free liquids in the old SSTs have been pumped to DSTs, and the SSTs are being evaluated under RCRA 3004(u) (7) for final disposition. "Failure" for SSTs may be the inability to support cleanup work or to structurally remain intact during a safe shutdown earthquake. This is a key definition that needs to be documented and subjected to peer review before expensive structural computer simulations begin.

Structural analyses will be updated as required to meet the new DOE standards through this program. This will support future updates to the safety analysis reports, as will analyses of structural response to hypothetical accident conditions. The accident conditions and in situ effects structural analysis results will be compiled to support tank lifetime assessment. This activity will include the following.

- Beyond-Design-Base Accident Dynamic Analyses

  Structural analyses will be performed to characterize tank dynamic response to accident conditions such as the hydrogen burn and ferrocyanide explosion events for the various tank designs as appropriate.
- Tank Life Expectancy Analyses

  The tank life expectancy analysis task is a multiyear activity that is intended to provide tank reasonable-lifetime estimates for either specific tanks or unique tank groups. Structural analyses will be performed, and the results will be applied to support tank life expectancy estimates.

SUMMARY

The task of evaluating the SSTs was undertaken in the early 1980's. Evaluating the SSTs requires periodic reviews and updates using updated material properties and analytical techniques. Inspections to determine the in situ material properties along with comparison to past operation loads to estimate the projected degradation, if any, are key to assessing the tank life expectancy.

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DEVELOPMENT OF TANK INSTRUMENTATION--THE SEARCH FOR APPROPRIATE MONITORING

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ABSTRACT

In the past, data on waste tanks at the Hanford Site was collected and stored. The type and amount of data needing to be collected is growing exponentially. The present challenge is to collect the more detailed and varied data while keeping costs low. More sensitive and extensive surveillance and monitoring instrumentation must be installed, data must be collected and made available to staff in a form that maximizes retrievability and ease of interpretation, and the data management process must accommodate real time trending, meet data quality objectives and generally conform to best management practices. Surveillance and monitoring needs for waste tank safety and operations will be described. Current strategies to meet these needs will be outlined and recent progress summarized.

INTRODUCTION

For over 40 years the 177 high-level waste tanks containing Hanford Site's nuclear processing wastes have operated without significant safety events. The processes being monitored and controlled were seen as slow acting and well understood. Of primary concern were the following:

- Heat of radioactive decay
- Containment
- Inventory
- Interstitial liquid level.

The methods and equipment used for surveillance purposes did not need to be particularly sophisticated, so they remained unchanged for many years.

In 1990, in response to unresolved waste tank safety issues, a major effort was focussed on providing the methods and equipment necessary to resolve these problems (1). The challenge was to devise and provide instrumentation to support a range of functions from detection and surveillance, to identification, characterization, and mitigation (2).

DISCUSSION

With the activities focussed on resolving safety issues, a plan of action was established as follows:

- Identify parameters to be measured
- Select candidate technologies for laboratory demonstration and feature tests
- Modify methods and equipment to operate a waste tank's environment
- Modify for extended remote operations
- Qualify the system and components for safe and reliable operations
- Deploy in waste tanks.

With the monitoring technology scope limited to tank safety issues, the following were targeted as near term needs:

- Tank contents and distribution (physical and chemical)
- Operational Parameters
- Tank Integrity Assessment.

Tables I, II, III, and IV list the parameters of interest.

In response to the identified needs, specific methods and equipment were selected and expedited as candidates for meeting the needs. Table V identifies and provides a status of these methods.

A comparison of data from the "old" surface level sensors [manual tape and the commercial Food Industry Corporation (FIC) gage] and the "new" surface level sensor (radar gage) is illustrated in Fig. 1. In addition to the improved data quality, the data acquisition is now automated. This will enabling future level sensing data requirements to be more easily met.

Some of the candidate methods and equipment have been demonstrated as viable candidates for laboratory demonstrations. The next question is "will it survive and operate in the hostile tank environment?". Tables VI and VII are illustrative of the hostility of a typical tank's environment.

Of the candidate that shows promise, selected methods (Table VIII) are being pursued.

Although significant progress has been made, a large number of issues remain before most of the candidate systems can be deployable. The step from the feature tests in simulated environments to actual deployment and use must include the requirements in Table IX, as well as all of the required safety assessment, and readiness reviews.

CONCLUSION

To provide adequate monitoring for Hanford Site waste tanks, an initial set of needed measurements have been identified and some candidate methods and equipment have been selected for hardening and feature testing. In general, the supporting data acquisition methods and equipment are being evaluated and enhanced. And finally, the entire instrumentation upgrade program is proceeding with a well defined program plan.

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TABLE I

Physical Parameters

- Sheer stress
- Viscosity
- Compressive strength
- Abrasiveness
- Particle size
- Density
- Thermal conductivity
- Permeability

TABLE II

Chemical Parameters

- Hydrogen
- Total organic carbon
- Nitrate/nitrite
- Ferro/ferricyanide
- pH/caustic
- Nitrogen oxides
- Carbonate/caustic
- Redox potential
- Toxic gases
- Water content

TABLE III

Operational Parameters

- Pressure
- Temperature
- Gas flow
- Surface level
- Humidity

TABLE IV

Tank Integrity Assessment

- Wall thickness
- Corrosion rates
- Structural strength
- Leak detection

TABLE V

Candidate Methods

Function	"Old" method	"New" method	Status
Level sensor	Manual tape FIC gage	Radar gage	Installed
Differential pressure	Analog readout	Redundant sensors Digital readout	Installed
Gas monitor	Teledyne H_2 sensor in exhaust header	Hydrogen sensor, mass spectrometer Three level sampling probe	Installed
Volumetric temperature	Fixed thermocouple "tree"	Multifunction instrument tree	Initial design
Surface temperature	None	Infrared scanner	Initial design
Video monitor	None	Inerted insert and lighting	Installed
FeCN Watch List Tanks			
Continuous temperature monitor alarm system	Manual with local operator	On-line, digital, and networked	Operational September 1991 for five tanks
High heat waste tank DAS (241-C-105 and 241-C-106)	None	On-line, digital and networked	Operational June 1992

FIC = Food Industry Corporation.

TABLE VI

Hostile Tank Environment

Temperature	105 to 145°F (41 - 63°C)
Pressure	-2.5 inches (typical) to +1 inches H_2O
Waste volume	~1 million gallons
Radiation flux	~300 to 700 rad/h
Relative humidity	38 to 100%
Crust thickness	Estimated 4 to 48 inches thick
Specific gravity	1.2 to 1.7

TABLE VII

Chemical Environment of a Typical Tank

Sodium	7 - 16*
Nitrate	1.5 - 3.0*
Nitrite	1.3 - 3.4*
Hydroxide	1.2 - 2.7*
Aluminum	0.7 - 2.5*
Carbonate	0.2 - 0.5*
Chloride	0.2 - 0.4*
Phosphate	0.06 - 0.2*
Sulfate	0.03*
Total organic carbon	9 - 25 g/L
Strontium-89/90	6×10^3 - 7×10^5 μCi/L
Technetium-99	9×10^1 - 2×10^2 μCi/L
Cesium-137	3×10^5 - 7×10^5 μCi/L
Plutonium-239/240	8×10^0 - 8×10^1 μCi/L

*Concentrations in molarity unless otherwise noted.

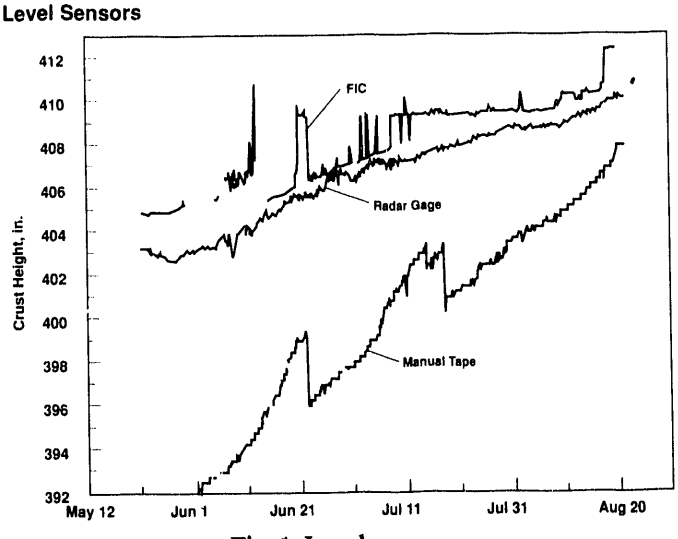


Fig. 1. Level sensors.

TABLE VIII

Candidate Methods/Technologies
(Outside of the Hanford Site)

- Raman spectroscopy for ferrocyanide detection - Florida State University
- Remote Fourier Transfer Infrared for chemical species identification - Jet Propulsion Laboratory
- Fiber optic sensors for physical and chemical sensing - Science and Engineering Association, University of Washington (CPAC)
- Neutronics for moisture detection - Massachusetts Institute of Technology, Lawrence Livermore National Laboratory
- Acoustic methods for bubble detection and mitigation - Massachusetts Institute of Technology, Los Alamos National Laboratory
- Seismic methods for strata identification - Massachusetts Institute of Technology, Los Alamos National Laboratory

TABLE IX

Additional Requirements and Constraints

- In situ measurements
- Limited access
- Maintain radiological barriers
- Remote operation
- Chemically hostile environment
- Radiologically hostile
- Extended survivability
- Replaceable and upgradeable
- In-place calibration
- Verifiable and traceable accuracy

A RISK COMPUTATION MODEL FOR ENVIRONMENTAL RESTORATION ACTIVITIES

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ABSTRACT

A risk computation model useful in environmental restoration activities was developed for the U.S. Department of Energy (DOE). This model, the Multimedia Environmental Pollutant Assessment System (MEPAS), can be used to evaluate effects of potential exposures over a broad range of regulatory issues including radioactive carcinogenic, nonradioactive carcinogenic, and noncarcinogenic effects.

MEPAS integrates risk computation components. Release, transport, dispersion, deposition, exposure, and uptake computations are linked in a single system for evaluation of air, surface water, ground water, and overland flow transport. MEPAS uses standard computation approaches. Whenever available and appropriate, U.S. Environmental Protection Agency guidance and models were used to facilitate compatibility and acceptance.

MEPAS is a computational tool that can be used at several phases of an environmental restoration effort. At a preliminary stage in problem characterization, potential problems can be prioritized. As more data become available, MEPAS can provide an estimate of baseline risks or evaluate environmental monitoring data. In the feasibility stage, MEPAS can compute risk from alternative remedies. However, MEPAS is not designed to replace a detailed risk assessment of the selected remedy. For major problems, it will be appropriate to use a more detailed risk computation tool for a detailed, site-specific evaluation of the selected remedy.

INTRODUCTION

Remedial action activities covered under the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) include consideration of environmental and health risks. In the early stages of these efforts, a risk baseline must be defined. To select a remedial action, candidate remedies are compared in terms of their expected reduction of long-term risks, short-term occupational and public health risks, and potential risks if the remedy fails. Both current and possible future land uses are considered for the long-term risks.

Computation models play an important role in the risk assessment process. A baseline risk assessment, based on modeling impacts using preliminary site characterization data, can provide direction to environmental monitoring programs. Risk computation models provide a means of evaluating impacts of future land-use and remedy-failure scenarios. To fit a need for one type of risk computation model, the Multimedia Environmental Pollutant Assessment System (MEPAS) was developed for the U.S. Department of Energy (DOE). This paper describes the risk assessment process for environmental restoration and the role of MEPAS in that process.

As part of the environmental restoration activities at DOE sites, risk assessments must be conducted to determine potential environmental and human health impacts. This assessment of risk involves a number of concurrent efforts aimed at defining a level of risk for an activity.

A formal risk assessment refers to the process of defining risk levels associated with an activity. In addition to risk computations, a risk assessment can include site inspections; monitoring or measurement to better define release, transport, and exposure parameters; surveys to define usage rates and exposure pathways; and epidemiological studies. Risk computation may be viewed as an integration step in risk assessment, in which all of the information collected to date is combined to provide a quantitative estimate of risk.

The risks evaluated in a risk assessment for an environmental restoration activity can be logically divided into three groups: baseline, during remediation, and after remediation. The baseline and after- remediation impacts are evaluated as long-term chronic risks. The during-remediation impacts are evaluated as both long-term chronic and short-term acute risks.

The risks to the public are normally considered either as maximum individual or population risks. Depending on the model, the modeling assumptions, and the toxicity assumptions, the estimated risks will have varying degrees of conservatism.

RISK COMPUTATION MODELS

The MEPAS risk computation model is one of a wide range of models currently used to make risk-related decisions related to environmental restoration activities at sites contaminated with hazardous wastes. Fig. 1 shows the relationships among different models relative to data requirements and uncertainty in estimated risk levels.

Screening Models

Screening models are used to determine whether a particular situation at a particular site should be considered as a potential problem. These models use general site information for input. Using either a value-based logic system or a very conservative physical model, a situation is defined as being either a possible problem or a nonproblem. The outputs from these models are normally inappropriate for relative ranking of problems.

The Hazard Ranking System (HRS) model as promulgated by the U.S. Environmental Protection Agency (EPA) is a screening model (1). An HRS score is computed for a site; if the score is above a defined value, the site is placed on the

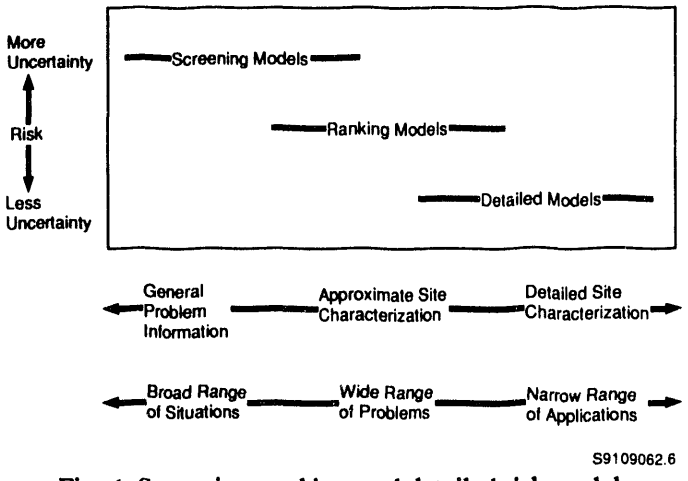


Fig. 1. Screening, ranking, and detailed risk models.

National Priority List (NPL). Consistent with this stage of problem characterization, EPA clearly states that the HRS score is not designed to rank the relative importance of problems.

Detailed Models

At the other extreme, detailed models are used to assess the levels of risk associated with relatively well-defined problems. Models for detailed analysis tend to focus on special sets of problems and special types of situations. The EPA provides separate models for different regulatory issues such as air emission evaluation, ground-water transport, nonradioactive exposure assessment, and radioactive exposure assessment. The U.S. Nuclear Regulatory Commission (NRC) provides a similar set of models for evaluating releases from commercial nuclear power plants. In addition, many of the major DOE facilities have site-specific models for assessing public exposures from radioactive material releases.

Although each of these detailed assessment tools is appropriate for its intended application, extension beyond the intended application is often either difficult or even inappropriate. For example, a detailed exposure model developed for an arid site cannot be expected to be necessarily applicable to a non-arid site, and vice-versa.

Ranking Models

Between the screening and detailed models, ranking models (also referred to as prioritization models) are used to assess the relative importance of problems. Ranking and detailed models are mainly distinguished by the level of generality and the detail of required site-specific data. Often the same models can be applied for both ranking and detailed analysis.

A model for a ranking analysis must be able to handle the application-specific range of problems and situations. To be useful as a ranking model over a range of environmental restoration activities, a model must be able to consider a broad range of problems and potential impacts. The results are typically used to prioritize between problems or between competing aspects of a single problem. Reflecting data input and model limitations, results of these applications are used for relative comparisons over broad ranges of impacts.

The EPA provides a number of models that could be used in ranking applications. The EPA models range from screening guidance for preliminary conservative assessments to formal, documented computer models. The application guidance for these models is to use progressively more realistic assumptions and more detailed models to obtain better estimates of risk.

The subject model of this paper, MEPAS, was developed by DOE to estimate public health risks for ranking applications covering a broad range of regulatory issues (2). MEPAS was designed so that application was possible across a range of DOE sites at various stages of site characterization.

MULTIMEDIA ENVIRONMENTAL POLLUTANT ASSESSMENT SYSTEM (MEPAS)

MEPAS is a multimedia environmental assessment system that starts with contaminant releases and simulates the movement of contaminants though major transport pathways to human exposure routes. MEPAS provides estimates of human health impacts though air, water, and direct exposure routes. Model outputs include environmental concentrations, health impact parameters, and related parameters.

This section provides a brief description of the MEPAS methodology. More detailed descriptions of the MEPAS formulations are given by Droppo et al. (3) and Whelan et al. (4).

Approach

MEPAS is designed for ranking problems over a broad range of applications. Exposures and resultant health impacts are computed based on environmental concentrations at the receptor locations. The mathematical algorithms in MEPAS are based on standard approaches for modeling releases, transport and dispersion, and health impacts in atmospheric, ground water, surface water, and overland transport media. Inhalation, ingestion, direct contact, and direct exposure pathways are included in the health impact component. The interaction and coupling among the transport pathways and the exposure assessment component of MEPAS are illustrated in Fig. 2.

To reduce the number of required inputs and standardize the values used for certain non-site-specific parameters, a MEPAS constituent database was developed (5). This MEPAS database contains toxicity data, transfer factors, chemical and physical constants, and other relevant constituent data. Toxicity data are based on EPA IRIS data whenever possible, with other references and estimation methods used only to supplement EPA data.

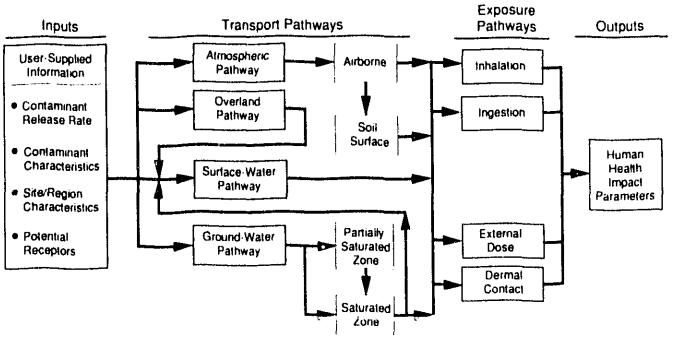


Fig. 2. MEPAS transport and exposure pathways.

Human Health Impacts

The human health impacts are computed by MEPAS and expressed in terms of regulatory-based risk factors. MEPAS considers three types of constituent impacts: radioactive carcinogenic, chemical carcinogenic, and noncarcinogenic constituents.

The computation of risk factors uses regulatory levels based on protection of public health from harmful exposures to a constituent. Carcinogenic risk factors are based on increased cancer incidence. Noncarcinogenic risk factors are based on acceptable daily intakes for the chemicals of concern based on EPA guidance.

The risk factor for carcinogenic effects from radionuclides is calculated assuming low-level exposure over the lifetime of an individual. The risk factor is equal to the product of the computed individual lifetime dose and the health effects conversion factor.

Chemical carcinogenic risk factors are defined for ingestion and inhalation exposure routes that are estimated from cancer potency factors (primarily developed by the EPA). These cancer potency factors relate the daily intake per unit body mass averaged over an individual's lifetime to the risk of developing cancer.

For noncarcinogenic impacts, EPA (6) defines the chronic reference dose (RfD) as an estimate or reference dose "of an exposure level for the human population, including sensitive subpopulations, that is likely to be without an appreciable risk of deleterious effects during a lifetime." The MEPAS risk factors for noncarcinogenic impacts are the estimated dose divided by the RfD.

Although normally only one type of impact is associated with a given constituent, a constituent can actually have different types of impacts. For example, a few constituents are carcinogenic for one exposure route and noncarcinogenic for another exposure route. Constituents also may be of concern as a result of both their radioactive and their chemical properties.

Environmental Releases

Each of the four primary transport pathways considered by MEPAS (ground water, surface water, overland, and atmospheric) is associated with several environmental release types. Detailed information on these release types may be found in Ref. 7. For the ground water, surface water, and overland pathways, the possible release types are precipitation-driven release rate, known contaminant release rate, and known water concentration at the receptor. The atmospheric transport pathway in MEPAS has three major release types: 1) stack/vent releases, 2) suspension of contaminated soil, and 3) gaseous releases through volatilization.

Implementation

MEPAS is available as a stand-alone system on an IBM PC with a user-friendly shell, allowing problem definition, data entry, and model execution as described by Droppo and Hoopes (8). A hard disk is required for execution, and a math coprocessor is recommended. The MEPAS software requires about 2.5 mb of disk space; additional space is required for application data files. Input, references, and output are stored in computer files.

SELECTED MEPAS APPLICATIONS

MEPAS has been applied to evaluation and comparison of risks from both active and inactive operations. These studies range from a nationwide comparison of DOE problems (9) to single-site constituent rankings (10).

The DOE's Office of Environmental Audit used MEPAS to compute risks for environmental problems identified in DOE's Environmental Survey (2). A preliminary ranking was made of potential environmental problems at 16 DOE defense production facilities (9). Subsequently, problems were ranked at 35 DOE sites using risk-based parameters computed with MEPAS.

The DOE's Office of Environmental Restoration is developing a risk-based Priority System (PS) that provides information to optimize funding decisions. MEPAS is a tool that, depending on the level of data available, can be used for computing risks and risk reductions as input to future applications of the Priority System.

The Remedial Action Assessment System (RAAS), which is being developed by the DOE Office of Environmental Restoration, is a computer tool to help in the selection of a representative list of alternatives in the feasibility stage of EPA's guidance for remediation at CERCLA sites. RAAS will first screen possible technologies for to obtain a candidate list and then will provide attribute information on that list of candidates. The attributes will be based on a subset of EPA's ten attribute criteria (11). To help in this process, MEPAS will be provided as a tool for computing risk for alternative remedies.

SUMMARY AND STATUS

MEPAS is a computational tool that can be used in several phases of an environmental restoration effort. MEPAS can be used to compute potential risks at a preliminary stage in the problem characterization effort. As more data become available, MEPAS can be used to provide an estimate of baseline risk, or to evaluate environmental monitoring data. MEPAS can be used to compute risk from alternative remedies.

A baseline version of MEPAS is complete and available for applications. An extensive set of documentation is available which includes the formulations (3,4), guidance documents (7,12,13), a sensitivity study (14), and a validation report (15).

This version of MEPAS provides detailed intermediate files that list release rates, modeling assumptions, and computed concentrations in various environmental media. The risk output includes the population risk, maximum individual risk, time of arrival and peak exposure at a receptor, and how each exposure pathway contributes to the total risk.

Updates and additions are planned to make MEPAS more effective in environmental restoration applications. A module is being added to allow the determination of the range of risk uncertainty based on input uncertainty (14). Annual risk commitments for the first 100 years will be provided. Other modules for estimating occupational and acute exposures are also being formulated. Based on a suggestion by EPA, an ecological impact evaluation module is being implemented. Several planned updates to the environmental transport modules will increase the applicability of the code.

The exposure computations are being updated to follow recent EPA guidance exactly.

ACKNOWLEDGMENTS

This work was supported by the U.S. Department of Energy (DOE) under Contract DE-AC06-76RLO 1830. Pacific Northwest Laboratory is operated for DOE by Battelle Memorial Institute.

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RELEASE CRITERIA AND PATHWAY ANALYSIS FOR RADIOLOGICAL REMEDIATION

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ABSTRACT

Site-specific activity concentrations were derived for soils contaminated at four different sites with mixed fission products (MFP), or uranium-processing residues, using the Department of Energy (DOE) pathway analysis computer code RESRAD. The concentrations and other radiological parameters, such as limits on background-subtracted gamma exposure rate, were used as the basis to arrive at release criteria for two of the sites. Valid statistical parameters, calculated for the distribution of radiological data obtained from site surveys, were then compared with the criteria to determine releasability or need for further decontamination. For the other two sites, RESRAD has been used as a preremediation planning tool to derive residual material guidelines for uranium.

INTRODUCTION

Release of radioactively contaminated sites for safe and unrestricted future use requires proof that radiological data obtained from the site meet regulatory criteria for such a release. The release criteria are typically a composite of acceptance limits that depend on the radionuclides, the media in which they are present, and on federal and local regulations. In recent years, the DOE has established a pathway analysis model to determine site-specific soil activity concentration guidelines for those radionuclides that do not have generic acceptance limits (1). The pathway analysis computer code developed by the DOE is called RESRAD. Similar efforts have been initiated by the U. S. Nuclear Regulatory Commission (NRC) to develop and use dose-related criteria based on generic pathway analyses (2) instead of simplistic numerical limits on residual radioactivity. This NRC effort is directed toward justifying release of structures at decontaminated facilities while the DOE analysis considers the potential effects of residual radioactivity in soil.

Radiological surveys performed at four sites are reported in this paper. Of the four, two were investigated for old mixed fission products (MFP) (Cs-137 and Sr-90) and the other two for uranium residues. The RESRAD code was used in all cases to determine the soil activity concentration guidelines for these radionuclides. Additional site-specific release criteria were also established and generic regulatory limits were used as appropriate. In what follows, we briefly describe the case histories, the criteria, and use of RESRAD.

BACKGROUND

MFP Cases. Formerly used and adjoining areas of a nuclear test facility in an arid region in Southern California were radiologically surveyed for residual radioactivity. Both structures (buildings) and open sites within the 117-hectare (290-acre) facility were surveyed. The two cases reported here include an isolated storage yard and a side yard adjacent to a building. In both cases, slight contamination of the soil with Cs-137 was measured and contamination with the associated fission product nuclide, Sr-90, was assumed. Following the remedial actions and analysis of data from radiological surveys reported here, residual activity at the two locations was determined to be well below the acceptance limits for release without radiological restrictions.

Uranium Cases. The two cases presented are sites under the DOE's Formerly Utilized Sites Remedial Action Program (FUSRAP), both contaminated with uranium. One site (in western New York) is a 55-hectare (135-acre) currently operating industrial facility where residual contamination remains from uranium ore processing operations carried out between 1942 and 1948 for the Manhattan Engineer District (MED). While processing residues were disposed off-site, uranium contamination currently exists at the site in several discrete areas, including buildings, a parking lot, and both surface and subsurface soils. The other uranium site, located in eastern Tennessee, is an 8-hectare (20-acre) area that is now being developed for industrial use. The site became contaminated when during the 1940s the MED, and subsequently the Atomic Energy Commission, stored uranium ore and ore-processing residues there. The site was radiologically surveyed, decontaminated, and released for unrestricted use in 1972. However, after subsequent surveys by the Tennessee Department of Health and Environment and with the emergence of stricter release criteria, the site was added to FUSRAP and is scheduled for further cleanup under the program. Residual radioactive material guidelines for uranium for planning and decontamination of both these sites were derived using RESRAD.

RELEASE CRITERIA

General. Remedial actions are undertaken with the ultimate objective of protecting public health and safety. Residual radioactivity levels at remediated sites should, therefore, be below certain limits so that a future occupant may use the site without radiological restrictions. Specifying the types of acceptance limits and establishing values, however, depends on numerous factors, some of which are discussed below.

Inspection-oriented numerical limits exist, such as those specified for residual surface contamination and in the NRC Regulatory Guide 1.86. These limits are the most directly applicable, and they facilitate confirmation of the decontamination operation, but they are not necessarily cost effective.

Dose-based limits, using dose conversion factors, such as those being currently investigated by the NRC (2), may be used. These allow greater flexibility in decontamination while achieving protection goals more directly than numerical limits.

Dose-limited pathways analysis, with generic or site-specific parameters, may be used, as provided by RESRAD. This yields the most direct measure of success of the decontamination operation and can be customized to the site by using applicable hydrogeological variables, future-use scenarios, and other relevant parameters.

Further considerations in selecting guidelines and acceptance criteria for remediation are:

1. External Exposure. Limits on dose rates from decontaminated or remediated buildings or sites are specified by agencies such as the NRC or the DOE (3).
2. Affected Media. Maximum release limits may be specified for water, air, and/or soil. For the cases of soil contamination, generic limits are available only for Ra-226 by the DOE and others, and for uranium and thorium by the NRC (4). Site-specific activity concentrations must be established for other radionuclides. For the present work, these were established using RESRAD for the MFP as well as uranium [as required by Ref. (3) for FUSRAP sites] and are the principal subject of discussion in this paper.
3. Federal and Local Regulations. Variations exist in numerical limits established by regulatory authorities. The limits also change from time to time.

Release Criteria for the MFP Locations. Although the DOE guidelines (3) recommend a value of 20 μR/h (at 1 m) above background for gamma exposure rates, a lower value of 5 μR/h above background was chosen for these surveys and was based on a previous NRC stipulation for the unrestricted release of a dismantled test reactor facility in the complex. Also, the 5 μR/h above background corresponds to the recently issued NRC limit of 10 mrem/yr (2000-h occupancy) under NRC's "Below Regulatory Concern" policy (5).

Criteria for residual Cs-137 activity concentration in soils were established for the above cases using the RESRAD code. Combined presence, in equal activity concentrations, of both Cs-137 and Sr-90 was assumed in both cases because of a conservative determination that the incidents leading to the contamination of these sites involved the presence of MFP. Selection of parameters and future-use scenarios employed in the calculations of the activity concentrations are discussed in the next section.

Measured gamma exposure rate and soil activity concentration data were also statistically analyzed with respect to the State of California guidelines (6) to demonstrate compliance. The statistical analysis procedure, known as sampling inspection by variables (7), is widely used in industry and the military. Its application to radiological surveys is described in Ref. (8). It suffices to state here that analysis of the measured data in this manner results in a parameter known as the test statistic (TS). To satisfy the State of California guideline for the MFP sites, it was necessary to demonstrate that the TS values for the gamma exposure rates and the soil activity concentrations were less than the 5 μR/h and the RESRAD-calculated limit, respectively.

Release Criteria for the Uranium Residue Locations. The above-referenced DOE guidelines apply to these FUSRAP sites, including the 100 mrem/yr "basic dose limit" for an individual member of the general public. Similarly, activity concentration guidelines for uranium isotopes and total uranium were calculated for these sites using RESRAD. The generic guideline specified for surface contamination and airborne radon decay product will also be applicable as remediation efforts progress at these sites.

PATHWAY ANALYSIS USING RESRAD

The pathway analysis method provides an estimate of a site-specific or generic radiation dose, subject to certain use conditions (scenarios), depending on whether the calculational parameters are accurate values for the site or are more general (representative) values, respectively. Accurate, site-specific values should be used to the maximum extent practical, for this not only improves the accuracy of the resulting dose but also enhances the acceptability of both the method and the results. As estimated doses approach limiting levels, it is important to use accurate values to ensure credibility of the result and avoid bias.

The RESRAD code is designed for interpretation of situations involving distributed radioactivity in soil and can aid investigations of long-term changes in the site. As described in Ref. 1, RESRAD incorporates considerations of the external radiation, inhalation, and ingestion pathways to exposure from sources in the ground, air, water, and in the food chain. Generic values for the hydrogeological parameters, food, water, and air consumption are provided as "default" inputs for the case of a family farm scenario. In all, there are about 80 input parameters. A library of radionuclides is included in the program.

The default scenario and associated parameters can be used for performing screening evaluation. Based on site characteristics and plausible scenarios for site use, the parameters are then modified. Sensitivity analyses are also performed to identify those parameters that significantly affect the end results, allowing the user to focus on obtaining accurate site-specific values for these parameters.

Based on the site- and scenario-specific inputs thus established, RESRAD can provide the activity concentration in soil for radionuclides identified for the site that would result in an exposure corresponding to the basic dose limit of 100 mrem/yr. Here, the basic dose limit is the input, and the resulting RESRAD-calculated concentration is the limit. In this context, RESRAD can be used as a preremediation planning tool (the uranium residue locations discussed here) where limits on soil concentration are developed and variations in cleanup decisions are tested for "as low as reasonably achievable" (ALARA) considerations. For postremediation cases (the MFP locations), RESRAD provides a means to not only compare the measured soil concentrations with the limit but also to estimate the dose corresponding to the measured concentration (used as input) to demonstrate the effectiveness of the cleanup accomplished by the remediation. If the measured concentration and its extent are less than the limit, the resulting RESRAD-calculated dose will be less than the

basic dose limit, satisfying this acceptance criterion. As discussed below, RESRAD was used in both these modes.

RESRAD PARAMETERS AND RESULTS

MFP Cases. The hydrogeological parameters employed in the MFP cases are nearly identical because they are part of the same complex, located in the arid southwestern United States. These parameters were determined for the complex and used as inputs to RESRAD. As for use scenarios, the sites are integral to ongoing industrial activities, and, thus, the industrial use scenario would currently be appropriate. Other credible future-use scenarios include residential or wilderness, given their proximity to both suburban and recreational locations. For these reasons, the family farm scenario, although used with the default RESRAD dietary and occupancy parameters for screening calculations, is not considered credible.

With site-specific hydrogeological data and modified dietary and occupancy parameters, RESRAD calculations were performed to determine the soil activity concentrations for the combined presence of Cs-137 and Sr-90 for the three credible scenarios. The screening and sensitivity calculations showed that conservative values should be used with regard to the extent of contamination (area and depth), the cover depth, and occupancy/inhalation shielding factors. For this arid region and for these credible scenarios, the results showed the majority of dose contributions are from external exposure pathways, which are determined by these factors. Thus, although the areas and extent of the contamination were relatively small, an "infinite" contamination area and depth were chosen for determining the limits. An area of 100,000 m^2 and a depth of 1 m, as inputs to RESRAD, correspond to the infinite case; that is, the calculated dose remains the same at larger values of these two parameters.

Of the two MFP cases, the storage yard area is smaller than that of the side yard. Therefore, different values were used for the shielding factors associated with occupancy and inhalation. Because of the relatively larger area of the side yard, the residential or industrial occupant would be exposed to more direct external exposures when he or she is outside of the building. For the smaller storage yard, a uniform slab shielding was a more accurate approximation. For the wilderness scenario, however, no shielding was appropriate.

Table I shows the RESRAD-calculated Cs-137 concentration limits for the three credible scenarios, using the infinite extent contamination and the applicable occupancy- and inhalation-shielding factors for the two areas. At both sites, all other variables were nearly identical except for the shielding factors. Reductions in external exposure rates by the uniform slab, assumed for the case of the storage yard, is the cause of the increased values for the limits for the residential and industrial scenarios. Because of the absence of any shielding in the wilderness scenario, the corresponding limits remained nearly the same for both locations.

The lowest value for either site corresponds to the residential scenario. Thus, if the measured concentrations were below this, then the site can be used for all the credible uses; that is, it can be released for unrestricted use. The lowest value is then the limit corresponding to the "credible and bounding" residential scenario.

Data shown in Table I are for the presence of Cs-137 alone. Because of the MFP-related assumption that an equal activity concentration of Sr-90 is also present, corresponding values for this radionuclide were also calculated using RESRAD. For the combined presence of both nuclides, in equal activity concentrations, the resulting acceptance limits for the credible bounding residential scenario were 314 and 60 pCi/g for the storage yard and side yard, respectively.

TABLE I

^{137}Cs-137 Soil Activity Concentration Limits (pCi/g)

Scenario	Limit (pCi/g) Storage Yard	Side Yard
Industrial	2,520	239
Residential	984	71
Wilderness	3,840	3,830

Results of activity concentrations measured from the soil samples collected from the two yards after their remediation can now be compared with the above limits. These are shown in Figs. 1 and 2 for the storage yard and side yard, respectively. Both figures have the measured Cs-137 soil activity concentration values (in pCi/g) on the y-axis and the Gaussian cumulative probability calculated for that distribution of data on the x-axis.

For acceptance, the TS calculated for the data must be below the acceptance limit. In Fig. 1, the TS for the storage yard data is shown at 29.5 pCi/g, which is well below the acceptance limit of 314 pCi/g. Similarly, for the side yard, Fig. 2 shows a TS of 11.7 pCi/g, much lower than the acceptance limit of 60 pCi/g. The data are also within the calculated Gaussian line, showing no significant deviations.

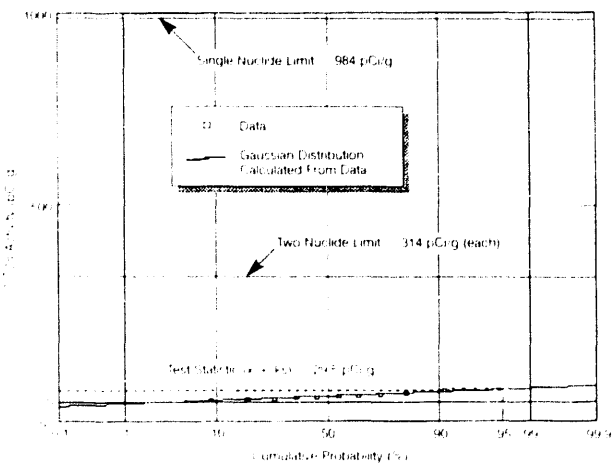


Fig. 1. Measured Cs-137 activity in the storage yard compared with RESRAD-calculated limits.

The average of the data shown for the two yards was also used to estimate, using RESRAD, the annual dose for a hypothetical current resident. In each case, actual areas and conservative estimates of the depth of the soil contamination were used. Results showed annual doses of 0.39 and 5.2 mrem, respectively, for the storage yard and side yard, both well below the 100 mrem basic dose limit.

Recalling that regulatory compliance also required that gamma exposure rates for the two yards be less than 5 μR/h

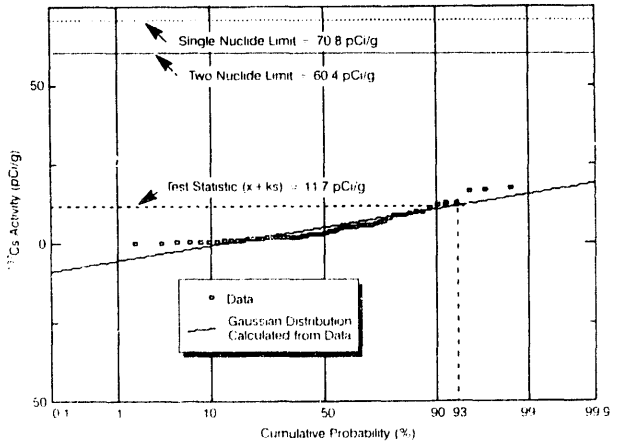


Fig. 2. Measured Cs-137 activity in the side yard compared with RESRAD-calculated limits.

above background, the survey data on these exposure rates were also examined. Statistical plots of the data, collected on gridded locations 1 m above ground, are shown in Figs. 3 and 4 for the side yard before and after remediation, respectively. The ambient exposure rates shown in Fig. 3 are for a larger area covering the side yard before remediation. The average of background data obtained from the nearby unaffected areas is 15.6 μR/h. About a dozen grid points are well above this background and also above the 5 μR/h above-background limit. The number of grid locations with such elevated exposure rates and their magnitudes resulted in the significant departure from the Gaussian line shown for the data. It was indeed from these data, and from preliminary analysis of soils collected from selected locations which showed Cs-137 contamination, that a determination was made to proceed with soil cleanup of the side yard. Data shown in Fig. 4 are from grid locations in the side yard after the cleanup and after subtracting the 15.6 μR/h background. The TS value for this data, 3.6 μR/h, is within the limit. The data also closely follow the Gaussian line in this figure. Similar compliance was

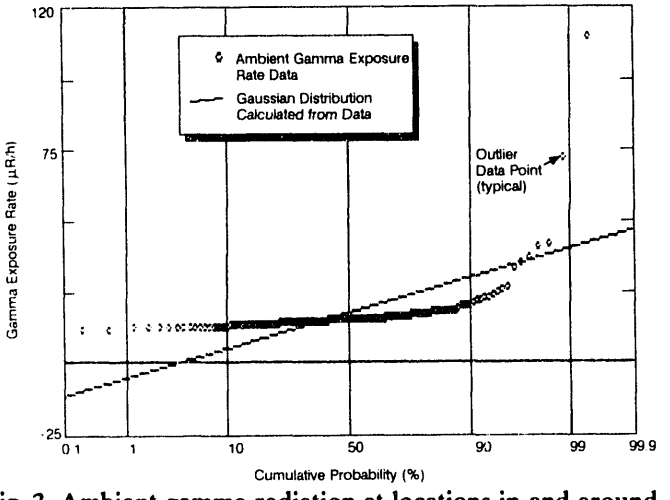


Fig. 3. Ambient gamma radiation at locations in and around the side yard before remediation.

achieved with respect to the storage yard.

Uranium Residue Cases. At the two FUSRAP sites, residual radioactive material guidelines were derived for total uranium and uranium isotopes using site-specific parameters and different scenarios as RESRAD inputs. The guidelines were derived on the basis of meeting the 100 mrem/yr basic

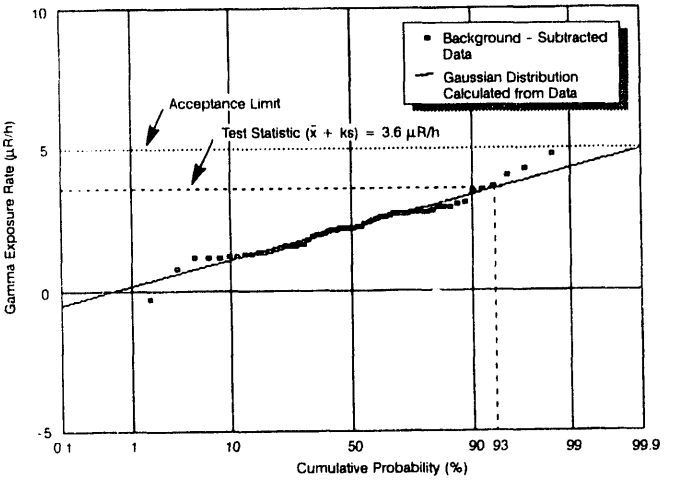


Fig. 4. Background-subtracted gamma exposure rates in the side yard (after remediation) compared with acceptance limit.

dose limit and assuming that U-238, U-234, and U-235 are present in their natural activity ratio of 1:1:0.046. It was also assumed that uranium is the only radionuclide present at an above-background concentration. All scenarios assumed that at some time within 1000 years following decontamination the area is released for use without radiological restrictions. The detailed assumptions and input data are available in Argonne National Laboratory reports (9,10), the results of which are presented here.

Three potential scenarios were considered for the New York site: industrial, residential farm, and recreational. Pond water is assumed to be the only usable water, based on site geological and other considerations (9). The industrial scenario assumes use of the site by a hypothetical worker who spends 2000 h annually (75% outdoor and 25% indoor) at the site and does not ingest any water or food from the site. The residential farm scenario assumes that a hypothetical occupant sets up residence in the immediate vicinity of the site, drinks water from a natural pond downstream of the site, eats plant foods grown there, and consumes meat and milk from livestock raised there. Fish consumption from the pond is also included. The recreational scenario (use as a public park) assumes the user spends 750 h annually at the site but does not consume water or food from the decontaminated site. Of the three scenarios, the industrial use is the most realistic, given current use of the site, and the recreational scenario provides a plausible alternative use. The residential farm scenario, while hypothetically possible, is unlikely but does provide the most restrictive activity concentration guideline corresponding to the basic dose limit.

Potential radiation doses resulting from the RESRAD-identified exposure pathways were considered. The seven pathways are:

1. Direct exposure to external radiation from the decontaminated soil
2. Internal radiation from inhalation of dust
3. Internal radiation from ingestion of plant foods grown at the site and irrigated with water drawn from the down-gradient side of the pond
4. Internal radiation from consumption of meat from livestock fed with fodder grown at the site and water drawn from the pond

5. Internal radiation from consumption of milk from similarly raised livestock
6. Internal radiation from consumption of fish from the pond
7. Internal radiation from drinking water drawn from the pond.

For a specific scenario, only the relevant pathways were considered and others were suppressed in the RESRAD calculations. For example, for the industrial and recreational use scenarios, only pathways 1 and 2 are applicable, whereas for the residential farm scenario, all pathways, 1 through 7, are relevant.

Table II provides the guideline values [in (pCi/g)] for residual radioactivities in the soil for the New York site, calculated by RESRAD that would result in a 100 mrem/yr exposure from the uranium isotopes and total natural uranium.

TABLE II

Residual Radioactive Material Guidelines for New York Site (9)

	Guideline (pCi/g)		
Radionuclide	Industrial Use	Residential Use	Recreational
Uranium-234	2,400	77	5,300
Uranium-235	480	27	1,200
Uranium-238	1,600	83	3,700
Total Uranium	1,800	77	4,200

For the Tennessee site, the industrial and recreational scenarios are similar to those discussed above. The residential farmer scenario has two variations: an adjacent pond provides the source of usable water in one, while the other uses groundwater drawn from a well at the down-gradient edge of the site. The exposure pathways are similar to those described earlier; however, an additional pathway of internal radiation from inhalation of emanating Radon-222 was also included. Again, pathways not relevant to a specific scenario were suppressed in the RESRAD calculations. Table III shows the resulting residual radioactive material guidelines for this site.

When implementing the above derived radionuclide guidelines for decontamination of the site when other nuclides are present, the law of the sum of fractions applies, as was the case for the combined presence of Cs-137 and Sr-90 for the MFP sites discussed earlier. As such, the data shown in Table II for the residential farmer and in Table III for the farmer/well scenarios provide the most restrictive guidelines on residual concentrations of uranium. The decision making on residual concentrations is, however, a complex process where other factors must be considered. These may include interagency agreements and past lower cleanup precedents, as was the case, for example, for the low limit of 5 μR/h above-background gamma exposure rate applied in the MFP sites. Similarly, relevant release criteria on exposure rates, surface contamination levels, and radon levels also need to be satisfied for the two uranium residue sites. For example, reference (11) provides such data and comparisons for the Tennessee site.

TABLE III

Residual Radioactive Material Guidelines for Tennessee Site (10)

	Guideline (pCi/g)			
Radionuclide	Industrial	Recreation	Farmer/ Pond	Farmer/ Well
Uranium-234	2,400	5,400	590	120
Uranium-235	450	1,100	150	47
Uranium-238	1,600	3,600	430	120
Total Uranium	1,800	4,000	470	120

SUMMARY

1. The RESRAD pathway analysis code was used to determine soil activity concentration limits for four sites. Of the four, two are sites remediated for the presence of MFP (Cs-137 and Sr-90) and the other two are sites with uranium ore residues.
2. Site-specific hydrogeological variables were developed and used as inputs to RESRAD in all cases. A variety of credible use scenarios were considered and soil activity concentrations were derived for these scenarios. The lowest of the concentrations determined the credible and bounding scenario.
3. In the remediated MFP sites, the soil activity concentration for the credible and bounding scenario (residential) was used as the acceptance limit for MFP residual radioactivity. The test statistic (TS) calculated from the measured soil activity concentration data at the two sites were well below the limits. Similarly, data on the gamma exposure rates were also found to satisfy the corresponding acceptance limits for the two sites. Therefore, the sites can be released for use without radiological restrictions.
4. In the uranium residue cases, RESRAD was used as a preremediation planning tool. The soil activity concentrations established for the residential farm scenario provide the most restrictive guidelines for the decision making in regard to future remediation of the sites, along with other release criteria.

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A FRAMEWORK FOR EVALUATING INNOVATIVE STATISTICAL AND RISK ASSESSMENT TOOLS TO SOLVE ENVIRONMENTAL RESTORATION PROBLEMS

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ABSTRACT

Environmental restoration activities at the U.S. Department of Energy (DOE) Hanford site face complex issues due to history of varied past contaminant disposal practices. Data collection and analysis required for site characterization, pathway modeling, and remediation selection decisions must deal with inherent uncertainties and unique problems associated with the restoration.

This paper presents a framework for selecting appropriate statistical and risk assessment methods that can be applied to the restoration problem. Using an example, it follows the selection process from option identification to statistical tools identification and selection.

INTRODUCTION

In the past, the data collection and risk analysis methods followed the path dictated by regulatory requirements, starting from the position of "prove that all imaginable contaminants aren't there," and "eliminate all risks to the population." Reality, limited budgets, and 10 years experience with the Environmental Protection Agency's (EPA) clean-up actions under the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) are leading remediation specialists to reconsider the old approach. Among the lessons learned are that the clean-up process must be streamlined, the characterization effort and remediation needs must be integrated, and some level of residual risk will be present even at the conclusion of a successful clean-up. New approaches such as the observational approach (1) and data quality objectives (DQO) (2) are useful tools for bringing reality and efficiency into the clean-up process.

The observational approach suggests focusing only on probable conditions of contamination and treating uncertainties as reasonable deviations to be handled by contingency plans. Data are gathered only to the point sufficient to make a remediation decision. The DQO answer such questions as: What type and quality of data are needed to answer key questions and make key decisions? How much data is enough? DQO allow decisions to be based on data with a predetermined and acceptable level of confidence. Both approaches rely heavily on statistical concepts very familiar to risk assessors: expected conditions, quantifying uncertainties, accuracy and precision requirements, setting the level of Type I and Type II errors (false positive and false negative decision errors), explicitly identified probabilities, etc. Other aspects of the environmental restoration problem also draw heavily on statistical tools: sampling strategies, analysis variability analysis, experimental design, data interpretation, etc. A framework for working through the statistical aspects of the site characterization and remediation selection problems is needed. This framework would facilitate the selection of appropriate statistical tools for solving unique aspects of the environmental restoration problem.

This paper presents a framework for selecting appropriate statistical and risk assessment methods. The following points will be made: 1) pathway modelers and risk assessors often recognize that "some type" of statistical methods are required but don't work with statisticians on tools development in the early planning phases of the project; 2) statistical tools selection and development are problem-specific and often site-specific, further indicating a need for up-front involvement of statisticians; and 3) the right tool, applied in the right way can minimize sampling costs, get as much information as possible out of the data that does exist, provide consistency and defensibility for the results, and give structure and quantitative measures to decision risks and uncertainties.

THE FRAMEWORK

The framework described below has five steps. Step 1: designing and evaluating a remediation options matrix. Step 2: setting DQOs using the results of the options matrix evaluation. Step 3: designing and evaluating a statistical tools matrix. Step 4: using the results of the tools evaluation to collect data and conduct analyses. Step 5: incorporating the data and analyses from Step 4 back into the options matrix, and reiterating through the steps until a remediation decision can be made. Figure 1 is a flowchart of the activities in the step. Since this paper deals with statistical tools, Step 3 is the focus of our discussion.

Step 1: The Options Matrix

The selection of a remedial action under both CERCLA and Resource Conservation And Recovery Act (RCRA) Corrective Action follows a structured approach, starting with a

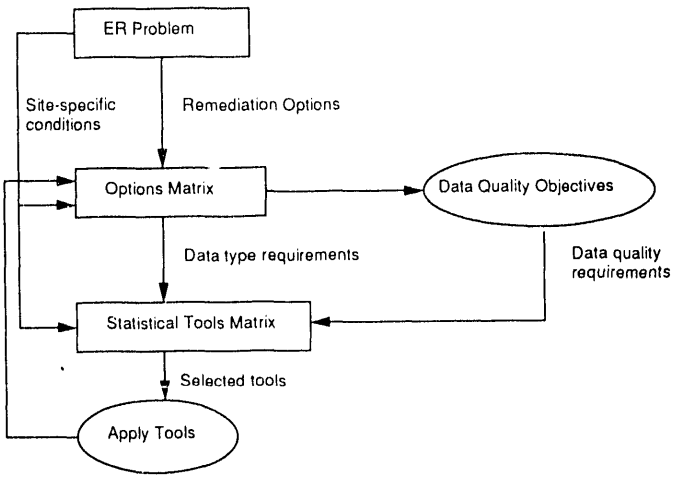


Fig. 1. Framework for environmental restoration tools selection.

conceptual model, then investigation and feasibility studies, leading to a preferred option for the remediation. Working through the options matrix helps identify this preferred remediation option.

Figure 2 shows an example of an options matrix where alternative remedial actions are evaluated against a list of criteria. A very short criteria list is shown here: health risk, ecological risk, schedule, and cost. An expanded list could include cultural impact, public acceptance, and land use impact. It is assumed that all options meet regulatory compliance. Other aspects such as economic impact and technical feasibility are included in cost and schedule. The example shown is for a simplified problem of buried waste. Options are to leave the waste where it is or retrieve it. A third option of deferring the decision is handled by the iterative approach in the framework. Variations on the two main remedial options are: 1) leave -- stabilize/contain the waste, treat it in situ; and 2) retrieve -- separate the waste and use less expensive treatment and disposal for cleaner wastes, treat it ex situ, and combinations thereof.

With the axes of the options matrix defined, the next task is evaluating the options relative to the criteria. This process can take years, often taking as long as there is money to fund the clean-up. The evaluation process is patterned after pathway modeling, starting with characterizing the contaminants on-site. The contaminant mix and concentration levels determine what options are viable, the health and ecological risks of each option, and the cost and schedule for each option. If the contaminants, their concentrations and locations are known, there are probably uncertainties as to how the various clean-up options will perform. Even if all of the above are known, there are undoubtedly disagreements over the criteria and the relative weights to be applied to them. Some options may perform well when evaluated against one set of criteria but poorly against another set. If one clean-up option is clearly dominated by another, it can be eliminated from further consideration.

In theory, output from Step 1 is a completed options matrix. The entries in the matrix can be binary (zeros and ones), ordinal (rankings), or cardinal (numerical scores). A more likely scenario is that the matrix cannot be completely filled out with the information that is available, and Step 1 results in a list of questions to be answered and a need for additional data. Before data is collected, objectives must be set for collecting and analyzing the data.

Step 2: Setting Data Quality Objectives (DQOs)

In setting Data Quality Objectives, the following questions are asked: What decisions need to be made? What data are required to make the decisions? What is a sufficient quantity and quality of data to meet pre-set levels for Type I and Type II decision errors? In addition to setting DQOs for data collection, this is the time to begin using the observational approach (3) to identify probable conditions and reasonable deviations for the clean-up. The observational approach relies on current information and most likely assessments to narrow the range of options to evaluate. The DQOs can direct the observational approach by focusing on those options that meet the objectives of the clean-up.

Continuing with the buried waste example, suppose health risk data is missing for each of the options. The type of data required to complete the options matrix is the following:

1. **Option**: Do nothing

   Question: Will contaminant get into the drinking water?

   Data Required: Groundwater model predictions; sample well monitoring data.

   DQO Issue: Contaminate data accuracy required only to point of determining if drinking water standard has been exceeded.

2. **Option**: Transport off-site

   Question: What is maximum exposure to transportation worker?

   Data Required: Maximum hypothetical exposure time, probability of hot spots within truckload.

   DQO Issue: Only investigate 95th percentile (and beyond) of accident scenarios.

Step 3: Statistical Tools Matrix

The data and analysis needs from Step 1, directed by the objectives from Step 2, are used to define the type of statistical tools that are needed to make the site characterization determinations and remediation decisions. Figure 3 shows on the horizontal axis some of the data collection and analysis problems associated with environmental restoration. On the same

Options / Criteria	Leave			Retrieve		
	Do Nothing	Stabilize/ Contain	Treat In Situ	Transport off-site	Separate	Remove/ treat on-site
Cost						
Schedule						
Health Risk						
Ecological Risk						

Fig. 2. Remediation options matrix.

Aspects of Problem / Tools / Criteria	Boundary Cond: Syst. Design Expr.Design Seq. Sampling	Spatial Var.: ANOVA Geo Stat GIS	Less-than-Values: Methods for Censored data Categ. Analysis	Non-normal: Non-Param. Stat	Uncertainty: Empirical Prob. Dist Confidence Int.	Hot Spots: Sampling Tech., H_0 Testing	Multiple Sources of Conflicting Data: Bayesian Analysis Modelling	Trade-offs: MUA Decision Analysis
Robust								
Data Req't								
Sensitive to Outliers								
Demonstrated								
Developed								

Fig. 3. Statistical tools matrix.

axis are shown some of the innovative tools that can be used when these problems are present. A general laundrylist of issues and tools is presented here to give a flavor of the complexity of environmental restoration problems.

Issue 1: Boundary Conditions: Concern is often focused on the boundary of a land-fill area where contaminants can be released to the environment. Unique conditions associated with the boundary can override average conditions within the land-fill as it relates to remedial action. Special statistical tools applicable in determining boundary conditions deal with sensitivity in detecting differences, ability to override central tendencies and focus on exceptions, and quickly sensing that a shift in conditions has occurred. Some of the statistical tools applicable to boundary problems are: 1) experimental design, systematic sampling, sequential sampling for setting up experiments and sampling designs that can quickly detect changing conditions; 2) simulation to assess the ability of engineered barriers to inhibit releases to the environment over a range of hypothetical conditions; and 3) sensitivity analysis used with pathway analysis models to investigate the range of outcomes, finding under what conditions algorithms used in the models break down or lose accuracy (4).

Issue 2: Spatial Variability: Heterogeneity in general, whether it is over time, over space, or between units of buried waste such as debris in drums or boxes, causes a special set of problems. A small number of samples may be unrepresentative of the total population of contaminants. Costs may be prohibitive for collection of large numbers of samples. The two key parameters used to describe wastes, central tendency (mean) and dispersion (standard deviation), may not be sufficient to describe the wastes under conditions of variability. The full distribution probability density function (pdf) is often required. If insufficient historical or sampling data is available to generate an empirical pdf, it may be possible to use process information to infer a pdf. Some geostatistical techniques have been developed to address spatial variability. Also, visually displaying data using a geographical information system (GIS) can facilitate analysis of spatial data sets for communication, planning and analysis purposes. In some situations, analysis of variance (ANOVA), can be used to assess between- and within-variability of data sets and establish the degree of interaction among variables.

Issue 3: Less-Than Values: With increased sensitivity of measuring equipment, limits of detection for contaminants are being lowered. Determining if a contaminant is detectable above background is a key concern. Substituting a less-than value for an actual measurement, or eliminating extreme values (censored data sets) can lead to erroneous results for many statistical methods. Many times, categorical rather than quantitative analyses are required when the variables being considered are binary (contamination vs. no contamination) or ordinal (rankings). Special statistical methods must be used with censored data sets (5).

Issue 4: Non-normality: The distribution of natural phenomena data is rarely normal (Gaussian). The assumption of the familiar bell-shaped distribution required by many statistical tools (e.g., the familiar Student test for testing whether sample results indicate contamination above some limit) cannot be justified. Outliers, measurement insensitivity, measurement errors, can all contribute to violating the normality assumption. In such cases, non-parametric tests and methods can frequently be used (6), although these methods are not as familiar to regulators or practitioners.

Issue 5: Uncertainty: Decisions must be made taking into account the magnitude of the uncertainty in the data, the uncertainty in parameters used in pathway models, and the uncertainty in the formulations used to model natural processes. If the data and model predictions are highly uncertain, the probability of making the wrong decision can be large. Hence, there is a need to access uncertainties and to use that information in the decision-making process. The concepts "most likely, expected conditions, reasonable deviations, worst case, and interaction of errors" require some knowledge of the distribution associated with one or more variables. Empirical probability distributions must be estimated; confidence or tolerance intervals must be reported along with the point estimate of a variable. Statistical tools can be used to make such assessments if the assumptions upon which the tools are based are not violated by existing environmental conditions.

Issue 6: Hot Spots. Hot spots are a special case of spatial variability. Most buried wastes exhibit the potential for areas of very concentrated contamination or rare events, such as ordinance buried along with chemically hazardous wastes. Some sampling designs (e.g., triangular grids) have a greater probability of detecting the hot spots, but usually come with associated higher costs. DQOs are required to specify the confidence the decision makers requires, i.e., how willing he/she is to miss one of the hot spots. The statistician can assist with matching objectives to sampling designs and determining the type of test to use to detect hot spots. Gilbert (6) gives nomographs for selecting the distance between samples located on a grid for the purpose of detecting hot spots.

Issue 7: Multiple Sources of Conflicting Data: Opposite of the "too little data" syndrome, the decision maker often is confronted by the problem of conflicting results. For example, historical records may show one type of contaminant buried at a location, sampling results may be inconclusive, remote sensing devices may indicate a second contaminant but have a very high and questionable detection limit, and prior modeling results may point to a third contaminant. Resolving discrepancies, establishing "best estimators," identifying relationships among variables, and finding correlations among the data values must be done within the context of the decision that must be made and how much confidence is required in the result. Bayesian analysis can be used with data that is obtained in stages, using the additional information gained in later stages to test prior assumptions (prior probabilities) in a backward logic approach (7). Discriminant analysis can be used with observational data to make assignments and discriminate among elements of a population (e.g., discriminate among waste types). Principal components and factor analysis can reduce the dimensionality of a problem (e.g., rather than deal with every chemical species and nuclide, reduce the problem to a few key ones) (8). Many of these techniques have not been used in environmental restoration problems but with modification could be applied.

Issue 8: Trade-offs: How do you trade tax dollars today for health benefits for future generations? How do you trade increased risk for remediation workers against saving a habitat of some rare species? Utility functions can be used to reveal preferences, interpersonal utility comparisons can be made, and multiple attribute utility functions can be generated. However, these tools must be stylized to the environmental restoration problem before they can be applied directly.

The tools of decision analysis--decision trees, influence diagrams, trade-off matrices, utility functions, and multi-attribute utility functions-- require input. The input -- probabilities on the states of nature, possible outcomes, decision alternatives, and lottery results--require a familiarity with rules of probability. The statistician can assist in developing the consistent and defensible probability distributions assigned to outcomes that are the key to the successful application of these decision tools (9).

Site characterizations and pathway models may not have all of the issues presented above associated with them. Further, many statistical tools are not applicable to a situation given the nature of the data and the hesitancy of the restoration manager to make assumptions and/or accept stated decision risks. The discussion demonstrates there is a need to identify the issues that may be encountered and the statistical tools to address them early in the planning process in order to have the tools available and validated at the time data collection is planned.

Once the horizontal axis of the tools matrix is established, the vertical axis that lists the criteria for evaluating the tools needs to be identified. Five criteria are shown in Fig. 2: robustness, amount of data required to implement the tool, sensitivity of the tool to outlying data points, whether the tool has been demonstrated/validated/benchmarked, and whether the tool is fully developed and functional. Tools are evaluated against a set of criteria to select the right tool for the right job. Not every statistical tool can or should be used for a particular environmental problem.

- Robustness - Does the tool perform well under the conditions present at the restoration site? Do the algorithms break down under special conditions such as values close to zero, large variability, correlated variables, non-linearity, disjoint data sets? Do the tools provide the same answer using similar data? Does a transformation of the data cause problems? Many of the environmental problems have unique aspects (interacting effects, measurement errors, compounding errors), and the tools to be applied must be able to handle the full range of contingencies.
- Data Requirements - Some tools require significant amounts of data before they can be applied. Other tools can become reasonably accurate with minimal data sets, or can be designed to quickly converge to an answer. For example, exponential smoothing for forecasting heavily weights more recent observations thus minimizing the effect of historically unreliable data. Sequential sampling can minimize sampling costs since it ends sample collection as soon as a decision can be reached.
- Sensitive to Outliers - Extreme values can cause problems for some statistical tools. Other tools can quickly recognize the difference between major shifts and the influence of only one or two extreme observations. For example, the mean can be affected by one or two extreme values, whereas the median is not. Tools that use ranks rather than quantitative values are usually better in situations when outliers are prevalent.
- Demonstrated - Many statistical tools look good on paper but have not been validated or benchmarked against field data. Complicated process models that predict concentrations of a contaminant at points in time and place may be quickly invalidated once sampling begins.
- Developed - Many tools have not beend modified or adopted to handle the unique conditions of environmental restoration. Tool development should be included in the planning phases of an environmental restoration.

Evaluating tools relative to a set of criteria, i.e., filling in the tools matrix can be done on an absolute level (each tool given a numerical evaluation) or a relative basis (each tools receives a "good" or "bad" evaluation). Applying some of the criteria requires some knowledge of expected site conditions (e.g., data availability, outliers). The primary benefit of filling out the tools matrix is to quickly eliminate some tools from consideration, and arrive upon a short list of tools that can be

given further consideration. The effort of evaluating the tools relative to the criteria can benefit the analyst in fully understanding the capability of possible tools and understanding site conditions.

The output of Step 3 is a set of tools to be applied, considering the DQO objectives and from Step 2.

Step 4: Application of Tools

In Step 4, the selected tools are applied and the results are analyzed following the tenets of DQOs and the observational approach. Many times, this step involves sample collection for characterizing a site -- determining the contaminants that are present, their concentrations and locations. Other times, if data are already available, this step may consist of a test of a hypothesis that contamination is present at some level. The data and analyses from Step 4 are used to answer the questions posed from trying to fill in the options matrix: the cost for cleaning up a site depends on what contaminants are there; the health risks for an option depend on the probability the contaminant will reach a populated area before remediation can begin. The application of the statistical tools provides the expected values, range of outcomes, and probability estimates to evaluate the options relative to criteria (cost, schedule, health and ecological risk) from the options matrix.

Step 5: Iteration of Steps 1 Through 4

Tools are not applied in isolation but rather in an integrated fashion. Sometimes they are used in parallel, other times sequentially, but always they are applied with the DQOs in mind. The application of one set of tools may provide some of the answers required to make a selection among remediation alternatives. These answers often lead to more questions as to how an option will fare under a refined set of criteria. Thus, there is an iteration through steps 1 through 4. Each time the analyst works through the options matrix, more options are eliminated, and more options are clearly dominated by other. Each time a candidate set of options is identified, the DQO questions must be asked: What data are required to select among the options? What quality of data is required to gain the confidence in the decision? Each time the DQOs are established, the tools necessary to obtain the data, analyze the data, and put it in a decision framework must be selected and applied again and again. The iteration stops when a decision can be made and its level of confidence quantified and accepted.

CONCLUSIONS

This paper has made the following points. Pathway modelers and risk assessors often refer to statistical methods but don't include tools selection in the early planning phases of the project. Statistical tools selection and development are problem-specific and often site-specific. The right tool, applied in the right way can minimize sampling costs, get as much information as possible out of the data that does exist, provide consistency and defensibility for the results, and give structure and quantitative measures to decision risks and uncertainties.

A framework for selecting and applying the right tools consists of developing an options matrix for evaluating a set of potential remediation options. Knowing these options and setting objectives for the quality of the data to be collected, a statistical tools matrix for tools selection can be developed. Applying the tools and iterating through the steps in the framework allows the remediation project manager to make a decision, at a quantifiable risk level, and be able to statistically defend the decision.

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BALANCING CERCLA RISK AND DOE RADIOLOGICAL PERFORMANCE ASSESSMENT METHODOLOGIES AND PRACTICES*

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ABSTRACT

Westinghouse Savannah River Company (WSRC) is engaged in an aggressive program to build new waste disposal facilities and to remediate contaminated areas at the Savannah River Site (SRS). The new low-level and mixed waste disposal facilities are being developed in accordance with U.S. Department of Energy (DOE) Order 5820.2A, which requires radiological performance assessments. Site remediation is being conducted in accordance with the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) of 1980, as amended, which requires assessments of the impacts of hazardous substances on human health and the environment.

Radiological performance assessments under Order 5820.2A and human health and environmental impact assessments under CERCLA are both conducted so as to achieve the same objective: adequate protection of individuals, populations, and the environment. The guidance, methodologies, and practices to be used for these two assessments, however, are different.

The assessment of groundwater contamination at the F-and H-Area Seepage Basins is the first CERCLA assessment at SRS. This assessment, composed of a baseline risk assessment of current site conditions and assessments of several remedial action alternatives is setting precedence for future SRS assessments and will influence CERCLA assessments at all other DOE facilities within the U.S. Environmental Protection Agency (EPA) Region IV.

It is the position of WSRC to apply the extensive body of DOE radiological performance assessments, models, codes, and approaches to the entire CERCLA assessment. This has required negotiation with EPA Region IV on issues such as institutional control, exposure scenarios, exposure pathways, time period of analysis, and acceptable models and assumptions. Of interest is assuring that the approach being followed under CERCLA is as consistent as possible with the approach used to develop new facilities under Order 5820.2A.

INTRODUCTION

The Savannah River Site (SRS) F-and H-Area Hazardous Waste Management Facilities each consist of a series of three unlined basins connected hydraulically by vitrified clay process sewers. Constructed in 1955, each facility received process wastewaters from the F-and H-Area Separation Facilities, respectively (The third H-Area basin was replaced in 1962 by a significantly larger fourth basin and has remained inactive since that time).

Wastewater flow to the F-and H-Area Seepage Basins was terminated in November 1988 in accordance with the requirements of the Resource Conservation and Recovery Act (RCRA) (1). During the 33-year period of operation, approximately 3.5×10^6 m^3 and 4.7×10^6 m^3 of process wastewater was discharged to the F- and H-Area Seepage Basins, respectively (2,3). The primary sources of effluent received at both areas included nitric acid recovery units and various evaporator overheads. During operations contaminants were released to the environment through evaporative processes and percolation of contaminated water through the basin subsoils. Wastewater contaminants eventually reached the underlying saturated zone, resulting in contamination of the underlying aquifers.

The F-and H-Area Seepage Basins have now been closed by placement of an engineered multi-layer cap over the basins. Pathway analyses and health risk assessments performed by Rogers & Associates Engineering Corporation formed part of the technical basis for selecting this closure alternative (2,3). Closure of the basins has had a dramatic impact on the modes of contaminant release. Placement of the caps over the basins has effectively curtailed contaminant losses due to evaporation and resuspension. The caps also limit the amount

* The information contained in this article was developed during the course of work under Contract No. DE-AC09-89SR18035 with the U.S. Department of Energy.

of water percolating through the basins, thereby reducing the rate of mobilization of basin contaminants due to leaching.

CERCLA ASSESSMENT

The next stage in remediation of the F-and H-Area is to decide if remediation of the groundwater is required and, if so, to select the remediation technique to be used. As part of the groundwater remediation decision-making process, human health and ecological risk assessments are being conducted in accordance with the Comprehensive Environmental Response, Compensation, and Liability Act of 1980, as amended,(CERCLA) (4) and supporting applicable guidance(5,6).

Monitoring data from the F- and H-Area Seepage Basins initially identified 78 potential contaminants of concern - 33 inorganic and 8 organic chemicals, and 37 radionuclides. After review, analysis, and screening of the monitoring data in accordance with EPA guidance (5,7), 29 contaminants were identified for analysis in the baseline CERCLA risk assessment. The 29 contaminants of concern are shown in Table I.

TABLE I

Contaminants of Concern for F- and H-Area CERCLA Baseline Risk Assessment

Aluminum	Arsenic
Barium	Cadmium
Chromium(III & VI)	Copper
Cyanide	Fluoride
Iron	Lead
Manganese	Mercury
Nickel	Nitrate
Selenium	Silver
Zinc	
Phenol	Tetrachloroethylene
Cm-243	Cs-137
H-3	I-129
Ra-226	Ra-228
Sr-90	Th-228
U-234	U-238

EPA guidance for the performance of human health risk assessments identifies specific requirements and methods to be used to assess the hazards posed by existing chemical and radioactive contamination. The U.S. Department of Energy (DOE) and the U.S. Nuclear Regulatory Commission (NRC) have both issued guidance for assessing the risk posed by the use, release, and disposal of radioactive materials. The requirements and guidance issued by these agencies are accepted as the standards by which the respective regulated communities are to conduct their activities.

Presently, DOE Order 5820.2A (8) and supporting guidance for the conduct of low-level radioactive disposal facility performance assessments (9)are being applied to the development of several facilities at the SRS. These facility performance assessments and the F- and H-Area CERCLA assessment are required to project the potential human health risk posed by several of the same radionuclides. The challenge posed by the F-and H-Area human health risk assessment was to ensure that it and the new disposal facility performance assessments were conducted in a consistent manner. Review of the EPA and DOE regulatory requirements and their supporting guidance identified three areas where consistency, if not total agreement, was deemed necessary:

- Assessment Approach
- Regulatory Limits / Performance Objectives
- Scenarios and Pathways

Assessment Approach

The risk assessment approach that EPA Region IV specified for use in the CERCLA baseline risk assessments of the F- and H-Area Seepage Basins is similar to the approach endorsed by DOE. The fundamental difference between the approaches is that, under the EPA approach, the worst case is to be projected while under the DOE approach the reasonable or most likely case is to be projected. Once worst case conditions are projected, the EPA allows them to be modified to represent more reasonable conditions and exposures to be assessed. The factors contributing to this fundamental difference are shown in Table II.

TABLE II

Differences in EPA and DOE Performance Assessment Approaches

Factor	EPA Approach	DOE Approach
Time dependency	Not addressed in baseline, addressed in remedial alternative assessment	Addressed throughout
Institutional control	Addressed as a remedial alternative	Addressed throughout
Period of analysis	Agreed to exposure period for baseline, same exposure period following implementation of the remedial alternatives	1,000 to 10,000 years

The impact of using the EPA approach for the baseline assessments is that it represents a static picture tied to present site conditions, while an assessment under DOE guidance is a dynamic picture of how risks change over time. The EPA approach projects the performance of the F- and H-Area Seepage Basins over time as part of the remedial alternative risk assessment. The EPA approach is conservative if present site conditions truly represent the worst case. However, at sites such as the F- and H-Area Seepage Basins, where there is an ongoing threat of contaminant release to the groundwater, the EPA approach may not be conservative.

The second difference in the EPA and DOE approaches is consideration of institutional control or other measures that restrict the period when exposures may occur. NRC, DOE, and the EPA Office of Radiation Programs all agree that institutional control can be relied upon to restrict access to facilities and controlled property for at least 100 years. For CERCLA assessments under EPA guidance, the 100 year institutional control period is not to be considered. The onsite

resident future land use scenario must therefore be projected as starting immediately. The EPA does, however, allow the consideration of institutional control period to be considered as part of the remedial alternative assessment.

The EPA baseline assessment focuses on a limited period of analysis. Exposures, risks, and health impacts are examined for either a 70- or 30-year analysis period. For the F- and H-Area Seepage Basins a 70-year exposure period was recommended based on EPA guidance. EPA Region IV directed that the exposure period be limited to 30 years. The remedial alternatives assessment examines the same 30-year exposure period for the future land use onsite resident scenario, but places it out in time. The only requirement is to calculate exposure, risks, and impacts under the future land use scenario at the end of remediation activities. For the F- and H-Area assessments EPA guidance would only require that exposures therefore be calculated for a 30-year period following the 100-year institutional control period and immediately following the 30-year treatment period.

DOE calculates exposures, risks, and impacts on a yearly basis. An analysis period of 1,000 to 10,000 years is commonly considered to be appropriate, based on the long half-lives of some radionuclides. Typically, the annual exposure for each radionuclide and for all radionuclides combined is calculated for each year. Peak individual and total radiation dose are scanned and the years where peaks occur are then examined in more detail. Qualitative estimates of projected behavior beyond the 1,000 or 10,000 year analysis period are developed based on site characteristics and the trends identified in the quantitative analysis.

The EPA and DOE approaches to analysis periods were combined in the F- and H-Area Seepage Basin remedial alternatives assessments. A 30-year exposure period was analyzed for five specific time frames:

- 30 years - End of the remedial alternative.
- 100 years - End of institutional control.
- 1,000 years - End of DOE analysis period.
- 400 and 700 years - Equally spaced points between 100 and 1,000 years

Regulatory Limits/Performance Objectives

As shown in Table I, the contaminants of concern for the baseline risk assessment consist of 15 inorganic and 2 organic chemicals, and 10 radionuclides. The chemicals must be assessed for both carcinogenic and noncarcinogenic hazard. The radionuclides are, for now, only considered to pose a carcinogenic risk. EPA guidance(5) requires the radionuclides be assessed using slope factors to give a direct measure of carcinogenic risk and dose conversion factors to give a direct measure of radiation dose.

DOE Order 5820.2A establishes facility radiological performance objectives that all LLW disposal facilities must meet and states these objectives in terms of radiation dose. The Order does not prescribe specific performance objectives for nonradioactive chemical contaminants. Rather, it invokes applicable Federal regulations for the proper management of hazardous chemical contaminants.

Presently the list of applicable or relevant and appropriate requirements for the F- and H-Area risk assessments is being finalized. However, it is clear that the State of South Carolina Hazardous Waste Management Regulations (10) apply. These regulations superseded those of the EPA when South Carolina became a mixed waste authorized state in September, 1987. Under the South Carolina regulations, groundwater contamination limits are set at either background levels, at specifically designated values for a select set of contaminants (eight heavy metals and six organics), or at alternative concentration limits. These limits are established in each facility specific permit. The CERCLA baseline and remedial alternative risk assessments are to be part of the documentation to be used by the state in setting the final groundwater limits for the F- and H-Area Seepage Basins.

The composite set of requirements being addressed by the F- and H-Area CERCLA risk assessments are listed in Table III. The three requirements applicable to chemical contaminants are individually unique and do not duplicate one another. Of the four requirements applicable to radionuclides, three of them are duplicative of each other. EPA and DOE both require that radionuclides be assessed in terms of radiation dose. In addition, EPA requires that radionuclides be assessed using slope factors to give a direct measure of carcinogenic risk. In that radiation dose can be readily converted into carcinogenic risk, all three requirements address carcinogenic risk. The potential therefore exists that, unless consistent methodologies are used, the same level of contamination may result in different estimates of carcinogenic risk.

Presently, the dose conversion factors and methodology used by EPA to develop carcinogenic slope factors for radionuclides are under review at SRS. Some radionuclide- specific values used by EPA differ from those used and accepted by DOE. The impact of these differences on the results of F- and H-Area CERCLA risk assessments is not believed to be great. Therefore, the EPA slope factors are being used without adjustment for differences in dose conversion factors.

TABLE III

Regulatory Requirements Being Addressed in the F- and H-Area CERCLA Risk Assessment

Type of Contaminant	Regulatory Requirement	Measure	Source of Requirement
Chemicals	Carcinogenic Effect	Risk (e.g. 10^{-6})	EPA (5)
	Noncarcinogenic Effect	Hazard Quotient (e.g. 1.0)	EPA (5)
	Level of Contamination	mg/L	South Carolina (10)
Radionuclides	Carcinogenic Effect	Risk (e.g. 10^{-6})	EPA (5)
	Radiation Effect	Dose (e.g. 4 mrem)	EPA (5)
	Radiation Effect	Dose (e.g. 25 mrem)	DOE (8)
	Level of Contamination	pCi/L	South Carolina (10)

Exposure Scenarios and Pathways

The EPA approaches the identification of receptor populations by dividing exposure scenarios into two categories - current land use and future land use. Under current land use three scenarios are being assessed - an onsite worker, an intruder, and an offsite resident. Under the future land use category, an onsite resident exposure scenario is to be considered. The current land use intruder scenario was renamed the trespasser scenario to avoid confusion with the onsite resident scenario, which is also commonly considered an intruder scenario.

The on-site worker scenario considers the exposure pathways, frequencies, and durations typically encountered by workers in the area under study. The exposure pathways, frequencies, and durations resulting from a trespasser involved in activities typical of the area where the site is located (e.g. hunting, fishing, etc.) are considered under the trespasser scenario. The offsite resident scenario addresses the exposure pathways, frequencies, and durations typical of the offsite population in the immediate vicinity of the SRS. The future land use, onsite resident scenario considers exposures received by a family living and farming within the area of contamination. Both chronic and subchronic exposure durations, frequencies, and pathways are taken into account.

SRS, working with EPA Region IV, successfully used site-specific data to define the exposure frequency and duration in the site worker and the trespasser scenarios. Site specific data were not available to allow modification of the offsite and onsite resident exposure pathways,durations, and frequencies. Table IV summarizes the exposure pathways, durations, and frequencies considered in the baseline CERCLA assessment of the F- and H-Area Seepage Basins.

For the most part, the exposure pathways included for consideration by the EPA are also routinely considered in DOE performance assessments. However, several pathways that are considered to be insignificant in most radioactive performance assessments can be very significant in an assessment that includes chemical contaminants. Included among these pathways are inhalation of volatile contaminants, dermal contact with contaminants, and ingestion of soil. Results from the F- and H-Area Seepage Basins demonstrate that all three of these pathways are, as expected, important for the chemical contaminants. However, the results also show that inhalation of volatile contaminants and ingestion of soil are important for radionuclides. The carcinogenic risk posed by only the radionuclides is greater than 10-6 for each of these pathways. This would indicate that under the given conditions and pathway parameters that both inhalation of volatile contaminants and soil ingestion be examined closely prior to being deemed dropped from DOE radiological performance assessments.

The third pathway, dermal contact with contaminants, is not considered significant by EPA(5) and is not routinely considered in DOE performance assessments. The logic that supports these positions is questionable. EPA requires that the exposure and risk posed by a nonradioactive contaminant, nickel for example, be considered for dermal contact. Adjustments are made to account for difference in absorption factors

TABLE IV

Exposure Pathways, Frequencies, and Durations

	Exposure Scenario			
Exposure Pathway	Worker 5 days/yr; 8 hrs/day	Trespasser 1 day/yr; 8 hrs/day	Offsite Resident 30 yrs; daily exposure	Onsite Resident 30 yrs; daily exposure
Dermal Contact:				
Groundwater				C&S
Surface Water		C	C	C
Sediment				C
Soil	C	C		C&S
Ingestion:				
Groundwater				C
Surface Water		C	C	
Soil/Dust				C&S
Sediment				C
Fish			C	C
Meat/Game			C	C
Milk				C&S
Eggs				C
Vegetables				C
Inhalation:				
Volatiles	C	C		C
Particulates	C	C		C
Direct Gamma				
Surface Water	C	C	C	C
Air				C
Soil	C	C		C

C = 30-year chronic exposure S = 6-year subchronic exposure

(absorption across the gut vs. absorption through the skin). Health effects for a given quantity of nickel, once in the body, are considered to be the same regardless of how the nickel got in. This would appear to also be true for radionuclides. Therefore, radionuclides should be considered in dermal contact exposure pathways.

SUMMARY

On the surface the EPA CERCLA and DOE radioactive waste performance assessment approaches appear to be quite different. Closer examination shows that each is sufficiently flexible to allow them to be combined without compromising themselves. Application of both approaches in a combined way requires close attention to detail so as to avoid unnecessary complexity. DOE's consideration of longer periods of analysis should be followed so as to thoroughly examine the potential long-term impacts. EPA's more detailed set of exposure pathways should be closely examined. In the case of the F- and H-Area Seepage Basins CERCLA risk assessments, two pathways that are routinely not considered under radiological performance assessments proved to pose carcinogenic risks of 10^{-6} or more from radionuclides alone.

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METHODOLOGY FOR CONDUCTING A PERFORMANCE ASSESSMENT OF AN ENGINEERED DISPOSAL FACILITY

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ABSTRACT

A performance assessment of an engineered disposal facility (EDF) or a waste storage facility (WSF) can be performed in such a way that the results are easily used to meet design, maintenance, and overall planning requirements. The information developed in a performance assessment can be applied to existing systems or new designs to provide the necessary information for evaluating cost, benefits, and risks posed to workers and the public. This paper describes a method for conducting a performance assessment on an EDF at the Fernald Site (FS) located near Cincinnati, Ohio. At the FS, the EDF has been renamed and is now called the Engineered Waste Management Facility (EWMF).

FS Description and Background

The FS is located near the unincorporated town of Fernald, Ohio approximately 32 km northwest of Cincinnati. The FS production facilities cover approximately 0.55 km^2 in the center of a 4.25 km^2 site. Several rural communities and commercial operators lie within 1.0 km to 4.8 km of the plant. Fernald produced high-purity uranium metal from the early 1950's until 1989 for the Department of Energy (DOE) defense nuclear fuel cycle. The metal was predominately fabricated into fuel cores and target elements. These were used in nuclear reactors at other DOE sites. Many chemical and manufacturing processes were used in the production of uranium metal. Process wastes and sludges containing low concentrations of uranium and thorium were disposed in large on-site waste pits. Typical commercial wastes were disposed in lime sludge ponds, fly ash piles, and sanitary landfills. Uranium contamination has been found in on-site soils and perched groundwater around process facilities and in a groundwater plume that extends approximately a kilometer off-site.

In November 1989, Fernald was placed on the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) National Priority List (NPL) to provide focus for ongoing cleanup initiatives. Although financing of remediation will not come from the Superfund, the FS will be remediated according to CERCLA using DOE funds.

An EDF may be constructed to meet the needs at the FS. The proposed EDF may require a capacity in the range of 1 to 2 million cubic meters. Figures 1 and 2 illustrate some of the basic design features considered for the EDF at the FS.

The following discussion provides a method for evaluating the performance of the engineered disposal facility (EDF) by incorporating a probability based risk assessment for the EDF and potential releases with an EPA based risk approach for the ultimate exposure and risk analysis (1,3). The results of a performance assessment methodology are provided in the form of risk estimates for failure and the associated impacts from such a failure. The impacts of a release and the resulting risks can be represented in a number of ways from the probability of cancer incidence or fatalities to the long term costs of reducing exposures. Utilizing the probability based methodology coincident with the typical EPA approach provides results in the form of probability and risk curves. These curves illustrate the range of possible outcomes along with estimates of the probability of a specific result. The potential impacts are then categorized in terms of both the probability of occurrence and the probability of a specific consequence.

The general approach is illustrated in Fig. 3. This figure shows the connection between modeling and the use of probabilistic formalism. Modeling of the EDF contains a number of separate considerations including structural integrity, source term analysis, and exposure scenarios. Once models are developed for each phase of the analysis, fault trees are used to estimate the probability of specific "failure" events. Fault trees are developed for each component or subsystem of the EDF to evaluate all the potential failure modes. In a similar fashion, fault trees are developed for release modes and environmental transport routes.

Examples of specific failure mode initiators that require evaluation include natural phenomena such as: seismic events, tornados or severe weather, and even flooding. The response of the EDF and ultimately the waste form contained inside need to be analyzed. The EDF generally requires design specifications that limit the total amount of waste that may leach from the system. The EDF relies on multiple barriers to accomplish the limited leaching rates. The long term considerations associated with the leachate from the EDF relies heavily on the nature and characteristics of the waste form. Use of the various fault and event trees in developing the failure and release sequences will facilitate the determination of those factors which lead to the largest probabilities of failure, leaching, or transport.

The fault trees are linked using event tree analysis methods to evaluate the consequences of an initiating event (1,2). Figure 4 illustrates the results obtained from the event sequence phases. In each phase of the analysis specific information is carried along in order to categorize the various event

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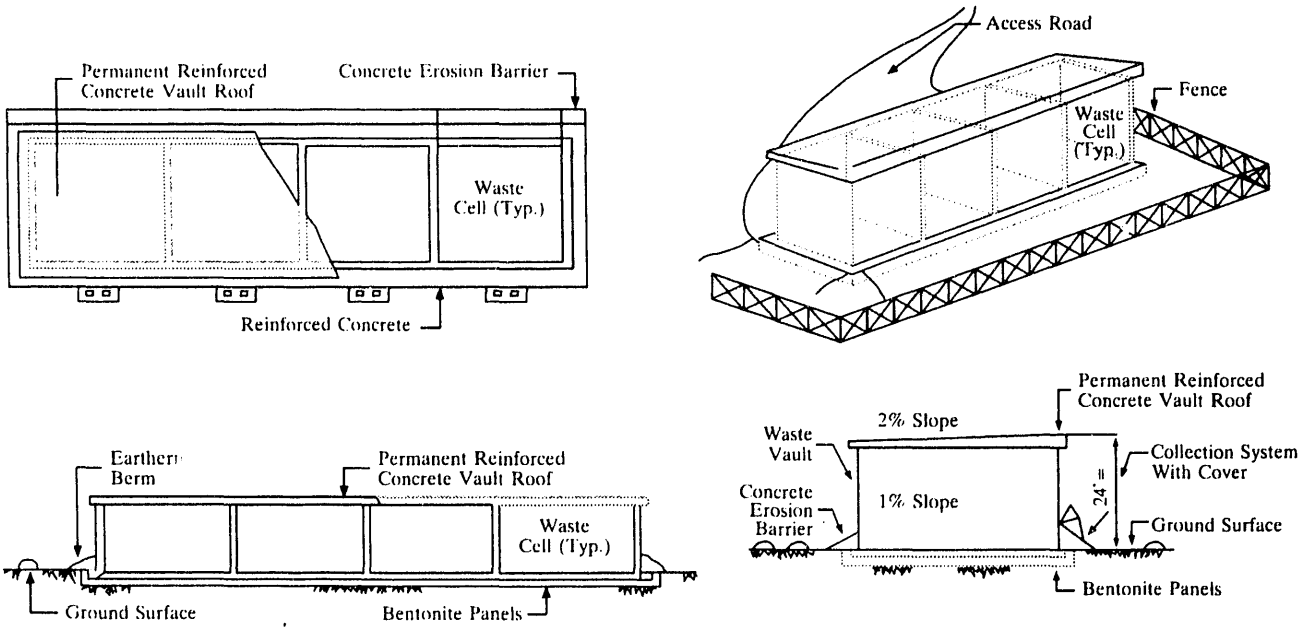


Fig. 1. Illustration of greater confinement vault facility.

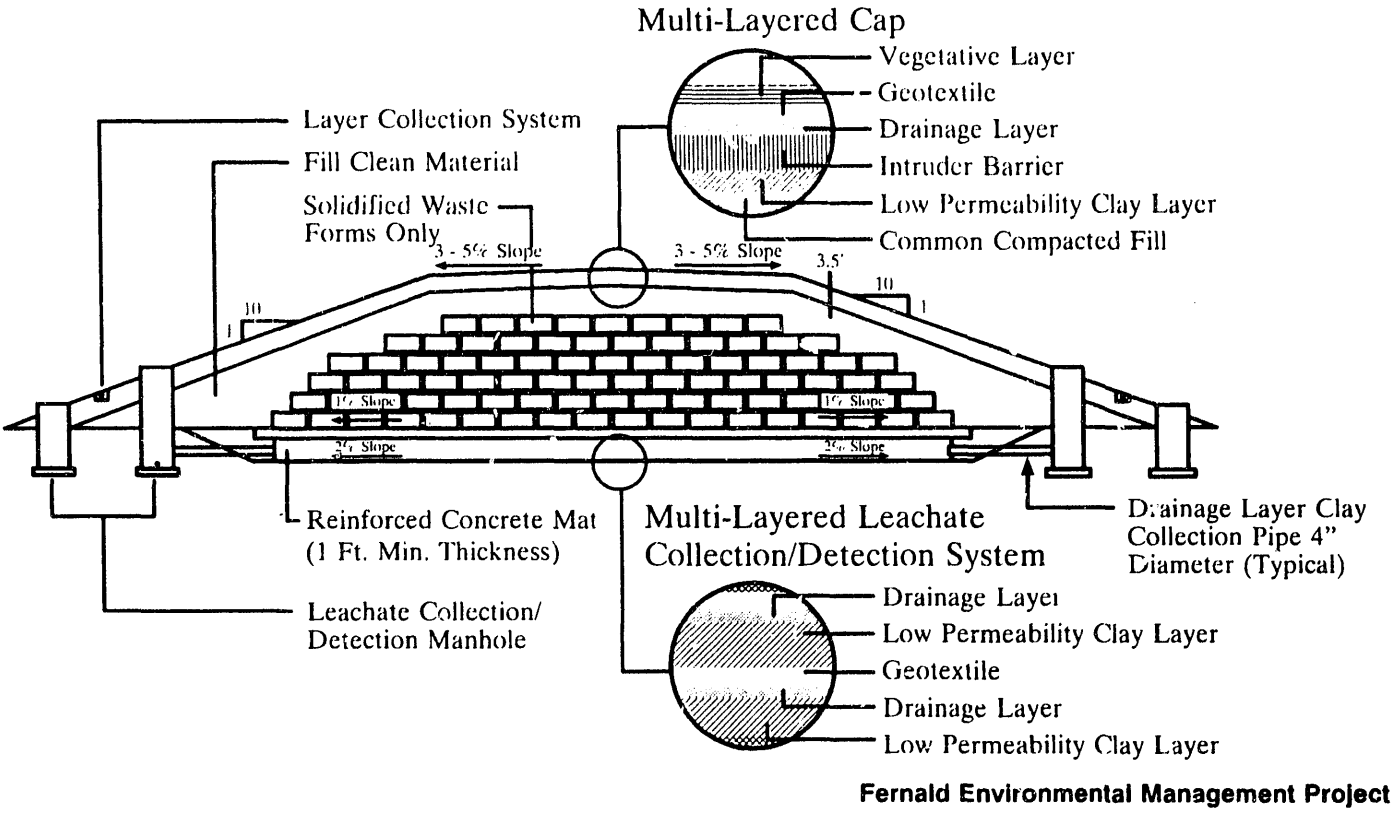


Fig. 2. Illustration of tumulus design for an EDF.

sequences. The failure probability of the EDF is related to the damage class. The damage class is then related to the release probability as described schematically in Fig. 4. Figure 5 presents a typical event tree as might be developed to evaluate the significance of a seismic (earthquake) initiator on the EDF (1,2).

The failure probability, sequence, and damage class are estimated and then tabulated for use in the next phase of the assessment. Using this methodology, initiators such as natural phenomena, human interaction, and accidents can be assessed for short and long term consequences. The use of fault and event trees form the basis of the probabilistic methodology in assessing the performance of the EDF.

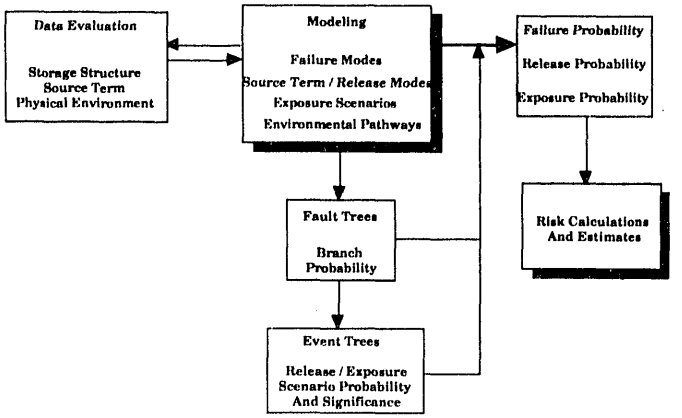


Fig. 3. Flow chart for performance assessment methodology.

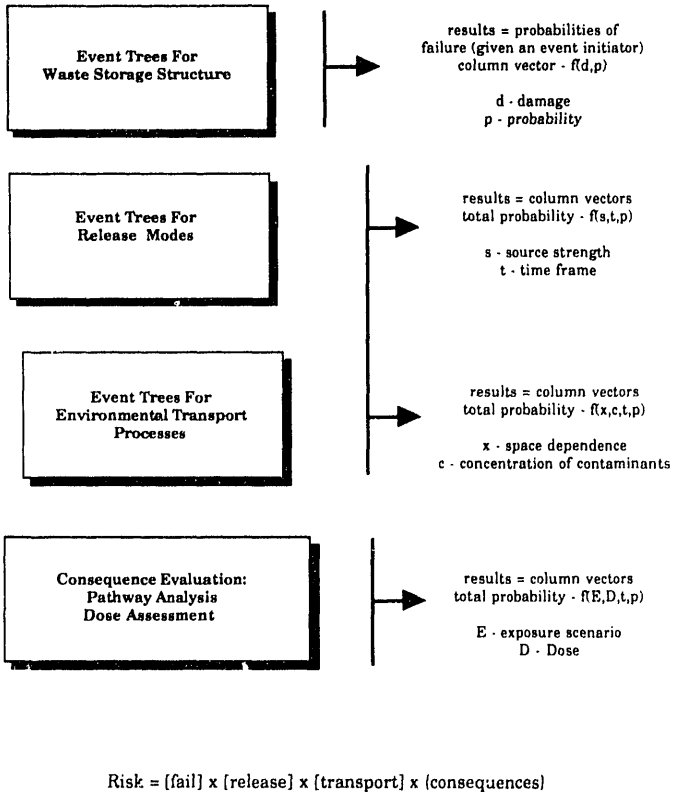


Fig. 4. Event tree relationships applied to the performance assessment methodology.

The results obtained from the probability assessments are linked with a specific objective or consequence in order to provide a series of probability estimates describing the potential for failure, release, transport, and ultimately human exposure. In this way an estimate of the probability and consequences of a specific sequence of events can be assessed in terms of the overall risk and not just the dose or failure potential. Incorporating the probabilistic methodology into the performance assessment of the EDF may provide a better understanding of the relationship of the structure to the exposure potential in both concentrations at specific locations and for specified durations.

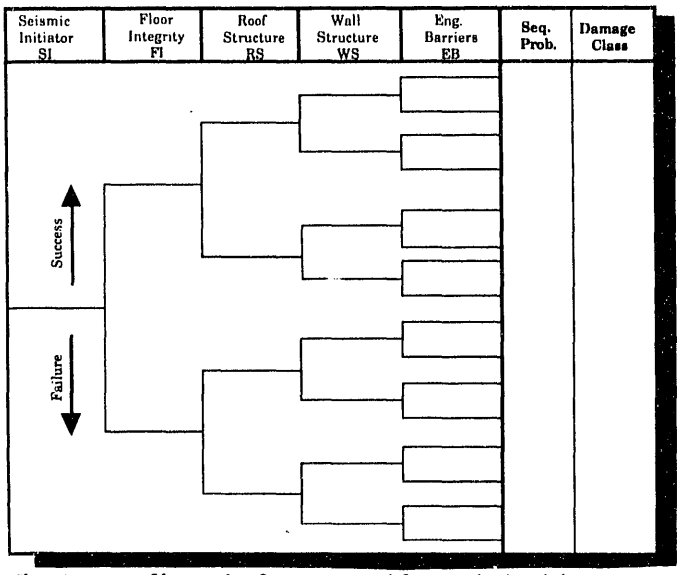


Fig. 5. Loss of integrity from natural forces (seismic) event tree for an EDF.

PERFORMANCE ASSESSMENT METHODOLOGY

The general approach to the performance assessment includes four phases. These phases are: 1) data evaluation, 2) modeling, 3) probability estimates, and 4) risk estimates and characterization. Each of these phases are described in the following sections. Each phase is addressed by considering all the various regulatory requirements. The regulatory requirements include design, implementation, and monitoring of the facility to ensure the appropriate level of performance of the structure for containing waste material.

Data Evaluation

The evaluation of the data for use in the performance assessment require a number of special considerations including model parameter evaluation. Model parameters may be of two types: 1) parameters assumed to be constant throughout the simulation period but have uncertainty associated with their values, and 2) parameters that vary through time in a stochastic way. Each phase of the failure mode analysis requires a detailed model to address the structural integrity, the release potential, and the environmental transport processes. The detailed model is required since the failure effects are by definition hypothetical. The detailed evaluation of the data will include a number of mathematical and non-mathematical methods. Sample and population statistics are generally the mathematical method used most often to evaluate data. To utilize the various statistical methods, the available data must be represented by either a discrete or continuous distribution.

The type of distribution is determined by the physical process being represented or by a priori knowledge. Distributions are important because they can be used to represent the uncertainties in the parameters and in the models. Distributions are characterized by parameters of central tendency or uncertainty. The value of x that divides the area under the distribution into equal parts is called the "median", the value of x corresponding to the peak of the curve is called the "mode" and the first moment of the distribution is the "mean", the "average" and the "expected" or "expectation value" of x symbolized as $E(x)$. The second moment about the mean is called the "variance" or "Var(x)" and the square root of the variance is the "standard deviation" and is symbolized with the greek

letter sigma (σ). Thus the median, mode and mean are measures of central tendency. Variance and standard deviation are measures of dispersion or uncertainty. The information obtained through this type of data evaluation is used to develop probability distributions and uncertainty in the model results leading to the eventual risk and performance estimates. The following sections depict the specific details associated with data evaluation in each phase of the overall performance methodology.

Structure

Structural information is evaluated with respect to integrity and potential failure modes. The potential failures must be considered for both internal and external initiators. Internal initiators include long term degradation induced by fatigue, weathering, and wear. Other internal initiators may involve waste form interactions such as acid/base or radioactivity effects. Each type of internal initiator must be examined in terms of both the data available and the data required since these two may not necessarily be the same. The difference between the expected and the actual data forms the basis of the uncertainty analysis. The actual data available provides the basis for development of the basic event probabilities leading to failure of the structure or a subsystem of the structure. The data evaluation process provides both measure of completeness and a statistical basis for the development of the failure potential.

Typical examples of data to support the basic event probability development include degradation (due to weathering and wear) rates for structural support members, erosion rates for fill materials, such as soil, clay, and vegetation, and stresses and strain limits for construction materials. An example of the type and quality of data, representing concrete quality, will be in the form of concrete thickness, reinforcing steel strength, and observations indicating number and size of the pore spaces, grain sizes, size and shape of fractures or cracks. These observations are generally determined by non-destructive examination methods. This data is then transformed into numerical values using some type of physical model such as an exponential degradation model, along with expected decay rates of the materials used. The type of model used will depend in part on the process involved and the degree of information required and available. The uncertainty in the predicted degradation rate versus the actual rate can be quantitatively assessed by considering the limitations of the model and the available data.

Source Term

Similar evaluations must be made on the source term. The source term in this case can take on a number of definitions. The two principal definitions are: 1) the total inventory of a particular contaminant and 2) the total quantity of material actually released. Both of these definitions are important in quantifying the probability of failure, release, and exposure. The total inventory of a contaminant is used in postulating the release term where as only the actual material available for release is considered in the exposure assessment. Depending on the level and quality of the information, these two values may be the same or different. In addition to the magnitude of the source term, the chemical and physical form of the contaminants is also significant. The specific details of the waste form are used to estimate release rates from the EDF and the transport potential associated with each of the hypothetical failure sequences. Leachability, volatility, and friability are all important parameters in ascertaining the potential for release and transport. The data is used to provide estimates of the uncertainty and probability for each facet of the release and transport process evaluated. Similarly, the level and quality of the data determines the degree of quantification associated with the uncertainty and or probability desired.

Physical Environment

Like the structural integrity and the source term, the physical environment must be well understood to determine the eventual exposure associated with failure of the EDF. Detailed knowledge of the hydrogeology of the environment surrounding the EDF is critical in evaluating the failure effects. The groundwater is considered to be the principal medium for transport of the contaminants from the EDF to the environment. The transport processes associated with the atmosphere, surface water, and surface erosion must also be addressed to evaluate completely the release, transport, and exposure potential. The significance of each transport process is in part determined by the failure mode considered.

The data required and or available for modeling the physical environmental transport processes is also used to establish the quantitative uncertainty and probability associated with the release and transport. Numerous parameters must be evaluated for incorporation to the various transport models. The quantity and quality of the data ultimately determines the success of the quantification process. Parameters such as hydraulic conductivity, distribution coefficients, and diffusion coefficients are required in evaluating the transport in the ground. The transport via surface erosion or by wind effects requires specific details on additional parameters.

Modeling

The modeling phase of the performance assessment is performed once all of the required data and the available data has been fully evaluated. The limitations of the modeling effort are addressed based on the desired information versus the available data. The available data is used to develop the distributions which will actually be used to determine the characterization parameters and the probabilities. The required data corresponds to that quality and quantity of data needed to determine the actual distributions and within a specified confidence level. This initial effort in addressing the limitations of the modeling will facilitate the quantitative uncertainty analysis as well as the development of probability curves representing the failure, release, and transport mechanisms.

Failure Modes

The possible failure modes must be determined and then modeled. Types of failure modes are considered initially in terms of the following classifications: 1) failure of the support structure, 2) failure of the waste package, 3) failure of the engineered barriers inhibiting leakage, and 4) failure of the leak detection and control systems. Each of these classes must be evaluated for all the ways in which the failure may occur. Each evaluation is then further classified as a failure scenario. Each failure scenario may involve a number of failure sequences. Each sequence is preceded by some type of an initiator. The initiator concept was initially referred to in the

section addressing structure with the central idea of two principal types of initiators being internal and external. The management of these classes, sub-classes, scenarios, and sequences is maintained through the use of fault and event trees. Specific details associated with event and fault trees are provided in the following sections.

Event Tree Development (Structure)

The development of structural failure event trees involves a failure initiator and a series of events which are a direct result of the initial event. An example of an event tree was provided in Fig. 5. The objectives and limitations associated with the development of all the event trees are discussed here. The first step involves the development and evaluation of a conceptual model. The conceptual model provides the basis for examining the possible results of a failure initiator (such as a seismic or tornadic event). The initiator event is postulated and then all the possible consequences are considered. Specific details associated with the development of the initiating event are explained in the section describing uncertainty and probability curves. In the case of a seismic initiator as depicted in Fig. 5, each of the events, relating to the consequences of the earthquake, were first considered independently and then coupled to form the final tree. This tree contains only four events in addition to the seismic initiator. Failure of each of the subsequent events represents a path or scenario leading to a potential release of waste material. These four events represent specific components of the EDF structure which must not fail in order to prevent waste material from being released. The first three relate directly to the structure via the floor, walls, and roof components. The fourth event relates to the engineered barriers such as the leachate detection and collection systems, the geotextile layers, and the base clay mats. Once the conceptual design of the EDF is complete, this tree can be re-evaluated to include additional design features.

Fault Tree Development (Structure)

For each of the events identified in the event tree, a corresponding fault tree is developed. The fault tree forms the structure for determining the event failure and success probability given the specified initiator. By using the "Wall Structure" event as an example, a typical fault tree can be developed. The corresponding fault tree is illustrated in Fig. 6. The descriptions continued in the circles represent the basic events, for which no further simplification is possible with the given amount of information. The events in the rectangles represent the connection between basic events and external events (continued in triangles). The specific connection is represented and calculated by the use of gates. There are two types of gates used in this fault tree: the "AND" and the "OR" gate. The AND gate indicates that each of the events must occur to reach the specified outcome, and the OR gate indicates that any one of the events will lead to the final result. These gates represent the type of mathematical operation to be used in determining the final event probability. The use of this method calculates the final or "top" event probability with only the input of the basic event probabilities.

Source Term - Release Modes

The conceptual modeling utilized for the source term and the subsequent release of contaminants must include all the

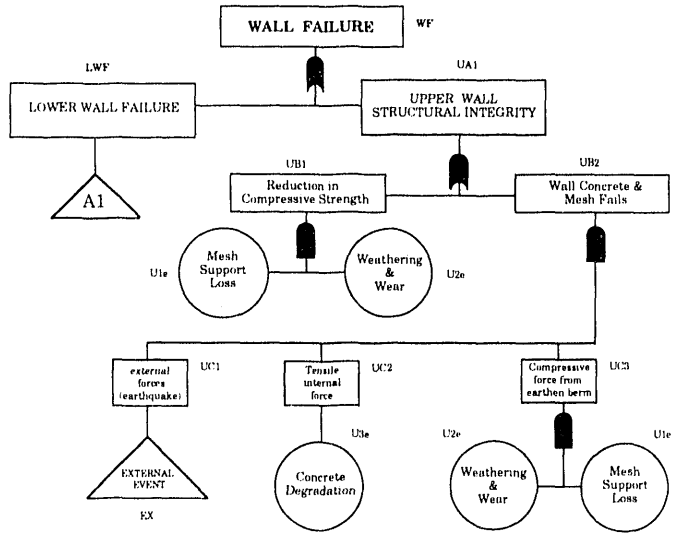


Fig. 6. Fault tree for wall failure.

available information resulting from the structural failure models described above. The modeling of the release term will then reflect the level of uncertainty in the structural failure. For each failure sequence considered in the first phase, a corresponding release sequence will be envisioned in this phase. The time frame of the release along with the magnitude of the contaminants released into the environment are evaluated. The results of the conceptual models representing the source term and the release must reflect two essential qualities: the source strength or magnitude and the time element of the release. The time element may be just a quantity, of a particular contaminant, over a relatively short time frame or the model may incorporate a distribution over a long time frame in either a continuous or discrete fashion. The scenario which may best represent a seismic initiator and subsequent failure of the structure may involve the release of contaminants through cracks and crevices. For a release to occur, a mechanism for the transport of the waste material through the cracks must be available. A potential transport mechanism is a storm event which would permit seepage and infiltration water to contact the waste. For this case of a seismic initiator and structural failure, the release term would correspond to a long time frame and a discrete distribution representing the occurrence of storm events.

Exposure Scenarios

An exposure scenario is essentially the link between the source term and a specific receptor in the environment. The route a particular contaminant will follow, after release, to the receptor is the exposure pathway. Pathways may be of two classes: 1) internal and 2) external. Internal pathways refer to the routes through the human body while external pathways refer to those in the environment. The modeling of exposure scenarios involves all the information accumulated through the modeling of the structural failure and the source term and release modes. The modeling process at this stage will involve primarily conceptual models identifying a range of possible scenarios. Detailed evaluation of these scenarios is made possible by integrating the results of the failure, release, and transport models.

Exposure scenarios will fall into time categories similar to the release modes. Leachate that results from seismic event causing structural failure will most likely be modeled by a long term release mode and a relatively small source term. The exposure scenario would then likewise cover a long time frame with chronic exposure terms such as through ingestion of contaminated water and ingestion of contaminated food products. EDF failure which might occur as a result of a catastrophic flood would result in an exposure scenario involving a relatively large source term and a relatively short exposure duration through similar exposure pathways. Each failure mode and release term must be considered in the wide range of exposure scenarios modeled. The specific exposure scenarios considered form the basis of the environmental transport models required to complete the exposure and risk calculations.

Environmental Transport

The exposure scenarios are used as the basis to develop conceptual and detailed models to represent the environmental transport mechanisms and pathways. The transport models are developed to address both the physical world and the limitations of the mathematical world. The ability to model the environmental transport within some specified confidence interval is limited by the models available and the data required to support those models. The emphasis in this methodology is in the evaluation of the uncertainty and subsequently the probability associated with a result. Increasing the complexity of a model initially improves its accuracy. However, uncertainty increases with complexity as less well known parameters and processes are added to the model. Optimizing between the complexity of the model and the uncertainty in the model parameters is one way of increasing the overall certainty in the results.

A variety of transport models are utilized in setting up the conceptual framework. Each model is then evaluated against the available data and the data required. This evaluation leads to the initial phases of the optimization process. In cases where complex models were used and there was little available information relating to the parameter values, distributions are constructed to represent the possible values to evaluate the uncertainty and the probability. The variety of models used to describe the transport mechanisms include: 1) atmospheric transport, via wind erosion and gaseous source terms, 2) surface water and groundwater, and 3) surface soil movement, resulting from erosion from rain and storm events. Additional models are required to represent contaminant transport in vegetation, animals, and within the human body.

Establish Uncertainty, Sensitivity, and Probability Curves

Once the data has been evaluated and the conceptual models including the event and fault trees have been developed, the next phase of the process is to incorporate the model and data evaluation results into the uncertainty, sensitivity, and probability curves. This phase of the overall performance methodology leads to the probability values used to estimate the final risk numbers and the uncertainty in the estimates.

Structural Failure Probability

The failure initiators such as seismic and tornadic events can be readily developed in terms of event probability and consequence probability. Using the tornado initiator as an example it is readily apparent that the occurrence of the event conforms to a discrete probability distribution where as the actual storm event, which includes description of the wind speed and pressure drop, conforms to a continuous probability distribution. The seismic initiator is similar to the tornado event in the sense that the occurrence of an earthquake is discrete while the exact frequency and wavelength of the ground disturbance is represented by a continuous distribution. Final evaluation of the initiating events provides the probability that the event will occur and the range of consequences associated with the specific event. The details of the initiating event are then coupled with the completed structural fault and event trees to provide the overall failure sequence probabilities. The failure sequence probability for the structure is then used to determine quantitatively the overall probability of the failure initiator and the subsequent failure of the structure. This information is then used to develop the probability of release and ultimately the transport of the contaminants.

Release Probability

The probability formulation of the release modes is dependent on the associated failure mode. For each failure mode considered a specific release term, distribution will be developed. The distribution will reflect the physical and mathematical representation in either a discrete or continuous manner. The probability of a specific release term is determined by the distribution and the associated confidence levels. The term "confidence" refers to the probability that a parameter, x, is less than or greater than a certain value, x_o. As an example confidence obtained from a discrete curve is found simply by adding the probabilities below or above x_o for the lower or upper bound confidence respectively. For a continuous curve the addition operation is replaced by integration above and below x_o, and for cases where the curve was not normalized, the result must be divided by the integral (or summation) throughout its allowed range.

Exposure Probability

The final exposure probabilities are in part a result of the development of the failure, release, and transport probabilities. The exposure probability also involves the details of the internal exposure models for contaminants that are ingested. The exposure probability can be represented by a range of values with a specified confidence range or a single value at a particular confidence level. Both of these formats may be presented and used depending on the objectives considered. The results of the performance assessment are used in a variety of ways. The results can be used to support management decisions in areas of compliance, design constraints, and monitoring requirements as well as others. The from of the probability and uncertainty curves will be determined as the needs arise. The benefit is that the supporting information is readily available regardless of the objective. The final exposure information will convey the specific details of the failure probability and failure mechanism, with the magnitude of the source term and the associated probability of release, and the type of environmental transport including the model and parameter uncertainty (or probability). The failure, release, and transport sequences also include the specific details of time and space. This information and these results provide the

necessary support criteria for the development of the final risk estimates and the overall performance characterization.

RISK ESTIMATES AND CHARACTERIZATION

The primary object in this methodology is the evaluation of the performance assessment of the EDF. The primary method of evaluation is basically to present the results in terms of human health impacts as a result of the exposure to contaminants released. This level of information is still available but now, through this methodology, includes the description of the exposures and the uncertainty in how the risk values were obtained. The probability numbers include the probability of failure, release, and transport instead of just the likelihood of acquiring a cancer in a specified time frame. This level of information and the associated support details concerning the uncertainty and confidence levels or probability can be represented by Fig. 7. This figure represents the various stages of the assessment methodology and the final results in the form of risk curves. Each level of information, probability, confidence bounds, and the overall uncertainty is accessible to the manager to provide the necessary details for making decisions concerning design, compliance, and monitoring issues.

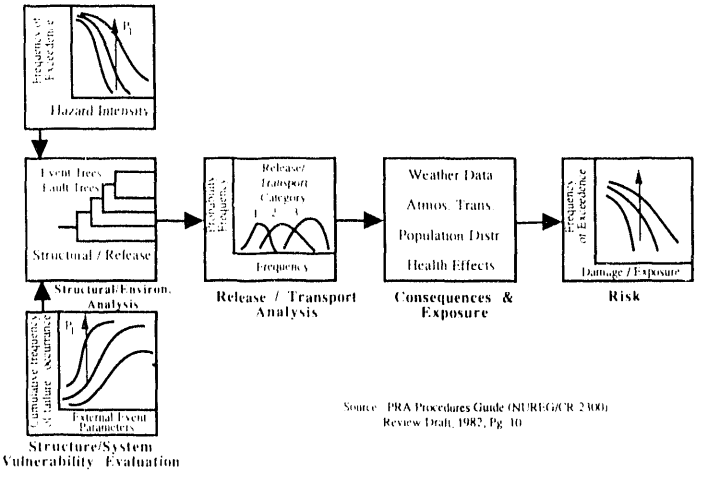


Fig. 7. Risk assessment methodology for external and release events.

As an example of the levels of information available, the following are a comparison of possible results associated with three types of failure initiators: 1) tornado, 2) natural degradation, and 3) an earthquake. The probability of the tornado is likely to be in the range of 1×10^{-7}, that of the earthquake may be approximately 1×10^{-5}, and the probability of natural degradation might be as great as 1×10^{-3} assuming all the probabilities have the same basis (probability per year that the event occurs and results in structural damage). The corresponding release probabilities may be on the order of 1×10^{-2} for each of these initiators described, but the magnitude of the source terms will likely vary by several orders of magnitude for quantity and at least the same variation in terms of the time frame. The advantage of the method described here is that all the information can be used to address the critical failure sequences which lead to the highest dose and has the greatest probability of occurrence.

SUMMARY

The quantitative aspects of this methodology has been presented such that the information provides a means for evaluating design changes or remedial actions in any number of ways, including cost benefit analysis, risk reduction considerations, and technical feasibility. The importance of this methodology is in the quantity and quality of the results. The quantity refers to the levels of detail relating the different modeling aspects, and the quality refers to the confidence levels relating to the probability and uncertainty estimates. Utilizing the total depth of the information available assists the manager in understanding the complexities and the corresponding uncertainties. Without this, detail focus may be applied inappropriately on issues that are less critical than others.

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AIRBORNE SOURCE-TERM MODELING OF PAST AND FUTURE INTERIM STORAGE PRACTICES OF HANFORD SITE WASTE TREATMENT FACILITIES USING AIRSOURCE MODEL

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ABSTRACT

A computer code, AIRSOURCE, was developed to characterize the airborne source terms of the waste treatment facilities at the Hanford Site. This code is based on simple engineering models of liquid to vapor material transport. The present model has data libraries for 72 inorganic, organic, and radioactive materials which are present in the waste treatment streams. The geometries in the code include many of the facilities such as vented tanks, holdup basins, and retention facilities which are used for waste treatment. Recent additions to the model have included aerosols formed by leakage sprays which will be used for accident studies.

Airborne source terms were determined for the waste treatment facilities of the past and future waste treatment facilities at the Hanford Site. The waste treatment facilities used in past practices include holdup basins, soil column disposal cribs, and flow-induced air entrainment in process piping. The future practices modeling included source term characterization of large covered holdup basins ranging in capacities from 1 to 6.5 million gallons, pumping stations, filtered vent systems, and effects of maintenance activities and small breaks in the covers.

The design of the retention basin cover was critical for facility acceptance. Several materials and designs were investigated. A design based on high-density polyethylene was found to be acceptable. The results of the source term modeling demonstrated that the future practices source terms were less than those of the past practices.

The AIRCOURCE code is sufficiently general and has a broad range of potential applications with liquid air interfaces where the liquids can contain both radioactive and hazardous materials.

INTRODUCTION

Westinghouse Hanford Company functions as the operations and engineering contractor at the Hanford Site U.S. Department of Energy (DOE) facilities. A major mission of this responsibility is to process the chemical and radioactive wastes from former weapons material production and other activities into a form suitable for permanent storage or disposal. These processing activities involve waste reduction which separates solid wastes from effluents that have trace concentrations of chemical and radioactive materials. This water had been previously disposed of in soil column cribs which sometimes resulted in a local below-surface contamination.

In 1989, the Hanford Federal Facility Agreement and Consent Order (2) was signed by the DOE, the U.S. Environmental Protection Agency (EPA), and the Washington State Department of Ecology (Ecology). The Tri-Party Agreement is an effort to restore the Hanford Site to environmentally acceptable standards and to end the practice of soil column disposal. As a result of timing commitments and processing schedules, a facility that will remove and permanently store the trace contamination materials from the contaminated effluent water will not be available for several years. It is necessary to provide interim storage of the effluent water in order to keep the waste processing functions operating until these effluent treatment facilities are made available.

In order to operate this interim storage facility, Ecology required a demonstration that atmospheric releases from the future practices interim storage would be less than those of the past practices operations involving the soil column disposal of effluents.

To achieve this objective, a description of equipment items and processes in the past practices and proposed future practices interim storage was made. This description involved concentrations, flow rates, temperatures, and parameters such as surface areas, ventilation rates, and filtration efficiencies which affect the atmospheric source-term releases. A diagram of the equipment items that contribute to atmospheric release is provided in Fig. 1. The design of the retention facility was not finalized at the start of this project. Several design variables were considered and evaluated before a design was finalized. At the beginning of this project, 72 inorganic, organic, and radioactive materials were considered in the effluent stream. Provisions were for possible addition to this list.

DISCUSSION

From consideration of the large number of materials involved and the variations expected in facility design, it was apparent that a computer model was required that would account for the characterization, material inventory, where appropriate, and atmospheric release contribution of each material. An investigation of available computer models did not identify a code that could be applied to the unique application of our situation. It was decided that the AIRSOURCE code would be developed in-house to fulfill our requirements and to meet the time constraints of the project schedule. The code was designed to have much broader applications than the illustration discussed in this paper.

The AIRSOURCE code provided a data library of temperature-dependent parameters such as vapor pressures, solubilities, and activity coefficients that were used to characterize the mass transfer coefficients and saturation limits of materials for a liquid-vapor interface. The concentrations in

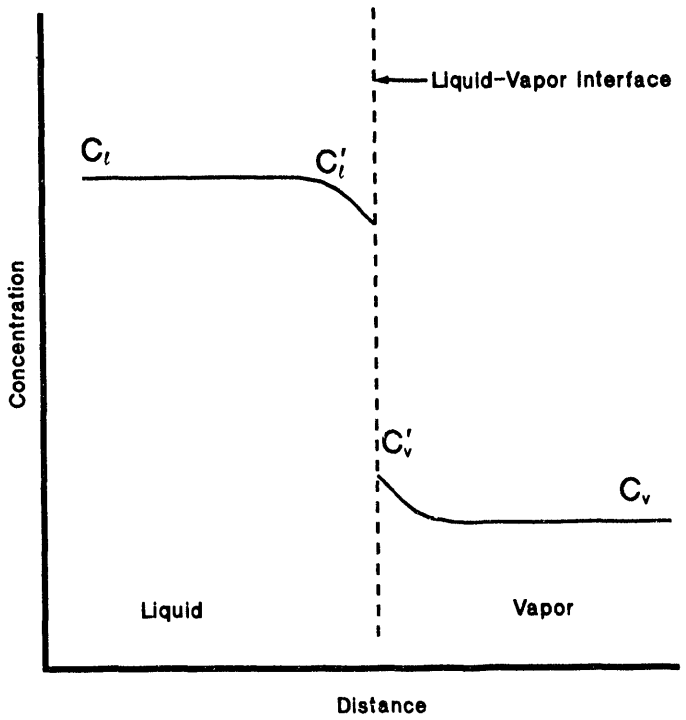


Fig. 1. Liquid-vapor interface mass transfer.

the liquid were found to be low enough to ignore material interactions. The particular geometries of each representative facility design were characterized by generalized straightforward engineering models. By this approach, the AIRSOURCE model provided a consistent and flexible basis upon which to model the atmospheric releases and to compare the source terms of the past and future practices.

Models were developed to determine the atmospheric release from a number of equipment items. These items included pump wells, storage basins, ground release cribs, uncovered and covered ponds, soil column cribs, and entrained air in piping. Most of the airborne sources estimated by these models were not highly significant when compared to the releases from the retention pond. The elimination of equipment such as the open retention cribs gave some advantage to the future practices approach with respect to atmospheric source terms. However, the source terms from the large retention ponds would have to be reduced considerably from those of the uncovered facility.

The design of the interim storage facility became the focal part of this study. The capacity of this facility is required to hold an annual accumulated flow of approximately 6.5 million gallons. These facilities would be required to retain effluent for about 4 to 5 years before a treatment facility is scheduled to begin operation. After that time, the storage facility may possibly serve in a standby capacity.

A number of candidates were considered for the design of this storage facility. One design considered was a double-lined evaporative pond which allowed volume reduction in the typically dry atmosphere at the Hanford Site. The modeling of this design provided for release by mass transfer of volatile materials and by particulates formed from wind-induced aerosols. The material inventory balance was accounted for in the vapor and aerosol releases to the atmosphere and in the concentration adjustment in the basin water. This design was rejected as a result of release rates which exceeded the past practices levels.

It became apparent that a fully covered storage facility would be required to adequately retain the volatile materials below the levels released by the past practices facilities. To meet this requirement, two covered storage facility designs were investigated. One design was an above-ground modutank of approximately 1-million-gallon capacity. The other design was a ground-level liquid effluent retention facility (LERF). The flow diagrams of these two facilities are shown in Fig. 2.

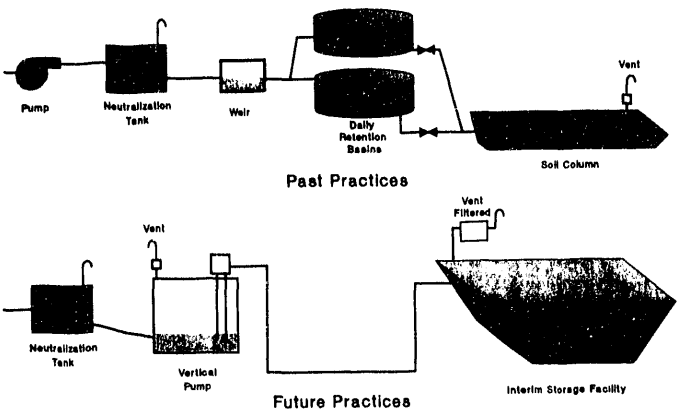


Fig. 2. Past and future effluent waste treatment.

The advantage of the modutank is that it is quickly built and can best meet the early time constraints of the project. The advantages of the LERF design are a larger volume-to-area ratio which results in lower atmospheric losses and cost-effectiveness of a more-compacted site use and simpler vent filtering requirements. It was determined that, depending on design acceptance, the LERF would be used for main storage. The modutanks would be built if the schedule of the LERF could not be accommodated.

A number of cover materials and designs were investigated. These materials included hypolon, metal-impregnated hypolon, mylar, and normal-, very-low-, and high-density polyethylene. Of these designs, a 2.54 E-04-meter-thick cover using very-low-density polyethylene was chosen on the basis of its simplicity and flexibility. The atmospheric model with a cover showed very significant reductions of source-term release over the models of an uncovered surface. The comparison between the covered and uncovered surface release rates is demonstrated in the following review of the models used to determine the release rates in both cases.

The case of a volatile material mass transfer across a liquid-vapor interface boundary is shown in Fig. 1. The bulk concentrations of liquid and vapor are C_l and C_v, respectively. The respective concentrations of the liquid and vapor phase in equilibrium at the interface boundary are C_l' and C_g'. At distances close to this interface boundary, a concentration gradient exist such that:

$$Flux = k_l (C_l - C_l') \quad \text{(Eq. 1)}$$

$$Flux = k_v (C'_v - C_v) \quad \text{(Eq. 2)}$$

where

k_l = the liquid interface mass transfer coefficient

k_v = the vapor interface mass transfer coefficient.

At the interface, Henry's Law applies which gives:

$$C'_v/C'_l = H' \qquad \text{(Eq. 3)}$$

As a result of a relative slow mass transfer rate and an ample supply of wind to exchange the vapor mass in an outdoor facility, the bulk vapor concentrations C_v is assumed to be zero. This assumption simplified the results and gives the most conservative results.

An overall mass transfer coefficient K is defined for the system such that:

$$Flux = K(C_l - C_v) \qquad \text{(Eq. 4)}$$

Solving and rearranging gives:

$$\frac{1}{K} = \frac{1}{k_l} + \frac{1}{k_v H'} \qquad \text{(Eq. 5)}$$

Henry's law constant is given by:

$$H' = \frac{\lambda P_v}{RT\rho} \qquad \text{(Eq. 6)}$$

or alternatively, if activity coefficients are not known:

$$H' = \frac{P_v}{SRT} \qquad \text{(Eq. 7)}$$

where:

λ = activity coefficient
P_v = partial pressure
R = Boltzmann gas constant
T = temperature (K)
S = Solubility
ρ = molar density of water.

A new correlation was derived for k_l from data in Lyman (3):

$$k_l = 36 * \left(\frac{85}{M}\right)^{0.5} * 10^{0.1477*vel}, m/s \qquad \text{(Eq. 8)}$$

The following correlation was obtained for k_v from Eq. 15-32 in Lyman (3):

$$K_v = 49518*vel*\left(\frac{18}{M}\right)^{0.5}, m/s \qquad \text{(Eq. 9)}$$

TABLE I

Typical Time-Average Wind Speeds on the Hanford Site

Group	Wind Speed (m/s)	Time Fraction (%)
1	0.894	26.3
2	2.46	38.2
3	4.47	22.6
4	6.93	9.2
5	9.61	3.0
6	12.5	0.6
7	15.7	0.1
8	19.0	0.0
9	20.6	0.0

where:

M = molecular weight
vel = wind velocity (m/s).

In the case of a surface having a polyethylene cover, a diffusivity was obtained from vendor-supplied permeabilities. This diffusivity can be extended to similar materials by analogy with liquid diffusivities as in Bird (1).

$$D = D_o\left(\frac{\rho}{\rho_{lo}}\right)^{0.6}\left(\frac{T}{T_o}\right) \qquad \text{(Eq. 10)}$$

$$\approx D_o\left(\frac{M_o}{M}\right)^{0.6}\left(\frac{T}{T_o}\right) \qquad \text{(Eq. 11)}$$

where:

D_o = diffusivity of cover for a representative material
ρ_l = molar density of solutes
M, M_o = molecular weights of solutes.

The liquid-vapor interface mass transfer is dominated by the resistance of the cover. The mass transfer coefficient becomes:

$$K_l = k_l H' \qquad \text{(Eq. 12)}$$

$$where\ k_l = \frac{D}{\Delta x} \qquad \text{(Eq. 13)}$$

TABLE II

Diffusivity Coefficients and Corresponding Cover Protection Factors of a 2.54 E-04-meter-thick High-Density Polyethylene Cover

Representative Material	Molecular Weight	Diffusivity (m^2/s)	Protection Factor (Ratio Mass Transfer Coefficient)
1. Methyl Alcohol	32	7.287 E-11	174,000
2. Acetone	58.08	6.955 E-11	61,000
3. Cyclohexane	84	2.437 E-09	2,600
4. Benzene	78	4.988 E-09	1,600
5. Chloroform	119.38	3.281 E-09	60
6. Ammonia	17	2.163 E-11	800,000
7. RuO_4	165.07	1.137 E-13	80,000
8. Tritium	20	9.644 E-12	250,000
9. Methyl Iodine	141.91	5.223 E-17	412,000

where Δx is the cover thickness.

The effectiveness of the cover for reducing airborne emissions can be estimated from the ratio of the mass transfer coefficients of the covered and uncovered cases. This ratio is referred to as a protection factor. The protection factor was evaluated for a 2.54 E-04-meter-thick cover of high-density polyethylene for a number of representative materials at 288 K. The wind speeds assumed in this evaluation are given in Table I. These wind speeds were used to determine the mass transfer coefficients of materials in the uncovered pond. The wind speeds listed are representative of yearly time averages at the Hanford Site. The results of the protection factor evaluations are summarized in Table II.

These results indicate that a cover provides a very effective barrier against the release of most materials to the atmosphere. The materials of primary interest for our application were the radionuclides. The radionuclides were represented by the materials in Items 7, 8, and 9 in Table II. For the levels of concentrations involved in this application, the retention of the LERF design was adequate to maintain releases well below permitted levels.

CONCLUSIONS

The models demonstrating the cover effectiveness to retain materials in the retention facility were vital to meeting the objectives of this project. The results of these model developments showed that the proposed retention basin cover was very effective in reducing the air emissions of the materials which were vital to project acceptance. The results of this study demonstrated that the total future practices atmospheric emissions were lower than those of the past practices. Because of these findings, the project permitting was allowed from Washington State and the construction of the interim storage facility is progressing according to schedule.

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BASELINE RISK ASSESSMENT METHODOLOGY FOR MIXED WASTE

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ABSTRACT

The presence of mixed waste (chemical and radioactivite) introduces several complex issues into a baseline risk assessment. A five-stage, serial methodology consistent with Department of Energy orders and Environmental Protection Agency regulations is available for the evaluation of risk at these disposal sites. The methodology suggests a simple-to-complex approach for the determination of risk. Guidelines for the combination of radiological and nonradiological risk are proposed.

THE PROBLEM OF MIXED WASTE

Many sites on the National Priority List (NPL) that have been addressed through the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) and Superfund Amendments and Reauthorization Act (SARA) process involve inorganic constituents which are long-lived relative to organic chemicals. The primary difference when radionuclides are present is that the radiological decay chain and the decay products need to be factored into the predictive results. The presence of mixed wastes introduces several complex issues into baseline risk assessment; these issues include:

- How will the radiological and nonradiological health effects be combined?
- How will the health effects of complex mixtures (more than one hazardous constituent) be combined?
- Have any studies been done to identify these combined effects?
- Can conservative assumptions be made to identify the upper bound of the combined risk?
- How can the CERCLA process address the effects of long-lived radionuclides?
- How can it be proven that any remedial action is protective of human health and the environment with long-lived waste constituents present?
- What existing computer programs (codes) and other tools are available for use in a risk assessment that address long-lived radionuclides?
- What specific data are required for these models?

RISK ASSESSMENT METHODOLOGY

A methodology for factoring radiological constituents into a health-based risk assessment consistent with the CERCLA guidance (1, 2) has been developed for evaluation of disposal sites at the Idaho National Engineering Laboratory (INEL). Additional perspective is obtained from Chapters II and III of DOE Order 5820.2A, Radioactive Waste Management. In general, health-based risk assessments are not required under RCRA regulations; however, a portion of the methodology is useful in modeling constituent migration to help in the implementation of ground-water monitoring plans as required in 40 CFR Part 265, Subpart F. Also, preparation of health-based risk assessments are useful in developing constituent levels for RCRA site-cleanup operations where no formerly adopted regulatory standards exist. In general, the baseline risk assessment methodology is a serial operation with five stages of analysis; they are: release scenario, source term definition, constituent transport, exposure assessment, and risk characterization.

Release Scenario

The release scenario sets the stage for constituent migration into the environment. The storage of waste, the direct disposal of waste into the environment, a time degradation of an engineered disposal system, a waste treatment process or remedial alternative, a long-term natural periodic event (erosion or precipitation), a catastrophic natural event (flood or earthquake/fault), or a human accident are important to the development of the source term. An initial set of reasonable assumptions leading to the release of waste constituents is the goal of this analysis. These assumptions affect both the magnitude and the release duration of the source term.

Source Term Definition

The source term is influenced by the release scenario, waste form, waste constituent properties, release mechanism, and surrounding environment. Mathematically, the source term is a constituent mass flux released to a medium (atmosphere, surface water, unsaturated subsurface, and ground water) over a specified period of time. The release of waste constituents to the surrounding natural media can be quantified using one or more of five general release mechanisms; they are:

- Subsurface infiltration
- Subsurface barrier permeation
- Surface water dissolution or particle sorption
- Atmospheric particle release or resuspension
- Atmospheric volatilization.

Release rate values are required for each waste constituent. The release rate values are based on chemical and site-specific factors and become the source terms for subsequent transport and fate analysis. Individual site releases of each constituent are summed to generate an overall, media-specific release rate. A steady-state condition is preferably assumed; however, short-term (transient) release rates can be developed as worst-case conditions.

Constituent Transport

The goal of the transport and fate analysis is to identify any constituent concentrations at off-site areas that may affect the exposure and subsequent health of human populations or other environmental receptors. An initial qualitative screening is recommended to identify the following:

- Relevant transport processes, phases, and media
- Preliminary directions and rates of potential constituent migration
- Potential receptor locations or areas.

Selection of appropriate computer models for each of the four transport media requires some familiarity with the multitude of codes that are currently available. Several published documents are available with useful code descriptions (3, 4, 5, 6). In general, simulation problems for constituent transport and fate are from field data limitations and not from computer model availabilities. At the present time, more generic data are available for transport simulation of radionuclides than for hazardous waste constituents.

Exposure Assessment

For the purpose of risk analysis, exposure is defined as the contact of a constituent with the exchange boundaries (lungs, skin, or gastrointestinal tract) of a potential receptor. The goal of exposure analysis is to quantify this constituent contact in a given time interval. The EPA provides guidance (7) for estimating exposure from three contact scenarios:

- Inhalation
- Dermal contact
- Ingestion.

A 30-year exposure lifetime is recommended (8) to provide a conservative upper bound on lifetime exposure (conservative assumption based on residential property turnover data). For CERCLA studies, an average adult body mass of 70 kg is used for exposure estimates. Constituent concentrations and durations at a receptor location estimated from transport and fate modeling provide the basis for the exposure assessment. Finally, each step of the assessment is reviewed to identify uncertainties and their effects on the final results. The uncertainty analysis provides useful information to evaluate remedial alternatives and associated implications for potential implementation risks and risk reduction effectiveness.

The analysis of exposed populations uses an initial screening to eliminate exposure pathways that are not likely to contact human populations. These pathways are excluded from further analysis. The remaining pathways require quantitative analysis to estimate the extent of human exposure. Population characterization is used to identify subpopulations that constitute high-risk groups. Some quantitative assessments may require additional partitioning to further determine age- and sex-specific exposure factors. An activity analysis to determine who may be exposed is a common refinement.

The exposure assessment is used to estimate a range of potential constituent intakes. Risks are estimated by combining toxicity information with estimated potential daily intake. In performing the calculations, a health-protective approach is used such that risks are most likely overestimated rather than underestimated.

Risk Characterization

For carcinogens, risks are expressed as probabilities. For chemicals, incremental lifetime cancer risks (ILCR) are estimated using:

- A carcinogenicity slope factor ([CSF], an upper-bound confidence limit on the probability of a response) for each constituent
- The estimated intake (chronic daily intake [CDI]) based on the exposure assessment.

The ILCR is expressed as potential additional cancers above background anticipated as a result of exposure to a carcinogen in drinking water, food, or air. Estimation of the ILCR is given by the product of the CSF and the CDI.

For radiation, the absorbed dose is converted to cancer risk by use of risk factors. These risk factors (RF) are commonly referred to as the Biological Effects of Ionizing Radiation (BEIR) III risk factors. The ILCR due to radiation exposure is calculated as the product of the exposure rate (ER), the RF, and the exposure time.

Noncarcinogenic risk is derived by estimating a hazard index (HI) for exposure to indicator chemicals as described in the Human Health Evaluation Manual (HHEM) (8). Acceptable levels of exposure are estimates obtained from current regulatory guidelines. These acceptable levels may be expressed as acceptable chronic daily intakes (AIC) or reference doses (RfD). Although both AICs and RfDs are similar in concept, the EPA prefers the use of RfDs, if available, because AICs are derived using a less strictly defined methodology than that required for RfDs. A constituent-specific HI is estimated as the product of the daily intake (by a specific pathway for a specific constituent at a specific location) and the acceptable intake (AIC or RfD) for chronic exposure.

MODELING APPROACH

The overall model selection process follows a three-level approach. In level one (screening), the constituent concentrations will be determined at a given receptor location from the simplest, most conservative model appropriate for a given constituent release site. If the exposure at the receptor location determined from this model exceeds a maximum allowable level, a more sophisticated model (level two) will be used to reevaluate the exposure. If the results of the level-two risk assessment exceed the acceptable risk value, then more detailed modeling efforts are warranted. This simple-to-detailed modeling approach minimizes the effort necessary to determine constituent exposure by avoiding complicated models that require detailed input and more complex computation when this level of sophistication is not necessary.

The third, and most detailed, level of modeling addresses processes and parameters of a highly site-specific nature. It requires refinement of existing models, the selection of more sophisticated models, or the development of new ones, particularly for simulating the source term. It also involves a much larger data collection task to support the modeling activities.

The screening level process is designed to evaluate the risk of a constituent release which is more than a hazard ranking, as discussed by Hartz and Whelan (9), and Whelan et al. (10, 11, 12). To conservatively assess the potential effects of a constituent release, the entire mass of constituent is first assumed to be directly released to the primary transport zone (where the primary transport zone is either the atmosphere, surfacewater, or ground-water zone). By assuming this, only the transport pathways which directly come in contact with the receptor are considered.

Constituent transport, via air or ground water, is modeled next to determine the concentration at the receptor. Once the constituent concentration is known at the receptor, a screening level exposure assessment will be conducted to determine the receptor exposure risk associated with the constituent. The risk calculated at this stage of the screening process determines whether additional, more detailed modeling is required. If the risk determined at this level is acceptable, the source will not require additional modeling.

The atmospheric fate of constituents released from waste sites can be estimated using equations contained in Superfund Exposure Assessment Manual (13). Where estimates of ambient atmospheric concentrations indicate potential health hazards, a number of computer codes are available. The following codes are recommended for transport modeling in air media: SCREEN (new code), INPUFF, AIRDOS, ISCLT, ISCST, and SPILLS. Other relevant EPA documentation contains additional resource requirements, references, and model sources (13).

The environmental fate of constituents entering surface waters is dependent on whether the water body is a stream, impoundment, or estuary. Methods for estimating constituent concentrations are published by EPA (13). Computer codes useful for more detailed analysis include: SLSA, EXAMS-11, and EQ3NR/EQ6 (solubility/speciation/reaction). Long-term average ambient water concentrations are calculated for the period of interest from average release rates and average stream flow rates.

Estimates of ground-water fate include initial evaluations of flow direction, flow volume, constituent concentration, and constituent volume. For ground-water modeling, considerations of constituent leaching, constituent percolation, unsaturated flow, ground-water flow, multiphase flow, dispersion, constituent transformation, and constituent retardation are important to the selection of appropriate computer models. Equations, generic values for hydraulic properties, and nomographs are published by EPA for screening-level estimation purposes (13). Computer models for application to unsaturated, subsurface media include: UNSAT1D, SUTRA, TRACR 3D, and FEMWATER/FEMWASTE. Computer models for application in saturated ground-water media include: SUTRA, FEMWATER/FEMWASTE, SWIFT III, and TRACR 3D. The water quality considerations affecting constituent transport can be helped, quantitatively, using the solubility/speciation/reaction pathway code EQ3NR/EQ6.

EXPOSURE TO MIXED WASTE

Little information is known about the interactions of ionizing radiation and chemicals. This interaction has best been documented in epidemiological studies of tobacco users exposed to radiation (14). Studies of miners exposed to both tobacco smoke and radon have not yielded definitive results as to whether the interactions of these exposures are additive or multiplicative (synergistic). Several small statistical studies have yielded mixed results. The largest study done by Whittemore and McMillan (15) on Colorado uranium miners supported a multiplicative interaction. On the other hand, studies of Swedish miners exposed to radon daughters and followed for a long period of time did not show synergism between smoking and radon exposure (16).

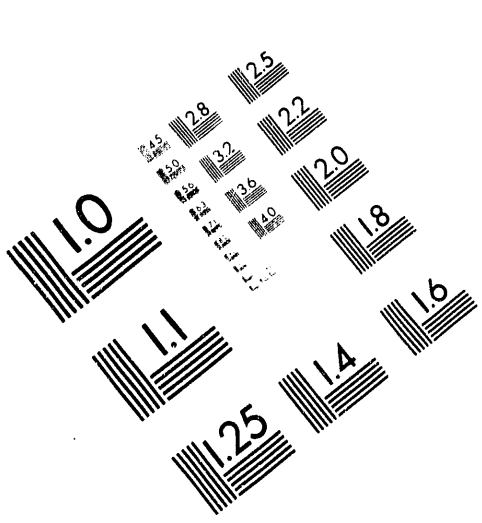
Studies on the A-bomb survivors provided no indication of interaction between smoking and ionizing radiation. In fact, both additive and multiplicative models fit the data obtained. However, these studies provide only limited data on addressing this interaction, because the association of cancer with each of the factors individually is more complex than can be statistically documented. The actual biological relationship between carcinogenesis and one of these exposure scenarios is characterized by interactions such as age at first exposure, sex, diet, and genetic predisposition. When studying the combined effects of cigarette smoking and radon exposure, factors such as the sequencing of exposures and the degree of overlap of exposures becomes important. Unfortunately, most models do not account for these factors. The BEIR Committee believes that a submultiplicative model may be the best method of addressing these complicated interactions.

The NCRP (17) reviewed the influence of environmental factors (in all cases, cigarette smoking) on radiogenic risk and whether such factors interacted with ionizing radiation to increase or decrease cancer effects. (No studies on the combined effects from exposure to low-level radiation and chemicals were available for review.) In the four studies reviewed, the NCRP found that cigarette smoking affected radiation cancer in the following manner:

- Lung cancer data - inconclusive
- U.S. uranium miners (radon daughters) - synergistic effects
- Swedish iron miners - additive
- A-bomb survivors - additive.

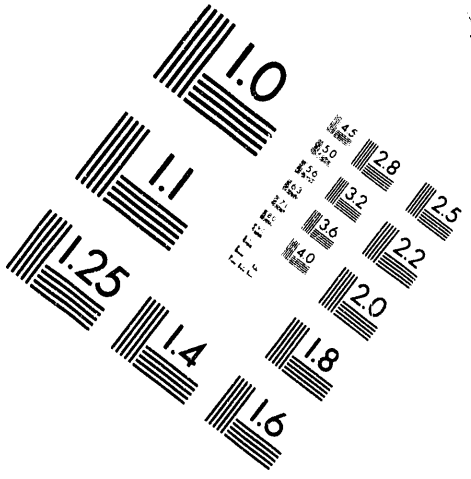
In perhaps the most extensive study addressing the issue of the differences between radiological and chemical risk, the NCRP stated that the principles for assessing carcinogenic risks of ionizing radiation and chemicals are in essence similar. However, differences do exist. Issues involved in these differences, some of which were addressed for the Savannah River study, are outlined below:

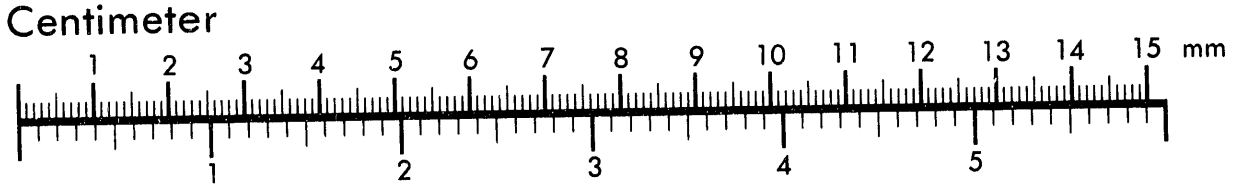
- While the risks of ionizing radiation can be inferred from one radionuclide to another, chemicals vary widely in molecular structure, metabolism, mechanism of action, potency, and the stage in the cancer process during which they act. It has been argued that these differences make comparisons to radiation risk difficult; however, the below-listed responses to this argument have been made. For both radionuclides and chemicals, carcinogenic effects have been noted in almost every organ of the body, so that major differences in distribution occur among radionuclides as well. This does not mean the comparisons are valid.
- Historically, risk from exposure to ionizing radiation has been calculated for exposures above background levels. While in the past, risks calculated for chemical carcinogens have been absolute values, the move towards calculating the risk above background exposure has begun.
- Of the 3500 potential carcinogens identified by the National Academy of Sciences (18), only 23 have been verified as human carcinogens by the International Agency for Research on Cancer (19). Ionizing radiation has been shown to be a human carcinogen. This is perhaps the greatest difference in comparing chemical carcinogens and radionuclides.

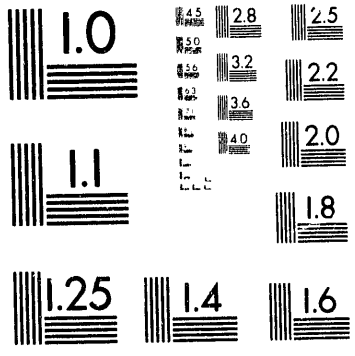


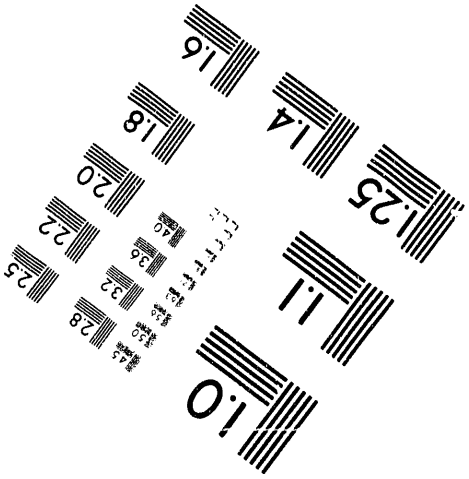


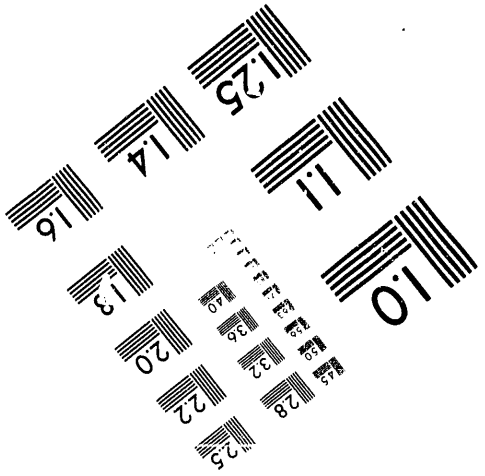
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4 of 10

- Approximately 23 chemicals are known to cause cancer in man. (EPA only lists 10 Class A carcinogens). For these chemicals, epidemiological data have been used to estimate human risks using a linear model, as is the case with radiation carcinogenesis. In both cases, the only extrapolation required is from high occupational doses to low environmental doses.
- Hundreds of chemicals have been identified as carcinogens in laboratory animals. To infer risk using these studies requires extrapolation between small rodents to humans using the linearized multistage model, and extrapolation from near toxic doses to low environmental doses. Radiological risk evaluation does not require interspecies extrapolation. However, according to recent studies (Rowe and Springer [20]; Hertz-Picciotto et al. [21]; Allen et al. [22]), the human health risks estimated using animal data closely match human risks estimated using data from epidemiology studies.

The issue of the combined effects of radiation and chemicals on cancer may not be solved for many years.

CONCLUSIONS

Regulatory guidance does not exist with which to address the issue of the health effects of mixed waste. Regulators have made statements suggesting that risks from multiple substances should be added to estimate the total cancer risk from a site.

- When dealing with chemicals that pose both a radiocarcinogenic risk and a chemical toxicity risk, selection of the method for determining acceptable levels can be done by two methods:
  1. If standards exist that address both the chemical form and the radioactive form of a compound, the lowest standard should be used to guide a cleanup effort.
  2. If no standards exists, the cleanup effort should be based on risk-based cleanup criteria. Using exposure pathway analysis and information on the potency of the compound, acceptable intake values can be inferred for both radiotoxicity and chemical toxicity. The lowest acceptable intake value should be used to represent the limiting health effect.
- Based on limited available information about combined effects from radiocarcinogenesis and chemical carcinogenesis, the following recommendations are made:
  1. Cancer risks can only be added with some certainty when they are based on epidemiological data and a common dose-incidence model, affect similar target organs, and display similar mechanisms of action.
  2. Adding risks from radiocarcinogens and chemical carcinogens that affect different organs at different stages of the cancer process is more tenuous. The exercise becomes even more uncertain when chemical cancer potency values are obtained from animal data. This exercise should only be resorted to when screening approaches are needed to provide an initial indication of the overall severity of a perceived hazard. However, since the 95 percent upper-confidence bound on the animal dose response curve is used to estimate the human risk, the total risk will most likely be even more health protective as the risks are summed (23). An explanation of the uncertainties associated with adding these risks should be clearly stated.
  3. Relative radiogenic and chemical cancer risks may be determined and the resulting ratios summed, perhaps alleviating some problems associated with comparing risks derived from two different methods.

Due to the lack of definitive regulatory guidance, application of these recommendations should only be performed with the aid of competent professional judgment.

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AN EFFECTIVE METHODOLOGY FOR ESTABLISHING CLEANUP STANDARDS FOR MERCURY CONTAMINATED SOILS

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ABSTRACT

The Department of Energy has determined that an integrated planning approach to the remediation of mercury contamination is an effective methodology for addressing the mercury related problems at the Oak Ridge Reservation. The methodology for determining the Soil Response Action Levels for the Oak Ridge site should be an important component of the integrated plan, thereby ensuring that the risk of migration of contaminants to groundwater will be minimized and acceptable.

The paper summarizes mercury related applicable or relevant and appropriate requirements (ARAR), based on federal, state and other regulations that must be met. The analysis in this paper shows that irrational application of the ARARs may result in the selection of alternatives that are not cost-effective. Whereas, the best technology based soil response action levels, selected on the basis of realistic risk assessment and TCLP test criteria, will yield a more practical and cost-effective cleanup standard.

INTRODUCTION

Mercury, known to ancient Chinese and Hindus, was found in the Egyptian tombs of 1500 B.C. (Weast, 1976). Mercury is the only common metal that is liquid at ordinary temperatures. It only rarely occurs free in nature.

On-site and off-site mercury contamination has been identified at the U.S. Department of Energy's (DOE) Y-12 Weapons Facility in Oak Ridge, Tennessee, as a result of significant mercury operations conducted there since 1950. Mercury released to the environment has been found in, around and beneath certain process buildings, in the East Fork Poplar Creek and its floodplain soils, and in sumps, sewers and the groundwater (Turner, 1989). This extensive contamination problem begs for a solution, which appears to be quite elusive at this time.

The difficult questions are: (1) what soils do we clean up? (2) how do we cleanup the soils and groundwater? (3) how expensive is it going to be? While our engineers and planners are grappling with these complex questions, this paper has made an attempt to address the first question. Our focus here is not to identify a specific solution, but to provide suggested methods for seeking an effective solution.

This paper explores suitable methodologies for establishing cleanup standards for mercury-contaminated soils that resulted from the Department of Energy's activities at the Oak Ridge Reservation in Tennessee. There are several methods and models that were developed to establish soil cleanup levels at Superfund sites (USEPA, 1989). An assessment of these techniques and resulting cleanup standards have been used to develop suitable and effective methodologies for addressing the need for an appropriate soil cleanup criteria at Oak Ridge. The findings of this critical assessment will be discussed, and the framework for a new and appropriate methodology will be presented.

SOIL RESPONSE ACTION LEVELS

Contaminated soils, wherever they may be, require necessary and appropriate corrective action. As such, soil contaminant concentrations can be established at which certain response actions may be required. Four major categories of action levels can be established with respect to mercury contamination (USEPA, 1989):

1. Background concentration or less; no action is required.
2. One order above background concentration or less; investigation required, and appropriate remediation may be necessary.
3. Resource Conservation and Recovery Act (RCRA) action level or less; investigation and remediation are usually required, and
4. One order above RCRA action level; interim remedial action or removal action is required.

These action levels should be identified for mercury contamination and suitable methodology established for their determination.

ACTION LEVEL DEVELOPMENT METHODOLOGIES

Three major models for establishing soil cleanup standards have been identified in the literature (USEPA, 1989):

1. Fate and Transport Methods,
2. Analytical Methods, and
3. Generic Methods.

A suggested new criterion for developing a more effective methodology is the application of Best Demonstrated Available Technology (BDAT) for soil cleanup to the chosen model. The methodology will include considerations of (1) the BDAT cleanup, (2) the daily intake of contaminants (Bashor, 1986), (3) the pathways of potential exposure, such as inhalation of dust/air, ingestion of fish/other foods/soils, etc. (USEPA, 1990), (4) the speciation of mercury (Revis, 1989), (5) the intestinal absorption studies on mice and humans (Revis, 1990), and (6) the Toxicity Characteristic Leaching Procedure (TCLP) test-based soil response factors (Willet,

1991). These factors and the aforesaid three methods of developing mercury-contaminated soil cleanup standards will be synthesized and integrated in this paper.

FATE AND TRANSPORT METHODS

These methods are designed to evaluate the transport of organic and inorganic contaminants in the soil and groundwater by way of leachate pulse generation, vertical and horizontal spreading (VHS model) in unsaturated as well as saturated zones of soil and aquifer. An overview of fate and transport models applicable to mercury contamination are summarized in Table I.

The model selected for this study is a VHS model, also called the RAPID assessment model or the SOCEM I model. The model includes a metal speciation subsystem, also called the MINTEQ model (USEPA, 1987), capable of analyzing the interactions of various forms of mercury with bacteria, abiotic, phytoplankton, and other metals (EPRI, 1990).

ANALYTICAL METHODS

These methods employ leachate extraction tests on contaminated soils to determine their soluble contents and compare them to existing health advisory levels and site conditions. The extraction tests include among others the Toxicity Characteristics Leaching Procedures (TCLP) and the EP Toxicity Test for substances with drinking water standards. A modified USGS three-dimensional groundwater fate and transport model is used to determine the "reasonable worst case" protection levels in soil.

Two major approaches may be employed to utilize these test values. First approach is to apply EP Toxicity regulatory levels directly to establish soil cleanup standards. The soil cleanup levels are set at a concentration that would result in leachate concentrations less than the EP Toxicity test maximum allowable values. However, the RCRA-established TCLP cleanup levels may not be adequately protective, since the remaining contaminants could cause groundwater concentrations to exceed health-based drinking water standards (USEPA, 1989a; Willet, 1991).

Second approach is to use the EP Toxicity or TCLP tests as the soil leaching test. This may be the most preferred approach, which assumes that the laboratory extraction leachate concentration is equivalent to leachate from the soil. Because of the variations in nature, this may not be a valid assumption.

An overview of five potential leachate extraction tests are summarized in Table II. The inherent limitations of these analytical methods are also enumerated in Table III, which is based on a comparison of alternative analytical methods.

GENERIC METHODS

The primary objectives of these methods is the protection of public health and environment based on defensible scientific principles and thumb-rules. These methods have been employed at several major hazardous waste sites, such as Woodbury Chemical (in Colorado), Distler Farm (in Kentucky), Hocomonco Pond (in Massachusetts), Pacific Place (in British Columbia), Lawrence Livermore National Laboratory (in Nameda, California), Ringwood Mines (in New Jersey), and as an initial site evaluation tool in the state of Washington (USEPA, 1989). An overview of these methods is presented in Table IV. In addition, sample investigation and remediation standards for a selected site have also been summarized in Table V.

EAST FORK POPLAR CREEK (EFPC): A CASE STUDY

A total of 2.0 million pounds of radioactively contaminated mercury has been released to the environment from the U.S. Department of Energy's Y-12 Weapons Facility in Oak Ridge, Tennessee, since 1950. The primary source of this mercury contamination has been the lithium isotope separation process, known as the Colex. However, almost all mercury operations and related activities at this site have reportedly ceased since 1980.

Releases of mercury to the air, surface water, and spills on soils are well documented (Turner, 1989). There has also been continuing releases of mercury to the EFPC. The major process buildings and their foundations still retain a significant volume of the released mercury. About 800,000 pounds of the released mercury are spread over the stream bed and floodplain soils in a complex spatial distribution and chemical speciation.

A systematic remedial investigation/feasibility study (RI/FS) is currently underway to define the nature and distribution of contamination and appropriate cost-effective remediation alternatives necessary to decontaminate and salvage this mercury. The distribution of mercury in the EFPC floodplain soils is shown in Fig. 1. The total mercury concentration in surface soils along the creek ranges between 0.05 to 950 ppm.

APPLICABLE OR RELEVANT AND APPROPRIATE REQUIREMENTS (ARARs)

One of the most significant tools for investigating and assessing soil cleanup standards is to have a complete understanding of the ARARs related to the contaminants under consideration. A detailed review of currently available ARARs for mercury contamination is presented in Table VI including the author's suggested levels.

BEST DEMONSTRATED AVAILABLE TECHNOLOGY

Several treatment alternatives for mercury contaminated soils and groundwater are being considered for the remediation of mercury and its recycling. These are: (1) retorting, (2) rotary kiln soil roasting, (3) alkali/acid leaching, (4) sodium sulfate salt leaching, (5) extraction with complexing agents, (6) electro-osmosis or electro-kinetic decontamination, and (7) ion exchange resins. Technologies applicable to mercury contamination are currently being assessed.

To date, EPA has only identified two major mercury nonwastewaters as a source of primary concern at the DOE sites (USEPA, 1990a): (1) metallic mercury containing radioactive tritium, and (2) waste hydraulic oil with metallic mercury and radioactive materials.

The BDAT for much of these wastes is the absorption technology, employing calcium polysulfide, flowers of sulfur, or elemental zinc powder. The zinc powder amalgamation with mercury waste in presence of dilute sulfuric acid (< 10 percent) is currently preferred by EPA, since it can significantly reduce mercury emissions to the air. Incineration residues are then to be treated by acid leaching. These and other technologies, such as electro-osmosis, alkali leaching, ion exchange resins, etc., are being assessed in detail in the context of the required integrated plan.

TABLE I

Fate and Transport Methods: An Overview

- These methods evaluate the movement of chemicals through the unsaturated zone.
- They are also employed to estimate the concentrations of inorganic constituents in the saturated zone as water infiltrates through an unsaturated soil column.
- Concentrations in groundwater depends on the residual contamination concentrations in the soil, prior to infiltration.
- EPA has adapted existing groundwater models to determine the concentration of sludge or soil borne contaminants in groundwater (USEPA, 1989a). The components of the epa model are:

  (1)The leachate pulse model,

  (2)The chain model,

  (3)The MINTEQ Model, and

  (4)The analytical transient model.

- The model is run through trial and error to determine the soil or sludge concentrations that cause allowable drinking water standards (or MCL) to be reached at the point of compliance.
- The model is applicable to many situations, such as land application of sludge for agriculture, wastes placed in a sludge-only landfill, soils contaminated with waterborne pollutants, etc. the model output includes parameters, such as leachate pulse time (years), leachate contaminant concentrations, and contaminant plume dimensions. Additional details of this model have been presented in USEPA (1990).
- The **Leachate Pulse Model** is employed to calculate the leachate pulse time, the period in which the contaminated soil or sludge releases metal pollutants to the unsaturated zone. the model equation is as follows:

$$T = (CS \times SS/CL) -- EL \times D/R$$

Where:

T = Leachate pulse time (years)
CS = Metal concentration in soils (mg/kg)
SS = Soil solids content (kg/l)
D = Soil or fill thickness (meters)
CL = Assumed leachate concentration (mg/l)
R = Groundwater recharge rate (m/yr)
EL = Excess liquid in original soil (l/yr)

- The EL factor is used to adjust the groundwater recharge rate based on aqueous soil characteristics.
- The equation assumes that the CL remains constant until the soil is entirely depleted of the contaminants. This represents a mathematical square wave leachate pulse release assumption.
- **The Chain Model** (Van Genuchten, 1985) assumes a steady rate of percolation through the unsaturated zone and is constrained by the leachate pulse time as estimated earlier.
- The model also computes the sorption of contaminants to the soil and the decay of organics, thereby adjusting the leachate concentration.
- **The MINTEQ Model** (Felmy, 1984) then adjusts the leachate concentrations based on solubility constraints, using information on PH and EH of the leachate. The adjustments are often achieved by means of an iterative process in the model (USEPA, 1987)/
- **Analytical Transient (AT123D) Model** for the saturated zone is employed to calculate the contaminant plume (Yeh, 1981) based on advection, diffusion, dispersion, sorption, decay, and distance of the contaminated unit from the property boundary or 150 meters.

Tables II, III, IV, V, VI and Fig. 1
NOTE: The above Tables and Figures have not been reproduced in this paper due to the lack of space. For a copy of these, please write to the principal author of this paper.

METHODOLOGY SELECTION CRITERIA

Based on an ongoing assessment of methodologies, data and criteria for integrated remediation of mercury contamination at Oak Ridge, the following suggestions for selecting methodologies that establish soil cleanup standards will be briefly summarized here for the lack of space:

1. An equation was developed for the calculation of allowable mercury concentration in soils which considers a daily intake and various pathways of exposure, such as inhalation of ambient air and dust, ingestion of fish and other foods, and ingestion of soil (Bashor, 1986). Based on estimated human intake levels and potential accumulation from soils by specific exposure pathways, a safe acceptable limit of 12.0 ppm has been suggested.
2. The natural background level of mercury in soils is considered to be about 0.1 to 0.3 ppm (Revis, 1989). A comprehensive study of background concentrations at the Oak Ridge Reservation is currently underway to verify this finding. The generic methods based on investigation and remediation standards requires acceptable mercury contamination to be below 2.0 ppm, see Table V and VI.
3. Intestinal absorption studies in Oak Ridge on mice, following intubation of mercuric sulfide, showed that the acceptable limit for mercury in soils at this site is 72 ppm, assuming a factor of safety of 10 (Revis, 1990). Clearly, this is not a critical pathway and is inconsistent with the methodologies discussed earlier.
4. Concentrations of soil mercury in the EFPC floodplain ranged between 0.5 to 3000 ppm in 1984 (Revis, 1989). Recent soil sampling in the same floodplain shows a range of 0.05 to 2110 ppm. This may represent a significant release of mercury from the soils and needs a through evaluation in the context of soil cleanup standards setting.
5. Reportedly, the EFPC soil mercury is 91% inorganic, 6% elemental, and 3% organic as methyl mercury. About 91% of the mercury may be in relatively insoluble HgS and elemental form (Revis, 1989). The industrial mercury fallout, generally measured at only a few parts per trillion in rain, adds about 0.3 gram/year to a 25-acre lake causing very serious contamination of fish and biota (Raloff, 1991). Acidic soils or acidic precipitation can cause significant methyl mercury formation through bacterial and abiotic action (EPRI, 1990). This process should be investigated for the Oak Ridge site within the framework of the soil cleanup standards development process.
6. Work is currently underway to investigate the effects of chemical form of mercury on the performance of dosed and contaminated soils by standard leaching protocols, like TCLP and EP Toxicity (Willett, 1991). Limited data compiled to date showed that soil samples with 0.72 ppm mercury produced a TCLP leachate with 0.83% of mercury in soil. The leachate percentage increases with higher soil concentration. Thus a 10 ppm soil will produce a 0.2 ppm leachate, assuming a factor of safety of 1. The TCLP-based soil cleanup standard for mercury should therefore be less than 10.0 ppm.
7. The TCLP-based standards may not be an adequate soil cleanup standard, since it does not consider the long-term impacts of bacterial and other action in soil under suitable pH and Eh conditions. This process should also be investigated within the framework of this methodology.
8. An innovative technology involving the use of electrokinetic reclamation is being tested for application to the cleanup of mercury contaminated soils. The use of ELECTROSORB polymers will also be investigated. The performance of this alternative, if successful, will determine the actual standard that would ultimately be set for soil decontamination. The details of this technology and the development process will be discussed elsewhere.

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DESIGN AND CONSTRUCTION OF AN INTERCEPTOR SYSTEM FOR RADIOACTIVELY CONTAMINATED SOLVENT

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ABSTRACT

During the conduct of fuel reprocessing operations at the Western New York Nuclear Service Center from 1966 to 1972, the site operator disposed of spent solvent by shallow land burial in the area used for disposal of solid radioactive waste. The spent solvent was placed in twenty-two 3785 liter (1000-gallon) steel tanks which were then placed in eight 6-meter-deep burial holes.

With the passage of time groundwater entered the tanks displacing the solvent (a mixture of tributyl phosphate and n-dodecane) and allowing it to enter the surrounding groundwater system. The solvent, which is lighter than water, floated to the surface of the groundwater within the burial holes and began to migrate laterally through cracks caused by weathering.

In 1983, after the U. S. Department of Energy (DOE) initiated efforts for the West Valley Demonstration Project (WVDP), trace amounts of solvent were encountered in a monitoring well near the perimeter of the burial area. Since the initial discovery, extensive studies and continued monitoring have been conducted of the solvent migration. In the fall of 1989, this monitoring showed evidence of further on-site migration of the solvent within the disposal area.

In response, the DOE authorized West Valley Nuclear Services Company, Inc. (WVNS) to proceed with the design and construction of a trench system to intercept the flow of solvent and prevent it from discharging to nearby streams.

Since the solvent and the contaminated groundwater samples taken in the area exhibited high levels of Iodine-129 in an organic complex, it was necessary to construct a pretreatment facility.

An important aspect of the trench construction was the management of contaminated soil and construction water. Contaminated soils were placed into storage containers and held for future treatment and disposal. All water pumped from the trench during construction was stored in large bladder tanks, analyzed for hazardous constituents, and upon finding none, was discharged.

BACKGROUND INFORMATION

Origin of the Solvent

The West Valley Demonstration Project is a high-level radioactive waste solidification project operated by the DOE. The WVDP is on a 3,345-acre reservation located approximately 75 kilometers south of the city of Buffalo, New York, and is owned by the New York State Energy Research and Development Authority (NYSERDA). A map showing the project site and its general location is presented on Fig. 1. The high-level radioactive waste was generated during commercial nuclear fuel reprocessing operations between 1965 and 1972.

The reprocessing of spent nuclear fuel involved dissolution of the fuel in nitric acid, and solvent extraction using tributyl-phosphate (TBP) dissolved in n-dodecane. Tributyl-phosphate is not soluble in water and was used for extraction of plutonium soluble in it. The n-dodecane, which is one of the primary compounds found in kerosene, is lighter than water and immiscible in it. Spent solvent was stripped of useable material and placed into a series of 3785 liter steel tanks together with a sorbent material. Disposal records indicate that at the time of disposal the tanks had a high level of surface radiation and had to be handled remotely.

Disposal of the twenty-two 3785 liter tanks with the solvent/sorbent mixture was performed episodically between 1968 and 1972, in a total of eight disposal holes in the disposal area ("NDA") (see Fig. 2).

Discovery of Solvent Migration

In the fall of 1983, shortly after WVNS became the contractor for the WVDP under DOE, a sample taken from a monitoring well at the northern boundary of the NDA (well 82-5A, Fig. 2) revealed the presence of radioactively contaminated solvent. This was the first sample taken from the well. In response, the DOE, WVNS, and subcontractors undertook an extensive exploration program which ultimately led to the exhumation of eight solvent tanks from two of the disposal holes (SH-10 and SH-11, Fig. 2). When the tanks were exhumed, it was found that much of the solvent had left the tanks and migrated into the surrounding soil.

In addition to the exhumation of the two burial holes, an extensive network of monitoring wells was installed between the section of the disposal area which contained solvent tanks and the closest drainage course. By the summer of 1988 this network contained more than 35 wells and standpipes which were tested weekly for the presence of solvent.

In August of 1988, the presence of solvent was detected in the monitoring well over SH-5. Borings were drilled and sampled around the perimeter of SH-5 and analyzed for evidence of solvent and radionuclide contamination. The results of this investigation indicated that migration from the hole was minimal. However, the new observation of solvent

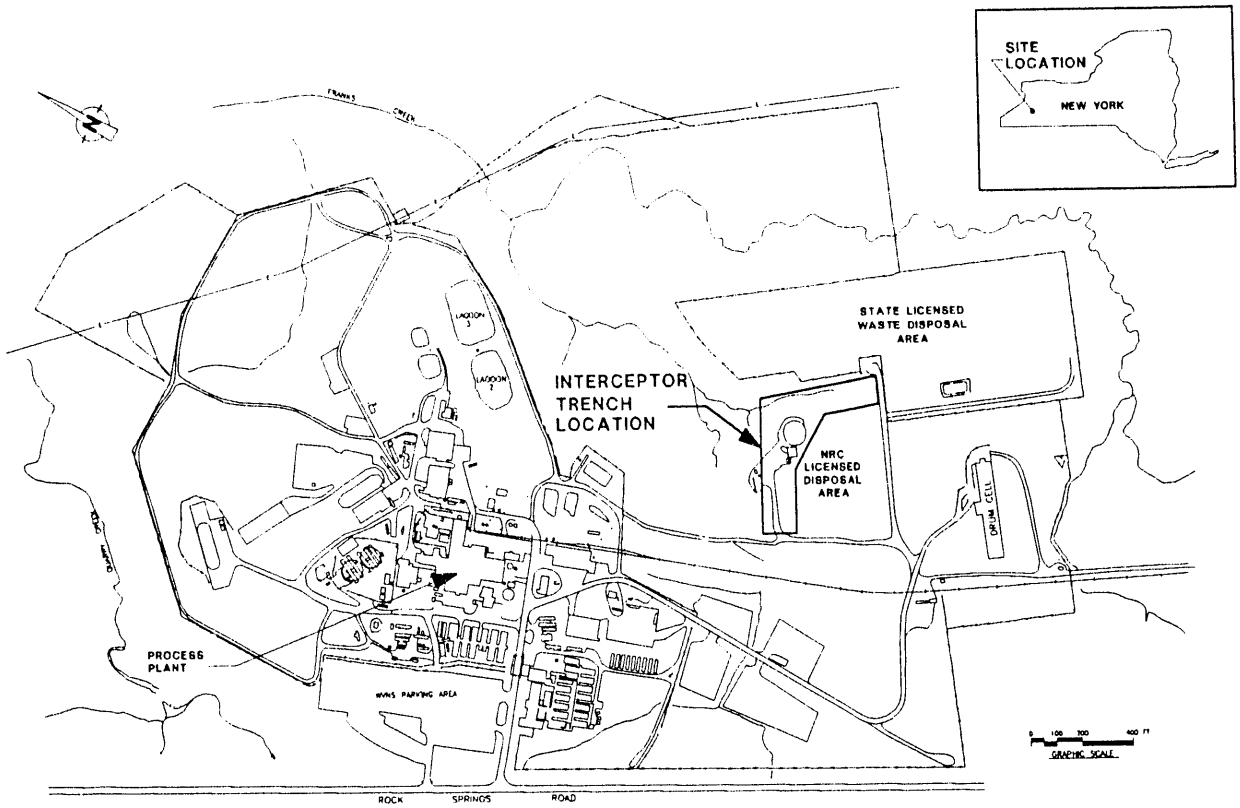


Fig. 1. Location map of project area showing disposal area sites.

suggested that further releases from the tanks could be anticipated. Therefore, the DOE requested WVNS to take further action to manage the situation.

Based on previous experience, a more detailed characterization program was undertaken to evaluate the nature and extent of subsurface contamination which had resulted from the solvent. This characterization program included exploratory excavations, installation of driven wells in the burial holes, and soil gas sampling. The results of these investigations revealed that the solvent had been at least partially released from the burial tanks in five of the six remaining solvent holes.

Site Conditions

The climate of the site area is humid. Approximately 1.1 meters of precipitation falls on the site each year. Half of this is in the form of snow. Evapotranspiration is low which results in high groundwater tables.

The site is located over a bedrock valley filled by a series of glacial tills and interglacial lacustrine and alluvial deposits. At least two till sequences are known to exist beneath the site. The uppermost till, the Lavery, is the burial medium and is a silty clay with a hydraulic conductivity on the order of 10^{-8} cm/sec. Data from wells and piezometers reveal that groundwater flow in the Lavery is essentially one dimensionally downward. Piezometer data indicate the phreatic level in the clay till is approximately 6 meters below the surface.

Recent investigations by the WVDP indicate that the upper 3 meters (approx.) of the Lavery Till is fractured and weathered. The contact between the weathered and unweathered till is gradational but occurs over a few centimeters. Tests indicate the weathered till exhibits a gross hydraulic conductivity of 10^{-5} cm/sec. Piezometric data from the weathered till indicate that it acts as a transient unconfined aquifer following periods of extensive precipitation or snow melt. Water levels within 0.6 meters of the surface have been observed in the weathered till.

Preliminary Engineering

As a result of the investigations described above, it was concluded that it was reasonable to assume that further migration of the solvent could occur through the shallow weathered till layer, primarily dominated by flow through fractures and cracks in the till.

Several alternatives to control the further migration of solvent were considered. These included construction of a barrier wall around the solvent burial holes, construction of an interceptor trench downgradient of the solvent burials, construction of a cap or cover over the burial holes to prevent further infiltration of water and thereby minimize the chance for mobilizing further solvent, and exhumation of the remaining solvent tanks and contaminated soil.

Construction of a barrier wall was considered inappropriate because, in addition to blocking the migration of solvent, it would also block normal drainage through the weathered till and could cause contaminated liquid to rise to the surface.

The use of an impervious cover was not considered appropriate for several reasons. First, there was some concern about the ability of the contents of the burial holes to support the necessary construction equipment and second, an impervious cover would stop evapotranspiration and have a limited effectiveness. Exhumation was likewise not considered to be an attractive alternative since it had been found that much of the solvent had already been mobilized.

The review of alternatives indicated that the most attractive remedial technology would be the interceptor trench, and that action would be taken when (and if) the monitoring well network exhibited evidence of further solvent migration.

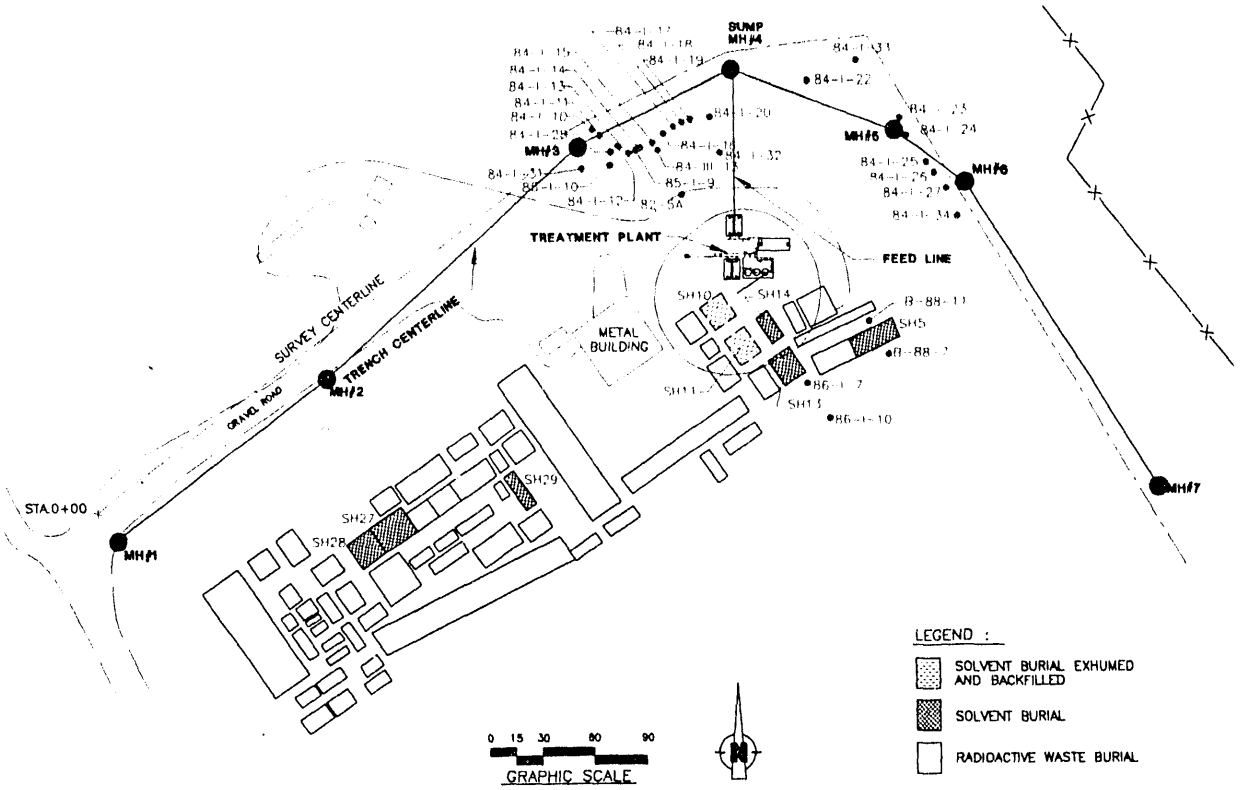


Fig. 2. Plot plan showing the location of disposal holes, monitoring wells and interceptor trench system.

DISCOVERY OF FURTHER SOLVENT MIGRATION

In November of 1989, solvent was encountered in a monitoring well located approximately 18 meters from one of the disposal trenches and in which solvent had not been encountered previously. This observation was interpreted as an indication of further solvent migration. In consideration of this discovery, a project task force was immediately formed consisting of engineering, operations, radiation and safety, and environmental assessment personnel. This team responded quickly to the situation and implemented the plan to prevent a potential release to the environment.

SYSTEM DESIGN

Design Approach

The overall requirements for the design were that it conform to the DOE and NYSERDA requirements for design of hazardous and radioactive waste management systems. This ultimately also included compliance with the Resource Conservation and Recovery Act (RCRA) as well as State Pollution Discharge Elimination Statement (SPDES) permitting requirements. Review times for compliance with these regulations can be quite extensive. To balance the need for proper compliance with the possible immediate need to respond to the situation, a dual track approach was used for design and construction. Design documents were prepared on an accelerated basis, construction materials were procured promptly, and training was held to safely implement the design. In parallel, a permit application was filed and internal design reviews and operational readiness reviews were held. The intent was to install the system in parallel with regulatory reviews and delay its start them until either a) all reviews were completed and proper permits issued; or b) environmental monitoring data indicated that observations of further solvent migration indicated a potential threat to human health or the environment. If the latter occurrence developed it was intended to put the systems in immediate operation under emergency action provisions in advance of the SPDES permit and store the processed water in tanks or lagoons until the permit was received.

Design Requirements

The design requirements for the interceptor system were to fulfill the following functions:

1. Prevent migration of solvent to the environment
2. Collect solvent and groundwater migrating from the disposal trenches
3. Store collected solvent for eventual treatment by solidification
4. Process collected water for further treatment on site
5. Provide the ability to sample extracted solvent and water prior to, during, and after processing
6. Provide the capability to shut down the entire system without incurring environmental impacts which would exceed the no-action case.

To meet these design requirements, two major components were required. The first was the trench to intercept and collect water and any solvent flowing through the weathered till and satisfy the first two design requirements. The second was a fluid management system that would satisfy the latter four requirements. A further design consideration included the need to construct it completely from the surface without requiring manned entry, and thus permit the use of a narrow trench with vertical sidewalls to minimize excavation. Such minimization was desirable because of the high probability for encountering contaminated soil, which is costly to manage. The estimated discharge from the trench was a topic which

required careful consideration. Available hydraulic conductivity data for the weathered till exhibits a variability in excess of two orders of magnitude. This, coupled with the transient nature of the flow through the weathered till, led to output predictions ranging from .4 to 114 liters/minute (0.1 to 30 gpm). In consideration of this, it was decided to design the system for a nominal flow of 13 liters/minute (3.5 gpm) with a transient flow capacity of 114 liters/ minute (30 gpm). Furthermore, it would not be prudent to construct the entire trench unless there were sufficient capacity to treat the discharge. Therefore, staged construction was used to test design assumptions before committing to the full design length of the trench.

In addition to storing the radiologically contaminated solvent, it was also necessary to pretreat the water which would be taken from the trench. Samples of water taken from monitoring wells in the NDA indicated that the levels of I-129 in the groundwater were higher than could be treated by available WVDP facilities to maintain compliance with SPDES permit requirements. The analytical data indicated that the I-129 was organically complexed and could be removed by granular activated carbon. Therefore, a pretreatment system was incorporated into the design criteria to lower activity levels of I-129 from 1.2×10^{-7} μCi/ml to 1.0×10^{-8} μCi/ml. Subsequent evaluations indicated that under the mixture rule it was necessary for the pretreatment system to be designed in accordance with RCRA requirements.

TRENCH DESIGN

The layout of the interceptor trench is illustrated on Fig. 2. A typical cross-section of the trench is illustrated on Fig. 3. The trench varies between 4.5-to-6 meters deep and generally extends at least .6 meters below the interface between weathered and unweathered till. Prior to construction, profile surveys and borings made along the proposed trench line defined both the ground surface and the depth of weathered/unweathered till interface, and were used to select the trench vertical slope and depth. The selected vertical alignment is shown on Fig. 4.

As shown on Fig. 3, a layer of high density polyethylene is placed on the trench bottom to minimize the potential contact of solvent with the underlying unweathered glacial till. The trench wall is lined with a geotextile to prevent the migration of clay and silt particles into the gravel backfill, and thereby maximize its drawdown potential. A corrugated high density polyethylene drainage pipe is placed at the bottom of the trench. As shown on the profile drawings, manholes are installed at all changes in vertical and horizontal alignment to facilitate cleanout of the drain pipe, and to allow sections of the trench to be sealed off and isolated with respect to other sections. The trench flows from the two ends to a sump (Fig. 3) located at the lowpoint near the center. A submersible pump is at the bottom of the sump delivers water to the pretreatment system. Level control switches in the sump control the on/off state of the pump during normal shift hours. An alarm in the sump is provided to alert plant personnel when the liquid level in the sump rises above the action level.

LIQUID PRETREATMENT SYSTEM

The flow diagram of the pretreatment system is illustrated on Fig. 5. The system first routes the material through one of two holding tanks from which a sample can be withdrawn to check for levels of activity, while the aqueous phase sinks to the bottom and the solvent rises to the top. The water is drawn off the bottom and flows through a filter system and two activated carbon units to remove the I-129 complex. As shown on Fig. 5, numerous sampling points are included in the system to allow constant performance monitoring. The granular activated carbon is contained in large high-pressure vessels to sustain high-flow rates. The entire pretreatment system is contained in two large double containments (bermed areas) incorporating level detectors. Double-walled piping was used from the sump to the first containment. All tanks, pumps, and lines were heat traced. The carbon units and filter were enclosed in a heated structure.

REMEDIAL CONSTRUCTION

Design/Construction Approach

The necessity for prompt action modified the normal sequential process utilized by WVNS for development of new systems. The following steps were followed to ensure that proper design activities and regulatory requirements were

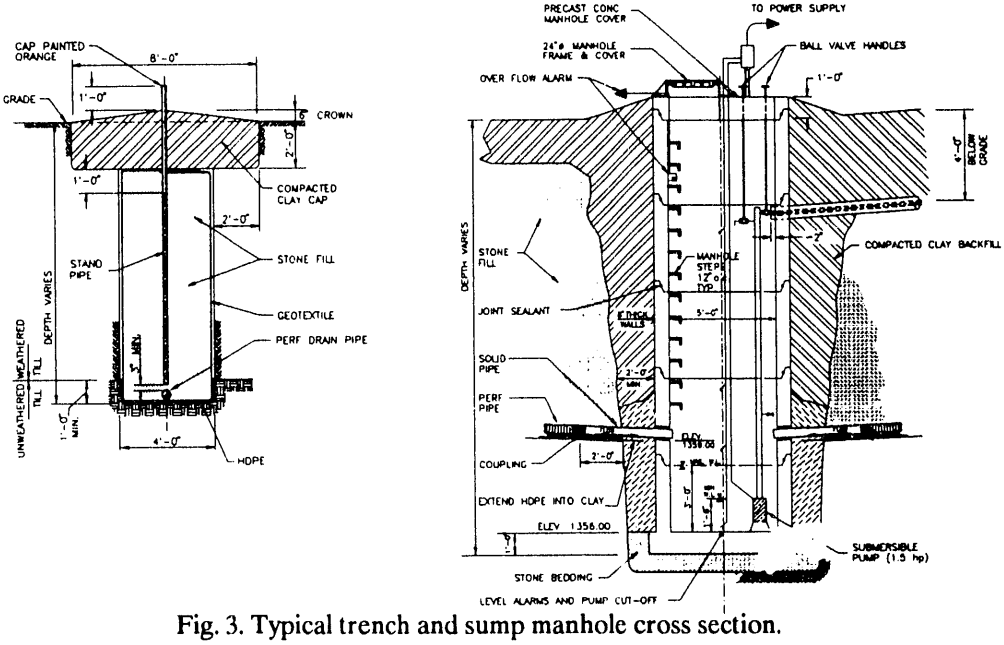


Fig. 3. Typical trench and sump manhole cross section.

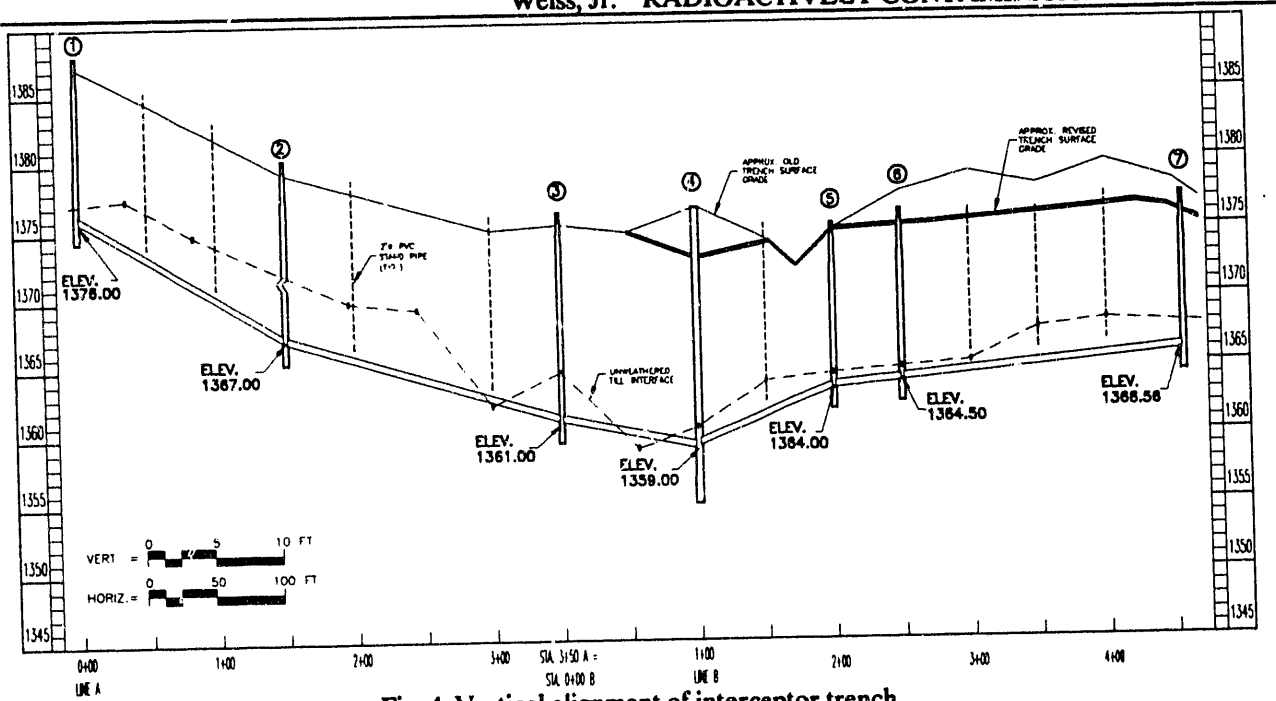


Fig. 4. Vertical alignment of interceptor trench.

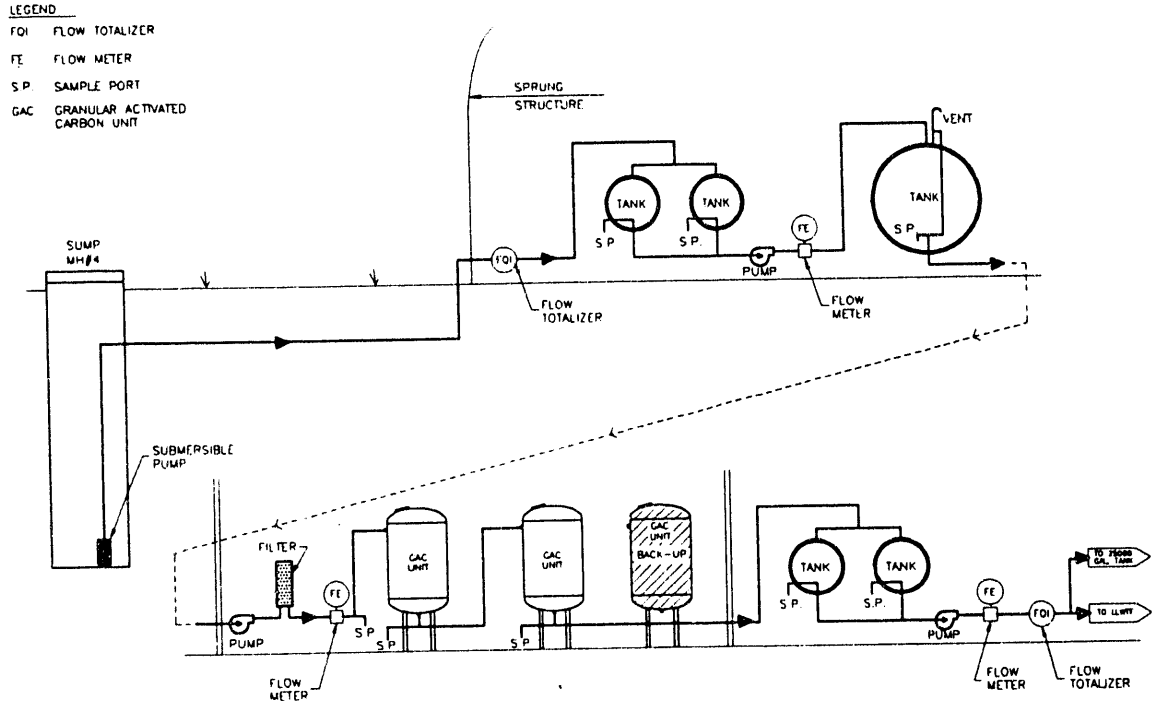


Fig. 5. Block process diagram of liquid treatment system.

met. As noted previously, all of these were accomplished by the task force over a 10-week period in parallel with detailed design and construction mobilization efforts.

- Environmental checklist developed, internally approved, and approved by the DOE Project Office.
- Development of design objectives (beyond initial requirements)
- Readiness review for trench construction
- Peer review of trench design
- Non-interactive design review

Additionally, discussions were held with DOE-Idaho, NRC, New York State Department of Environmental Conservation (NYSDEC), and others to develop permit requirements and additional documentation necessary to permit operation of the trench on an emergency basis should solvent break through prior to completion of construction.

Provisions were developed for the handling of radioactively contaminated soil and for handling and disposition of surface and ground water encountered during construction.

Trench Construction

Construction of the first 30 meter trench section began on January 24, 1990, following completion of the items noted above. In spite of adverse weather conditions, excavation and placement of the sump proceeded on schedule. Prior to

excavation, two 94,635 liter (25,000 gallon) bladder tanks were procured and installed with berms (constructed using concrete barriers and 35-mil polyethylene over a sand base) near the construction area. The tanks were used to accumulate construction and ground water until a discharge permit (SPDES) could be received from NYSDEC. Approximately 26,000 liter (6900 gallons) of construction water were pumped from the excavation in the first two weeks alone. The permit application was submitted on March 1, 1991, and received on September 13, 1991, during which time over 170,000 liters (45,000 gallons) of water had been accumulated. The water in the tanks was sampled and analyzed for hazardous and radioactive constituents prior to disposition. No hazardous constituents were ever detected; radioactivity was sufficiently low to permit discharge to the WVDP Low-Level Waste Treatment System for processing prior to discharge.

As expected, contaminated soil was encountered during initial trench construction. Prior WVDP practice had been to package contaminated soil in S-70-8 boxes for storage in the low-level radioactive waste storage facilities. Given the anticipated volume, however, it was decided to characterize the soil as it was excavated. Soil that was radiologically "clean" (less than background radiation) was placed in a spoils pile, soil with activity ranging from 1 to 5 counts per minute (alpha) and/or 70-300 counts per minute (beta/gamma) above background was placed in rolloff containers (for future disposition in a contaminated spoils area); and soil with activity greater than 5 counts per minute (alpha) and/or 300 counts per minute (beta/gamma) above background was packaged in S-70-8 boxes for storage. This segregation process avoided substantial costs in box procurement, but had an adverse impact on construction progress. A "slip-forming" technique using a disposal box with the bottom removed was developed to place the stone, geotextile and backfill in the portions of the trench adjacent to the sump and manholes where large excavations were required to maintain sidewall integrity. This method also greatly reduced the magnitude of soil removed by allowing a steeper slope on the sidewalls.

Upon completion of the first 30 meters, activity was temporarily suspended to permit monitoring of ground water influx. During this period, average influx was approximately 950 lpm (250 gallons) per day. This equates to approximately 5.7 lpm (1.50 gpm) equivalent for the total trench length, well under the design bases. Because of weather conditions, the clay cap could not seal effectively, permitting rainwater to infiltrate the trench. Construction was resumed, and the second 30 meter from the sump southward to the next manhole was completed in 6 days without incident.

Again, construction was suspended to permit evaluation of ground water influx over a 10-week period. While the average influx for the first 30 meters was 950 liters (250 gallons) per day, the average influx for the 60 meters was only 310 liters (90 gallons) per day. This reduction is primarily attributable to the sealing afforded by the improved clay cap construction possible at the end of the freezing season.

In both monitoring periods, a strong correlation between precipitation and water influx was observed. This effect lessened with time as the clay cap seal was developed.

Construction was again resumed and progressed smoothly until a higher than normal reading was noted by a Radiation and Safety technician in a box of contaminated soil. An investigation revealed that a spent fuel hull from the former fuel reprocessing operations had been transferred during disposal operations to the trench excavation area. Construction was suspended for a 4-week period to allow further investigation and development of changes in operations to preclude recurrence. Modifications were made in radiation survey instrumentation to achieve greater sensitivity, and in limiting the amount of soil excavated by the backhoe bucket. The result, while achieving an even higher level of confidence, was to halve the rate of construction progress.

Construction then resumed for the last two legs totaling approximately 183 meters. Field efforts were hampered by the need to manage large quantities of radioactively contaminated soil, heavy rainfalls which caused periodic cessation of activities so that the surface water could be pumped out, and in the use of the more extensive surveying techniques. As a result, excavation was completed on December 12, 1990, when the initial clay cap was completed. Some statistics are interesting to note:

- 189 boxes of contaminated soil were filled, totaling 430 cubic meters
- 98 rolloffs of slightly contaminated soil were filled, totaling 750 cubic meters
- Over 1.5 million liters of water from both the surface and the ground were collected, analyzed, and discharged. No solvent was detected in the discharged water.

The final clay cap was installed in May 1991, effectively halting the influx of surface water. Since that time, the average ground water flow rate has been approximately only 473 liters per day (125 gallons per day) or .34 liters per minute (.09 gpm) for the entire 245 meter length of the trench far below the design bases.

Liquid Pretreatment System

The liquid pretreatment system (LPS) procurement and installation proceeded relatively smoothly, impacted by the decision to design the system in accordance with RCRA, on the basis that the potential for unknown hazardous materials exists from operation during the reprocessing period. This decision meant modifying the design to include secondary containment around the entire system; additional certifications, calculations, and verification inspection by a professional engineer and NYSDEC, level alarms for leakage into the secondary containment, additional waste analysis and inspection requirements, and closure and post-closure plans.

The LPS was completed in parallel with trench construction, tested for functional and operational performance, and placed into operation in July 1991.

CONCLUSION

As of this writing, no solvent has been detected in the interceptor trench. Nonetheless, the quick response in the design and construction of the interceptor trench system has provided a positive barrier to the potential migration of the solvent. The pro active stance of both the DOE and WVNS, and the thoroughness of design detail and overview, have demonstrated the value of the WVDP and the continued commitment for the safe management of waste.

Lastly, the approach to design and construction of environmental control systems in parallel with the permitting process provides a technique to assure the protection of the environment while complying with regulatory agencies.

ACCELERATED CLEANUP OF CARBON TETRACHLORIDE IN A RADIOLOGICALLY CONTAMINATED SITE AT THE HANFORD SITE

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ABSTRACT

Radioactively-contaminated acidic aqueous wastes and organic liquids were discharged to the soil column at three disposal sites within the Hanford Nuclear Reservation, resulting in the carbon tetrachloride contamination of the ground water and unsaturated soils. A CERCLA Expedited Response Action (ERA) has been initiated for the removal of carbon tetrachloride from the unsaturated soils to mitigate further contamination of the ground water. Based on the contaminant nature and distribution, site physical characteristics, and technology pilot tests, soil vapor extraction with above-ground treatment of the soil vapor was chosen as the preferred remedial technology for the ERA.

INTRODUCTION

Radioactively-contaminated acidic aqueous wastes and organic liquids were discharged to the soil column at three disposal sites within the Hanford Nuclear Reservation, Washington (Fig. 1). As a result, a portion of the underlying ground water is contaminated with carbon tetrachloride, a suspected carcinogen, several orders of magnitude above the maximum contaminant level accepted for a drinking water supply. An expedited response action has been initiated to address the contamination in the unsaturated soils to minimize or stabilize further contamination of the ground water.

Background

At the Hanford Site, carbon tetrachloride was used primarily as a solvent for plutonium extraction processes. From 1955 to 1973, radioactively-contaminated acidic wastes and organic liquids from this process were discharged to the soil column at three adjacent disposal sites. Between 363,000 liters (96,000 gallons) and 580,000 liters (153,000 gallons) of carbon tetrachloride were discharged to these disposal sites along with 190 kg of plutonium and americium. It is thought that a substantial amount of carbon tetrachloride, a dense nonaqueous phase liquid (higher density than, and immiscible with, water), remains in the unsaturated soils beneath these disposal sites and continues to contribute to the long-term contamination of the ground water.

In December 1990, the U.S. Environmental Protection Agency and the Washington Department of Ecology requested the U.S. Department of Energy (DOE) proceed with detailed planning to implement cleanup of the carbon tetrachloride in the unsaturated soils through an "Expedited Response Action" (ERA). An ERA is a provision included in the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) of 1980 that allows for accelerated cleanup activities. The goal of this ERA is to stabilize the spread of the carbon tetrachloride in the unsaturated soils beneath Hanford's 200 West Area (Fig. 1) by removing carbon tetrachloride from the unsaturated soils thereby mitigating further contamination of the ground water.

APPROACH

The Environmental Division of the Westinghouse Hanford Company, a subcontractor to the U.S. Department of Energy, has initiated the ERA using a phased approach to address the residual contamination remaining in the unsaturated soils. To meet the accelerated ERA time schedule, constrain costs, and meet the requirements of working in a radiologically-controlled area, the initial phase of the ERA optimizes the use of field screening-level data, existing boreholes, and minimizes the generation of radioactive and hazardous wastes.

Conduct of these field activities in a mixed waste (radiological and chemical) environment differs from conducting conventional environmental activities at chemical waste sites (1). Extensive training, administrative and engineering controls, technical documentation and logistical support are required because of the potential for radiological contamination.

SITE CHARACTERISTICS

The geology of the 200 West Area consists primarily of basalt overlain by fluvial and glaciofluvial sediments (Rohay and Hagood 1991) (1). The unsaturated soils in this area range in thickness from 58 m (190 ft) to 82 m (269 ft) and lie entirely within the sediments overlying the basalt. The uppermost aquifer in the 200 West Area is unconfined and located within the fluvial sediments overlying the basalt. The saturated thickness of the uppermost aquifer ranges from 67 m (220 ft) to 113 m (371 ft). Ground water velocities are estimated to range from <0.1 to about 47 m/d (154 ft/d). Ground water flow directions are generally radial outward from the southwest portion of the 200 West Area primarily because of the continuing influence of a residual ground water mound beneath a decommissioned disposal pond.

Carbon tetrachloride contamination has been detected in both the unsaturated soils and in the ground water of the 200 West Area. Carbon tetrachloride vapor has been detected at depths ranging from 1 m (3 ft) to 63 m (207 ft) below ground surface. A concentration maximum of 915 p/m vol was recorded during the soil vapor extraction test (2). Chloroform was detected in trace amounts during the soil vapor extraction pilot test as well. Plutonium and americium have been sampled and analyzed in the unsaturated soils beneath the three cribs; radiological contamination has been detected at all three disposal sites using scintillation logging techniques (1).

Ground water in the 200 West Area is contaminated with carbon tetrachloride with observed concentrations of up to a

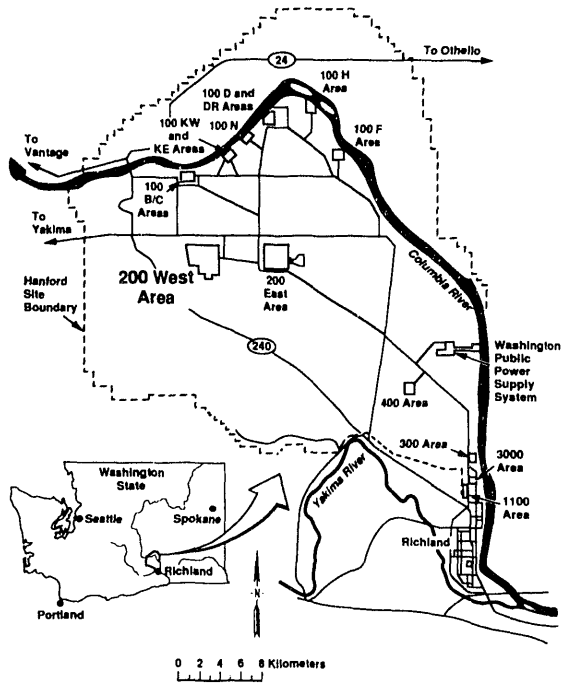


Fig. 1. Location map.

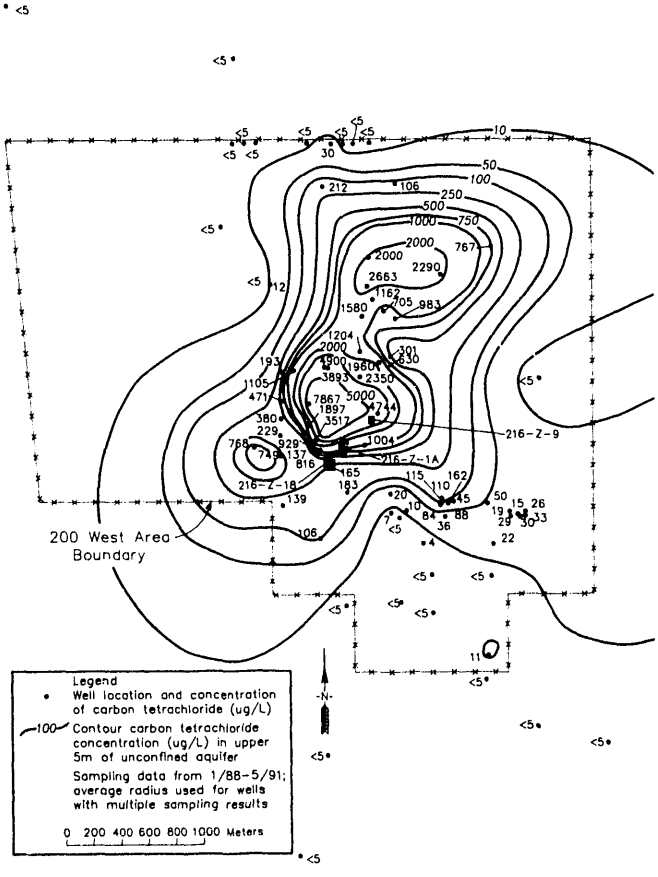


Fig. 2. Figure of ground water contamination

maximum average of 7,340 p/b (Fig. 2). The carbon tetrachloride plume appears to be emanating from the area of the disposal sites and extends primarily to the north. Carbon tetrachloride has been detected at the water table, and in one location, to a depth of 116 m (380 ft). It is estimated that the ground water plume (as defined by the 5 p/b contour) covers an area of 11 km^2 (4.2 mi^2) but only contains a small percentage of the carbon tetrachloride thought to have been disposed of in the three disposal sites (1).

ENGINEERING EVALUATION AND COST ANALYSIS OF REMEDIAL ALTERNATIVES

An engineering evaluation and cost analysis (EE/CA) was conducted on remedial action alternatives for the cleanup of carbon tetrachloride in the unsaturated soils. An EE/CA is a rapid, focused, feasibility study, which uses specific screening factors and selection criteria to assess the feasibility, appropriateness, and costs of available technologies for the removal of the carbon tetrachloride. Screening criteria consist of compliance with applicable or relevant and appropriate requirements (ARARs) and protection of the environment and public health. The second step of the selection consists of evaluating the effectiveness, implementability (including startup time), and cost.

Preliminary screening of alternatives in the early phase of the project indicated that soil vapor extraction of the carbon tetrachloride in the unsaturated zone, with some form of above-ground treatment of the soil vapor, would be the preferred remedial technology. Vapor extraction technology uses a vacuum to induce air flow through the soil, volatilizing carbon tetrachloride from the soil into the air stream. The relatively high volatility of carbon tetrachloride in conjunction with the relatively ideal site characteristics (Table I) indicate this technology to be highly applicable in the vicinity of the disposal sites. As a result of the screening, the EE/CA focused on further evaluating soil vapor extraction technology in conjunction with a detailed evaluation of the soil vapor treatment technologies and well field design options.

Soil Vapor Extraction Pilot Test

A soil vapor extraction system (VES) pilot test was conducted at the 216-Z-1A Tile Field (one of the three disposal sites) in April, 1991 (2) (Fig. 3). The test was designed to determine if soil vapor extraction and treatment are feasible for the removal of a carbon tetrachloride vapor plume from the unsaturated soils in and around principal carbon tetrachloride disposal sites.

Prior to testing, a safety analysis was conducted (3) to determine the potential hazards associated with the pilot test. It was determined theoretically that plutonium (Pu) and americium (Am) would not be extracted by the vacuum applied to remove the carbon tetrachloride given the vapor pressure characteristics and the mobility of these two metals (4). As a precaution, the VES was modified from its "off-the-shelf" configuration to include both radiological and VOC detection and warning systems that automatically shut down the system if thresholds were exceeded. The system was also equipped with prefilters and a high-efficiency particulate air (HEPA) filter to contain radiological particulate, which potentially might be extracted from the wells. Radiation and VOCs were monitored in and around the system with hand-held instrumentation as a redundant safeguard for onsite personnel.

Vapors extracted during testing consisted principally of carbon tetrachloride. Trace amounts of chloroform were also detected. During one 80-hour test at a soil vapor extraction rate of 8.5 cubic meters per minute (300 cubic feet per minute), a concentration of 915 ppm carbon tetrachloride in the

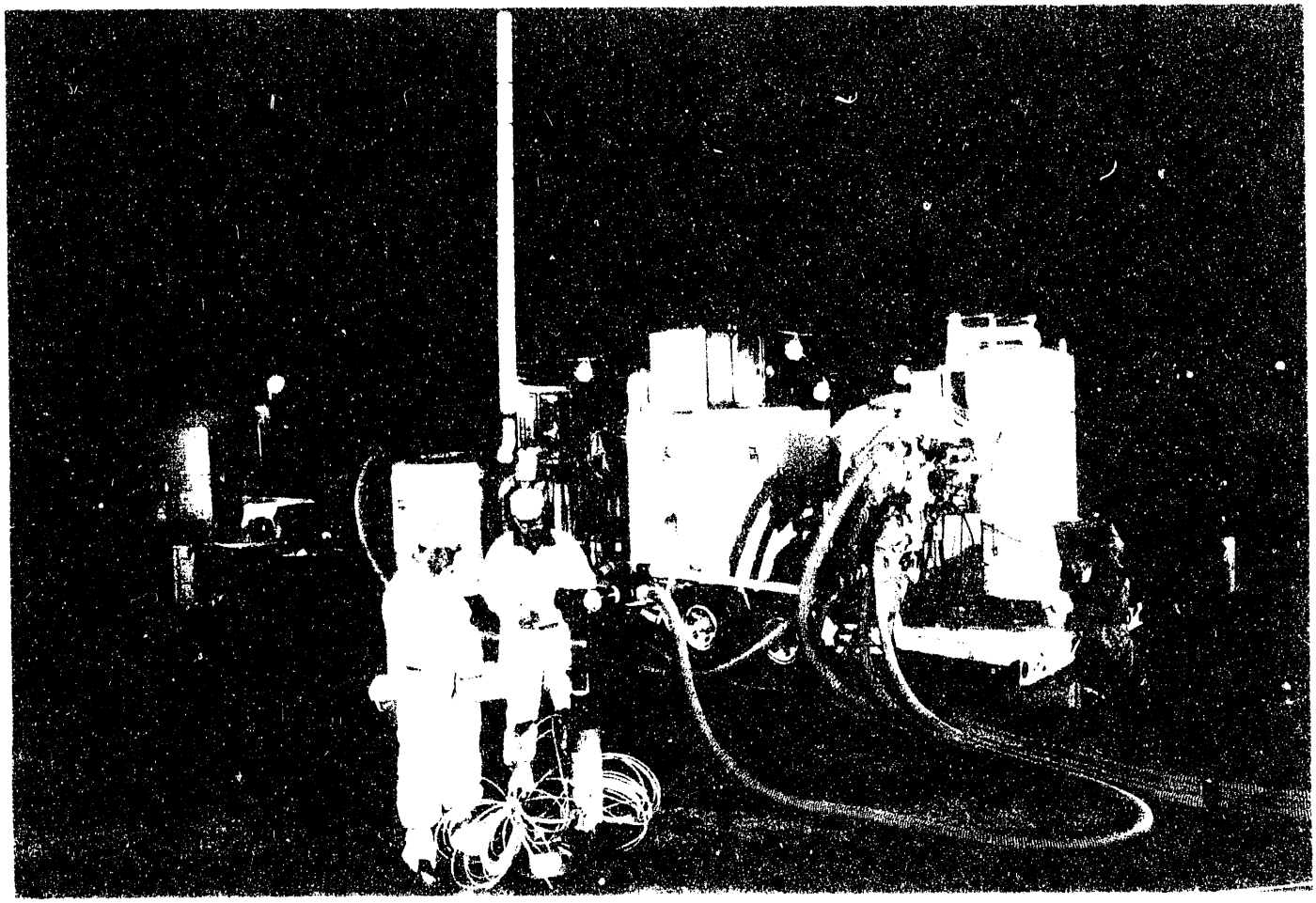


TABLE II

Vapor Extraction System Treatment Altenatives.

Treatment alternative	CCl_4 removal efficiency (%)	CCl_4 in effluent (lb/d)	CCl_4 destruct offsite	HCl created onsite	HCl in effluent (lb/h)	Secondary waste amount and type	Secondary waste disposal	Ability to meet ARARs	Time until start (mo)	Costs for start-up	DOE exemption required	Costs for annual operation	Costs for secondary waste	Total costs for first year	Total costs for first three years
No treatment	0	1,000	No	No	0	N/A	N/A	A: N/A D: Yes B: Yes E: No C: No F: Yes	4	$960,000	No	$270,000	N/A	$1,230,000	$1,770,000
GAC with offsite regeneration	99	10	Yes	No	0	..00 lb/d GAC (powder)	Offsite incinerator	A: N/A D: Yes B: Yes E: Yes C: Yes F: Yes	4	$1,153,000	No	$512,000	$312,000	$1,977,000	$3,625,000
GAC regenerated onsite with offsite treatment of condensate	99	10	Yes	No	0	80 gal/d CCl_4 (liquid)	Offsite incinerator	A: N/A D: Yes B: Yes E: Yes C: Yes F: Yes	8	$1,960,000	No	$274,000	$136,000	$2,370,000	$3,190,000
GAC regenerated onsite by UVOX	98	20	No	Yes	42	N/A	N/A	A: N/A D: Yes B: Yes E: No C: Yes F: Yes	11	$1,484,000	No	$298,000	N/A	$1,782,000	$2,378,000
GAC regenerated onsite by UVOX with acid scrub	98	20	No	Yes	<4	1,900 lb/d $CaCl_2$ (powder)	Non-rad, hazardous landfill	A: N/A D: Yes B: Yes E: No C: Yes F: Yes	11	$1,974,000	Yes	$330,000	$70,000	$2,374,000	$3,174,000
High-efficiency CATOX	98	20	No	Yes	42	N/A	N/A	A: No D: Yes B: No E: No C: Yes F: Yes	10	$1,430,000	No	$330,000	N/A	$1,760,000	$2,420,000
High-efficiency CATOX with acid scrub	98	20	No	Yes	<4	1,900 lb/d $CaCl_2$ (powder)	Non-rad, hazardous landfill	A: No D: Yes B: Yes E: No C: Yes F: Yes	10	$1,920,000	Yes	$362,000	$70,000	$2,352,000	$3,216,000
Ultra-high-efficiency CATOX	99	10	No	Yes	42	N/A	N/A	A: No D: Yes B: No E: Yes C: Yes F: Yes	10	$1,450,000	No	$330,000	N/A	$1,780,000	$2,440,000
Ultra-high-efficiency CATOX with acid scrub	99	10	No	Yes	<4	1,900 lb/d $CaCl_2$ (powder)	Non-rad, hazardous landfill	A: No D: Yes B: Yes E: Yes C: Yes F: Yes	10	$1,940,000	Yes	$362,000	$70,000	$2,372,000	$3,238,000
High-efficiency THERMOX	98	20	No	Yes	42	N/A	N/A	A: No D: Yes B: No E: No C: Yes F: Yes	8	$1,246,000	No	$1,264,000	N/A	$2,510,000	$5,038,000
High-efficiency THERMOX with acid scrub	98	20	No	Yes	<4	1,900 lb/d $CaCl_2$ (powder)	Non-rad, hazardous landfill	A: No D: Yes B: Yes E: No C: Yes F: Yes	8	$1,736,000	Yes	$1,296,000	$70,000	$3,102,000	$5,834,000
Ultra-high-efficiency THERMOX	99	10	No	Yes	42	N/A	N/A	A: No D: Yes B: No E: Yes C: Yes F: Yes	8	$1,286,000	No	$1,465,000	N/A	$2,751,000	$5,681,000
Ultra-high-efficiency THERMOX with acid scrub	99	10	No	Yes	<4	1,900 lb/d $CaCl_2$ (powder)	Non-rad, hazardous landfill	A: No D: Yes B: Yes E: Yes C: Yes F: Yes	8	$1,776,000	Yes	$1,497,000	$70,000	$3,343,000	$6,477,000

NOTES: All values are approximate and may be changed as further information is acquired.

For the purposes of this table, it is assumed that two identical systems are operating simultaneously, each with a flow rate of 1,400 acfm and a CCl_4 loading of 500 lb/d. The numbers shown represent the combined flows of the two systems.

ARARs:
A: 99.99% CCl_4 Conversion Efficiency
B: <4 lbs/hr HCl in Effluent
C: ASIL for CCl_4 (0.067 $\mu g/m^3$)
D: ASIL for HCl (23.3 $\mu g/m^3$)
E: Reportable Quantity for CCl_4 (10 lb/d)
F: Reportable Quantity for HCl (5,000 lb/d)

Key:
GAC: Granular Activated Carbon
UVOX: Ultraviolet Light - Ozone
CATOX: Catalytic Oxidation
THERMOX: Thermal Oxidation
CCl_4: Carbon Tetrachloride
HCl: Hydrochloric Acid
ASIL: Acceptable Source Impact Level

TABLE III

Hydrochloric Acid Treatment Alternatives

HCl Treatment Alternative	Costs of Equipment	Costs of Installing Utilities	Costs of Annual Operations and Feedstocks (yr)	Secondary Waste Type	Secondary Waste Amount	Secondary Waste Handling and Disposal Costs	Time Until Start	Total Costs For Start-up	Total Costs of Annual Operations and Waste (yr)
No treatment	$0	$0	$0	None	None	$0	0 d	$0	$0
Wet scrubber with evaporation ponds	$67,000	$19,100,000	$64,000	Salt Cake	290 tons/yr	$58,000	4-5 yr	$19,167,000	$122,000
Wet scrubber with discharge to 282WA Reservoir	$67,000	$260,000	$62,000	Dilute Brine Solution	18,400,000 gal/yr	$0	1.3 yr	$327,000	$62,000
Wet scrubber with mechanical evaporator	$1,067,000	$100,000	$130,000	Salt Cake	290 tons/yr	$58,000	1.3 yr	$1,167,000	$188,000
Dry scrubber	$490,000	$0	$32,000	$CaCl_2$	350 tons/yr	$70,000	7 mo	$490,000	$102,000

NOTES: All values are approximate and may be changed as further information is acquired.
For the purposes of this table, it is assumed that two identical systems are operating simultaneously, each with a flow rate of 1400 acfm and a CCl_4 loading of 500 lbs/day. The CCl_4 is converted and the subsequent HCl loading is 500 lbs/day/system. The numbers shown represent the combined flows of the two systems.

TABLE IV

Summary of Environmental Regulations Applicable to the 200 West Area Carbon Tetrachloride ERA

Regulation	Applicable	Comments
WAC 246-247 (formerly WAC 402-80) (RAEP)	Yes	If radionuclides are extracted during the test, pre-operational notification to DOH is required.
40 CFR 61 (NESHAPs)	No	Applicable only if extracted radionuclides result in a dose of 0.1 mrem or greater, using 40 CFR 61, Appendix D methodology.
WAC 173-400 (PSD)	No	Unless emitting large quantities of carbon tetrachloride (more than 40 tons/yr).
40 CFR 264-265, Subpart AA and BB (RCRA Organic Air)	Possible	CERCLA actions of this type are specifically excluded from permitting, but compliance may be required.
40 CFR 264, Subpart O Incinerators	Yes	99.99% conversion efficiency of carbon tetrachloride in thermal units < 4 lb/h HCl in emissions
State TAP Regulations WAC 173-460	Yes	ASIL for carbon tetrachloride is 0.067 $\mu g/m^3$ (annual average) ASIL for HCl is 23.3 $\mu g/m^3$ (24-h average)
CERCLA Reportable Quantities (40 CFR 302)	Yes	Reportable quantities are over 4.5 kg carbon tetrachloride/day/disposal site and 2,270 kg HCl/day/disposal site.
WAC 173-160	Yes	Well construction standards.

ASIL = Acceptable Source Impact Level
CCl_4 = Carbon Tetrachloride
DOH = Washington Department of Health.
HCl = Hydrochloric Acid
NESHAPs = National Emissions Standards for Hazardous Air Pollutants
PSD = Prevention of Significant Deterioration
RAEP = Radiological Airborne Emission Program
TAP = Toxic Air Pollutants
T-BACT = Best Available Control Technology for Toxics

soil was recorded with an estimated total collection of 365 pounds of carbon tetrachloride (2) on activated carbon. Naturally-occurring radon gas and associated progeny were extracted from the wells also. No man-made radionuclides were detected during testing or within the VES equipment. The testing supported the preliminary evaluation that vapor extraction was feasible at the site.

Extracted Soil Vapor Treatment Options

Extracted soil vapor treatment systems assessed during the EE/CA included granular activated carbon (GAC), catalytic oxidation, and thermal oxidation alternatives (Table II). These categories represent mechanisms by which the carbon tetrachloride is captured or reaches its final disposition. Since the regeneration of the GAC, thermal destruction and catalytic oxidation alternatives produce HCl onsite as a secondary waste, acid scrubbing alternatives were evaluated as well (Table III).

The principal ARARs the treatment systems are to meet are shown in Table IV. Additional Department of Energy Orders also apply but are not discussed here. Based on this evaluation, the only two alternatives able to meet all ARARs were the use of GACs with offsite treatment and the use of GAC with onsite regeneration and offsite treatment of the condensate. This evaluation was based on the design criteria flow rate of 1400 cfm and a carbon tetrachloride loading of 500 lbs/day for two sites operating simultaneously. Potential impacts to the public were assessed by two modeling efforts. The ability to meet the Acceptable Source Impact Levels (ASILs) is based on the results of air dispersion modeling performed to predict the concentrations of carbon tetrachloride and hydrochloric acid at the Hanford Site boundary as a result of emissions from the VES. Operation of the VES and treatment equipment will not have a significant adverse effect on public health or the environment.

In addition to the ability of the treatment options to satisfy ARARs, several other factors were considered in the selection of the excavated soil vapor treatment options. These factors included implementability, effectiveness, and cost. For implementability, the estimated time until startup for each of the options ranged from 4 to 11 months (Table II). The option requiring half the time (4 months as compared to 8 months)

of any other option was GAC with offsite regeneration. The long-term effectiveness of carbon tetrachloride removal from the extracted soil vapor was determined to be 99 percent for GAC with offsite regeneration, placing it with several other options as the most effective. The estimated total purchase and operation costs for the first year of VES implementation ranged from $1,760,000 to $3,343,000 depending on the extracted soil vapor treatment option. The least expensive option was predicted to be catalytic oxidation and the most expensive option was predicted to be thermal oxidation with acid scrubbing. The cost using GAC with offsite regeneration was predicted to be about 110 percent more than that for catalytic oxidation. Based on the criteria described, GAC with offsite regeneration was selected as the extracted soil vapor treatment for the first year of operation of the VES.

Well Field Options

There are over 46 wells completed within the vadose and saturated zones within, and near, the vicinity of the three disposal sites. These wells could be used to extract carbon tetrachloride vapors from the unsaturated soils. Existing wells can be quickly modified for extraction using a downhole perforating tool and appropriate well-completion practices. Placing new wells through the radiologically contaminated zone would be a very costly endeavor, incurring greater delays, produce mixed waste, and realize greater safety concerns. Installation of horizontal wells for vacuum extraction was also assessed, but the feasibility of this activity at the Hanford Site for an initial phase of the ERA is not appropriate. Injection of air, in conjunction with extraction, was also assessed but was deemed not feasible due to the inability to predict the impact of injection on contaminant transport.

Proposed Remedial Action

It has been proposed that soil vapor extraction from existing wells be used in the initial remediation phase of the ERA. Treatment will consist of using GACs. The GACs will initially be sent offsite to a permitted facility for regeneration and the destruction of the carbon tetrachloride.

Concurrent with the initial phase of remediation, a detailed evaluation of extraction and onsite treatment technologies will be conducted. This will be followed by field testing of selected technologies(s) in conjunction with the DOE Volatile Organic Compounds Arid Integrated Demonstration. The goal of the treatment assessment will be to find an onsite treatment technology which meets ARARs and the other selection criteria. For extraction enhancement, well field designs (including looking at horizontal vacuum extraction wells) will be assessed with other emerging technologies. Additionally, more site characterization and modelling of the air flow and soil vapor extraction process will be conducted to assist in upgrading the well field design. The evaluation of these technologies and site characterization information will lead to implementation of treatment and well field modifications for a second phase of the ERA remediation.

PRELIMINARY DESIGN FOR PHASE I

The preliminary design of the VES system consists initially of upgrading the existing pilot test system to expedite extraction at one of the disposal sites. Two additional systems are being designed and built to provide extraction at all three sites. The existing pilot test system will then be replaced and used for testing at other locations on the Hanford Site.

The preliminary vapor extraction design will cover the filtration trailer, blower trailer, office trailer, and well field. The filtration trailer will consist of a seven-well intake manifold, high efficient particulate filters, sample cabinet (sample individual wells), radiological continuous air monitors, main electrical power distribution center, and various instrumentation. The blower trailer will mount the vapor extraction vacuum blower, exhaust stack, and various instrumentation. The office trailer shall house an onsite data logger and computer connected to all transmitting instruments. The data logger and computer will monitor extraction operations, perform trend analysis, monitor alarm points, and shut down the system as required.

The wellfield design will incorporate extraction wells for removing soil vapor from the subsurface and monitoring wells to provide indication of the radial influence of the extraction wells. The extraction and monitoring wells will be selected from existing vertical wells and perforated at intervals based on an assessment of the geology, distribution of radioactive contaminants in the soil, accessibility, and well construction. Borehole scintillation logging will be conducted to determine locations of radiologically-contaminated soils. A borehole video camera will be used to verify the construction and integrity of the wells. The wells will be perforated to provide a soil vapor flowpath into the wells. Each extraction well will typically have several perforated intervals to allow extraction of soil vapor from selected depths. The carbon steel casing will be perforated using appropriate tooling. Well completion will include packers and other mechanisms to isolate pathways to the perforated intervals.

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LAND SURFACE CLEANUP OF PLUTONIUM AT THE NEVADA TEST SITE

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ABSTRACT

The Nevada Test Site (NTS) covers approximately 3300 km^2 of high desert and is located approximately 100 km northwest of Las Vegas, Nevada. Soil contaminated by plutonium exists on the NTS and surrounding areas from safety tests conducted in the 1950s and 1960s. About 150 curies of contamination have been measured over 1200 hectares of land surface. Most contamination is found in the top 5 cm of soil but may be found as deep as 25 cm. The cost of conventional removal and disposal of the full soil volume has been estimated at over $500,000,000.

This study is directed toward minimizing the volume of waste which must be further processed and disposed of by precisely controlling soil removal depth. The following soil removal machines were demonstrated at the NTS: (1) a CMI Corporation Model PR-500FL pavement profiler, (2) a CMI Corporation Model TR-225B trimmer reclaimer, (3) a Caterpillar Model 623 elevating scraper equipped with laser depth control, (4) a Caterpillar Model 14G motor grader equipped with laser depth control, (5) a Caterpillar Model 637 auger scraper, and (6) a XCR Series Guzzler vacuum truck.

The most effective removal technique tested was the pavement profiler, which provided for dust control and precisely removed thin layers of soil. Soil removal with the motor grader and paddle scraper generated unacceptable dust levels, even after the soil was extensively watered. The vacuum truck was ineffective because of its limited intake volume which is a function of its small intake size, its weak intake force, and the tendency of its filters to clog.

INTRODUCTION

The Nevada Test Site (NTS) is located in Southern Nevada approximately 100 km northwest of Las Vegas and encompasses an area of over 3300 km^2. It is surrounded on all but the southern side by the much larger Nellis Air Force Range (NAFR) as shown in Soil contamination exists on the NTS-NAFR complex from nuclear testing as well as other more common industrial practices. The most extensive surface soil contamination, however, is with plutonium released during the detonation of explosives associated with safety tests conducted in the 1950s and 1960s. These explosions, together with the wind, dispersed plutonium-239 and -240, primarily as plutonium dioxide (PuO_2). About 150 curies of contamination have been measured over 1200 hectares of land surface (1). Most contamination is found in the top 5 cm of soil, but can be found as deep as 25 cm (2,3).

In contaminated areas, the surface is typically flat to gently sloping (less than 5 percent grade) desert pavement. The land is barren with sparse yucca plants and desert scrub brush. The vegetation in some areas is only a few percent of the mass associated with the contaminated soil. Soils are alluvial and colluvial derived from the adjacent mountain ridges with high sand contents (greater than 50 percent) and low moisture contents (less than 10 percent). Most of the plutonium is associated with soil particles ranging in size from 5-125 μm (3).

Remediation practices that have been tried for the safety test areas include both isolation and soil removal (4). The plutonium has been isolated by either spraying the soil surface with road oil or paving over it with asphalt. Plutonium has also been forced below the surface by leaching it with water or turning it over with a plow. Some trial areas have been decontaminated by scraping the top 15 cm of soil into windrows and hauling it elsewhere for burial. Removing the top 15 cm of soil over the entire contaminated area would result in over 1,600,000 m^3 of waste that would require further processing or burial at an estimated cost of $300/$m^3$, for a total cost exceeding $500,000,000 (4).

Some of the removal techniques investigated prior to this study included vegetation removal with timber chippers, soil removal with vacuum trucks, and both soil and vegetation removal with graders and scrapers (4). Preliminary tests using two different vacuum trucks were conducted, but effective soil removal was hindered by dust control practices such as wetting the soil surface before vacuuming (making it difficult to pick up), and passing the vacuum discharge through filters that clogged (4,5).

The objectives of this study were to evaluate conventional and specialized earth-moving equipment and techniques which may provide for the effective removal of thin layers of surface soil while minimizing re-suspension of plutonium dust. Specifically, six types of soil removal machinery were compared: (1) a CMI Corporation Model PR-500FL pavement profiler, (2) a CMI Corporation Model TR-225B trimmer reclaimer, (3) a Caterpillar Model 623 paddle scraper, equipped with laser depth control, (4) a Caterpillar Model 14G motor grader, equipped with laser depth control, (5) a Caterpillar Model 637 auger scraper, and (6) a XCR Series Guzzler vacuum truck. The investigation was conducted by Reynolds Electrical and Engineering Co., Inc. (REECo).

The demonstration area was located in Area 6 of the NTS, approximately 1.6 km east of Mercury Highway, and 120 m south of Tweezer Road (Fig. 1). The standing vegetation on the test plot consisted of primarily dead or dormant shadscale *(Atriplex confertifolia)* less than 60 cm tall, with stem diameters of less than 2.5 cm. The shadscale canopy was visually estimated to extend over approximately 30 percent of the surface. Particle size distributions of soil samples from the demonstration area are shown in Fig. 2. The soil contains 15 to 30 percent

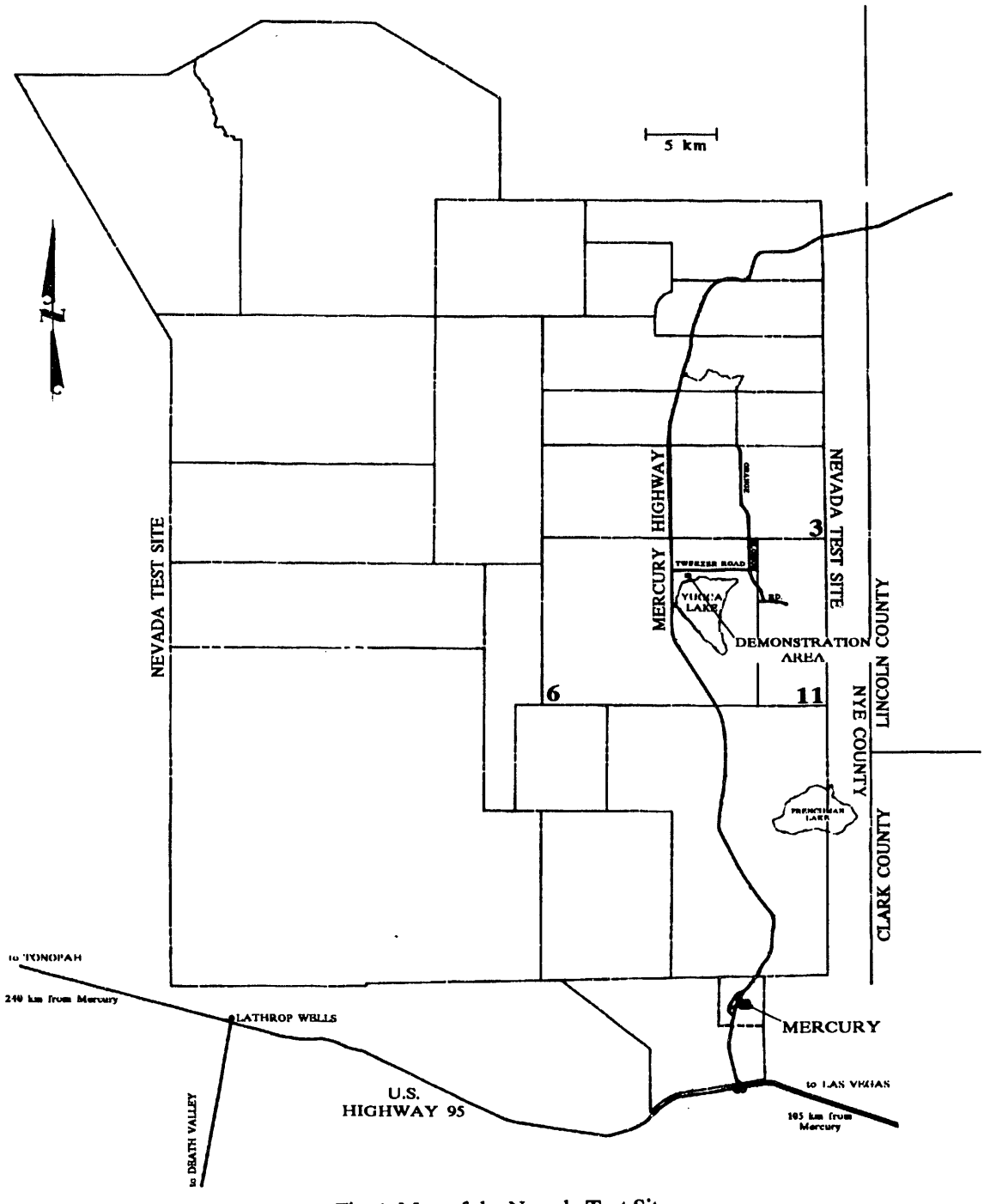


Fig. 1. Map of the Nevada Test Site.

clay and 10 to 30 percent silt. The organic fraction comprises less than 2 percent of the soil. The soil in this area is the most comparable to contaminated soils located in Area 13 of the NAFR. Soil particle size and PuO_2 distribution in Area 13 soil are shown in Fig 2.

A 15-meter grid was established in the demonstration area. Rows were designated 0 through 9 from south to north and columns as A through K (excluding I to prevent possible confusion with the numeral 1) from east to west (). Machine passes were numbered from an adjacent grid row, assigning north as the positive direction. For instance, pass 0 + 1 designates the first pass to the north of the southern boundary and pass 1-1 refers to a pass made immediately south of grid row 1. The maximum length of a machine pass was 140 m.

Dust produced during the demonstrations was quantified and characterized by drawing air samples through an assortment of filters and cyclones attached to standard air samplers. Total suspended particles, respirable particles (less than 10 μm) and the suspended particle size distribution were determined. Air samplers were placed on the primary machines, on the operators, on other supporting personnel, and in both the upwind and downwind directions at the beginning of each operation.

THE CMI CORPORATION MODEL PR-500FL PAVEMENT PROFILER

A pavement profiler (Model PR-500FL) made by CMI Corporation of Oklahoma City, Oklahoma, was demonstrated on March 4-5, 1991, to determine its effectiveness in precisely

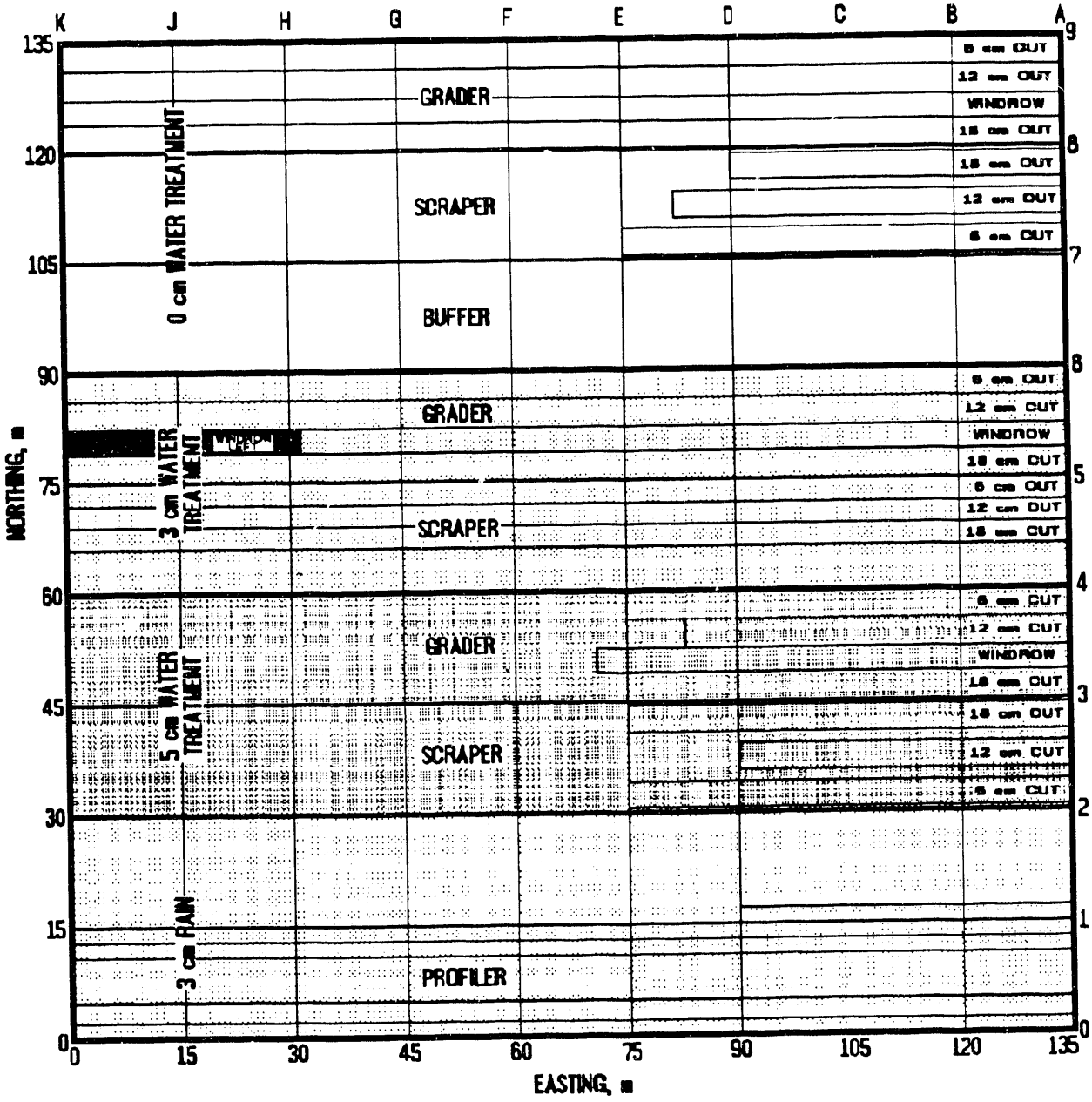


Fig. 2. Plot layout and treatments.

removing thin layers of soil. The profiler, a common machine used for resurfacing concrete and asphalt roadways, is almost 15 m long, weighs approximately 35,400 kg, and is mounted on three 2 m by 25 cm crawler tracks. The profiler has a 220 cm cutting width, and a maximum cutting depth of 25 cm. Its cutting mandrel consists of auger flights (approximately 1 m in diameter) with 150 conical tungsten carbide teeth along their edges. The mandrel rotates at 90 rpm. The unit has an integral water spray system for dust control including a 4,900-liter tank, 10 water spray nozzles located on the cutter shroud, and additional sprays located above the conveyors. This machine is equipped with a hydraulic grade and cross-slope control system that can maintain a tolerance of ±0.3 cm. The profiler is equipped with a gage wheel for depth reference. The profiler can pick up as much as 13 m^3/min of soil and discharge it into an accompanying truck through a front-mounted belt conveyor.

Weather conditions during the profiler demonstration were cloudy with temperatures of approximately 280 K and predominately southwesterly winds of 40-55 km/h with gusts to 70 km/h. Operations were ceased on March 4 1991, in the mid-afternoon when high winds threatened to tip the truck during dumping. Approximately 2.5 cm of rainfall occurred in the four days prior to the profiler demonstration which moistened the soil 5-7 cm deep.

Seven passes (0 + 1, 0 + 2, 0 + 3, 0 + 4, 1 + 1, 1-2, and 1-1) were made along the south end of the demonstration area with the pavement profiler (Fig. 2.). The depth of cut was adjusted during each pass. Depth measurements along each side of some representative passes are shown in Fig. 4. With the exception of the single scraper point at A, pairs of depth measurements taken from the north and south sides of the cut at each point are shown. Soil samples were taken after each pass to ensure that all particle size classes were picked up by the profiler.

The profiler produced a clean, flat cut; virtually all loosened material was collected. However, when the gage wheels passed over mounds associated with shadscale, the cut depth

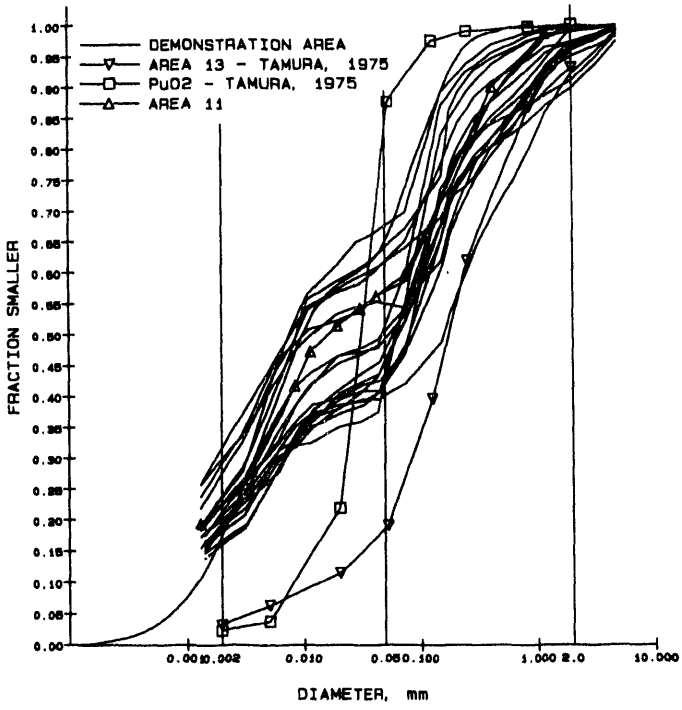


Fig. 3. Soil particle size distribution.

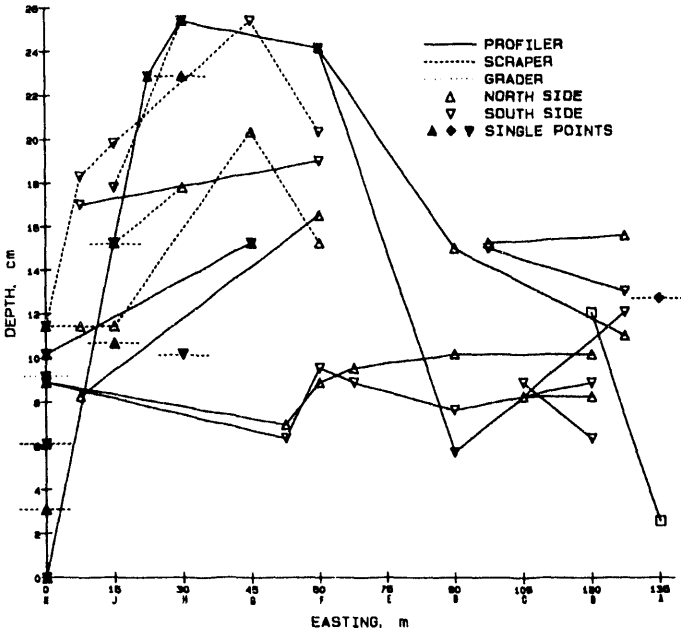


Fig. 4. Machine cut profiles.

varied. Modifications were made to link the depth control system to the cutter shroud end plates. These plates are sufficiently heavy to level the mounds as they slide along the ground surface, improving the precision of cut depth.

On unmodified natural terrain, the profiler was capable of removing layers less than 5 cm thick at a rate exceeding 110 m/hr. The maximum rate of removal could not be determined in the test, since the two 18 m^3 (24 yd^3) dump trucks supporting the demonstration were not able to carry away removed soil at the maximum rate of production. The profiler held a fixed cut depth with a tolerance of ±1.3 cm during the demonstration. Improved depth sensing and control techniques may be capable of narrowing this tolerance to its limit of ±0.3 cm.

Standing vegetation had no effect on the machine or the smoothness of the cut. Vegetation was removed together with the soil and broken into small pieces 2.5-7.5 cm long. In cuts less than 3 cm deep, some loosened soil was lost as plant roots that were not undercut passed under the moldboard following the cutters. In addition, there remained some concern about the ability of the profiler to handle soils containing small boulders with diameters of 25-30 cm. To test this concern, pieces of waste concrete (up to 60 cm in diameter) were placed in the path of the profiler. These pieces tumbled in front of the profiler cutters until reduced to a size that could be easily picked up by the machine.

Dust levels produced during the operation were undetectable by the air samplers. No differences were measured between upwind and downwind filter loadings. The profiler produced much less visible dust than did the supporting trucks. However, some mud droplets were blown from the soil stream at the end of the discharge conveyor and damp soil accumulated on the machine at the transfer point between the pickup and loading conveyors. The rainfall prior to this demonstration resulted in a soil moisture content of 13 percent. This is similar to that obtained by the addition of 5 cm water to plots used for the grader and scraper demonstrations (Fig. 5).

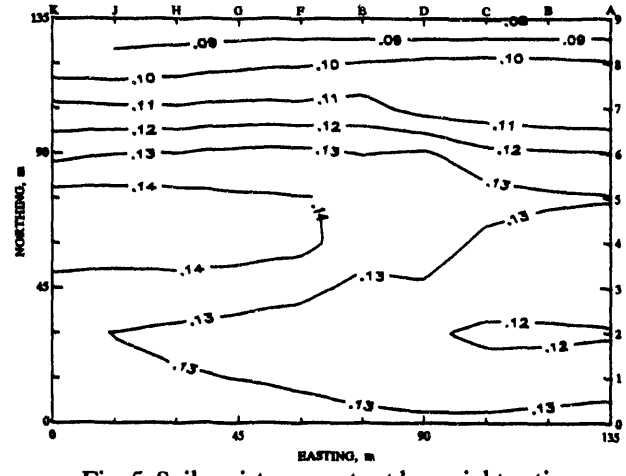


Fig. 5. Soil moisture content by weight ratio.

THE CMI CORPORATION MODEL TR-225B TRIMMER RECLAIMER

The TR-225B trimmer reclaimer demonstration was conducted on May 22, 1991, at the CMI plant located west of Oklahoma City, Oklahoma. The trimmer is similar in design to the PR-500FL profiler. Differences found in the trimmer include a rear discharge system, lack of an internal dust control system, and a design specific to work with soils. Consequently, this machine is lighter (less than 22,000 kg) and less powerful (190 KW) than the profiler. In addition, the chisel-shaped cutting teeth are made of carbon steel. The trimmer exhibited depth control precision similar to that of the profiler, but soil clinging to the belt of the discharge conveyor was dropped behind the machine. This could potentially result in contaminated soil being left behind. This fact, together with the lower durability of the trimmer in soils with rocky outcrops and boulders, led to the elimination of this and similar models from consideration.

THE CATERPILLAR MODEL 623 ELEVATING SCRAPER AND MODEL 14G MOTORGRADER WITH JOHN DEERE MODEL 844 LOADER

The Caterpillar Model 623 elevating scraper weighs 29,900 kg, is 13 m long, and has a capacity of 16.8 m^3. The scraper generates a 3.5 m wide cut with a maximum depth of 33 cm. The scraper has a large chain-and-flight elevator, located in the front of the bowl, which distributes the loaded material. The Model 14G motor grader weights 18,370 kg, has an overall length of over 9 m, and has a 5-m blade. Laser depth control receivers (Laser Alignment, Inc.) were installed on staffs at each end of the grader blade, and on the right side of the scraper bowl. The laser control on the grader was completely integrated into the hydraulic system for automatic depth control. Scraper depth was manually controlled in response to a panel indicator. Laser receivers were used in conjunction with a LB-4 dual grade laser beacon that achieves a rotation speed of 40 rps and has a grade accuracy of 2.2 mm per 30 m. A John Deere Model 844 wheel loader and 18 m^3 dump truck supported the grader operation. The loader has an articulating 4 m^3 bucket that is 3.2 m wide.

Demonstrations with the scraper and grader were conducted on strips 2 through 9, as shown in Fig. 2, from May 1-6, 1991. Wind during the demonstration was predominately from the south, gusting to about 40 km/h, but during May 1 the wind gusts were as high as 100 km/h. Cuts of 6, 12, and 18 cm depth were made with each machine on plots subjected to three dust control treatments (the addition of 0, 3, and 5 cm of water). The strips between rows 6 and 9 were left dry, where the strip between 6 and 7 served as a buffer for water runoff. Water was applied by a 38,000-liter capacity Klein KT-100 water hauler. Three cm of water were applied to the strips between rows 4 and 6 and five cm of water were applied to the strips between rows 2 and 4. Water was applied lightly in numerous passes over a two-day period to reduce runoff. Considerable pooling occurred on the 5-cm treatment strips, and some runoff occurred beyond row 2. The 3-cm water treatment strip were left one day following the final water application, and the 5-cm treatment strips were left for three days. This allowed the water to percolate into the soil. Resulting soil moisture contents in samples taken immediately before and after each demonstration are shown in Fig. 5. The water hauler trampled most of the vegetation on the 3-cm treatment. Essentially all of the vegetation on 5-cm treatment was flattened.

The grader was demonstrated on a dry strip (8-9) on May 1, a 3-cm water treatment strip (5-6) on May 3, and a 5-cm water treatment strip (4-3) on May 6. The grader cuts were made with consecutive passes of about 6 cm depth each. All cuts were approximately 3 m wide. The laser beacon was set (using readings taken by the receivers at each end of the strips) to rotate in a plane parallel to the soil surface. Since the soil surface was almost perfectly flat, this process resulted in excellent depth control. Deviations in all cut depth dimensions were virtually indistinguishable. Depth control is expected to be less precise on undulating terrain.

Dust generated by grader and loader operations on the dry treatment, in addition to high wind gusts, limited visibility to near zero downwind of the demonstration area. Dumping soil into the truck from the loader bucket created a piston effect that blasted huge volumes of dust into the air. Besides the large quantities of dust produced, the grader filled all voids intersected by the blade's edge with the surface soil being moved. This would result in leaving contaminated soil behind. Thus the use of graders is not recommended.

The scraper was demonstrated on a dry strip (7-8) on May 3, a 3-cm water-treated strip (4-5) on May 2, and a 5-cm water-treated strip (2-3) on May 6. The laser beacon was set up as with the grader, but the scraper was unable to exhibit similar precision in depth control. The cutting edge on the side with the laser receiver could be closely controlled by the operator. However, the scraper is not designed to allow changes in the relative position of each end of the cutting edge. Furthermore, the left end of this particular scraper blade tended to cut deeper than the right, and as the left tire followed the deeper cut, the left cut depth increased as the cut progressed. This resulted in differences in cut depth greater than 12 cm at the end of a 140 m pass. Unsuccessful to attempts minimize this difference were made by starting each pass with the rear wheels on level ground, alternating the direction of passes, and off-setting each subsequent pass to the left.

Soil disturbance by the elevating scraper generated large quantities of dust even during shallow passes on the water treated test strips. Calculated 8-hour time weighted average (TWA) results for the total dust ranged from 0.02-7.06 mg/m^3; respirable dust ranged from 0-9.17 mg/m^3. One respirable dust sample was in excess of the associated permissible exposure limits (PEL) established by the Occupational Safety and Health Administration (5 mg/m^3). This was an area sample collected on May 1 during very high wind conditions; the sampling pump was located downwind (Row 9, Stake E) of the motor grader demonstration on dry soil. All other total respirable dust sample results were below the associated PEL. The sample filters located on the right and left of the motor grader cab were also heavily loaded with dust. The acceptable limits when working in contaminated soil would be considerably lower than the PEL.

THE CATERPILLAR MODEL 637 AUGER SCRAPER

The operation of a Caterpillar Model 637 auger scraper at the NTS was video recorded for comparison with the other machines. This auger scraper has a capacity of 24 m^3 and weighs 55,000 kg. This scraper has a large auger in the bowl that distributes the load. This system seemed to generate less dust than the loading flights of the elevating scraper, but air sampling data were not taken. The solid apron located in the front of the bowl reduced soil spillage relative to that of the chain-and-flight elevator of the elevating scraper.

The principal conclusions from this demonstration were: (1) scrapers can remove soil quickly and efficiently; (2) the unmodified scrapers raise more dust than can be tolerated in plutonium removal, even when the soil to be removed is previously heavily watered (the auger scraper raises somewhat less dust than the elevating scraper); 3) the only means of unloading soil from the scrapers is by dumping through the front of their bowls, which leads to the suspension of more dust and means that special unloading ramps would have to be constructed to permit the use of the scrapers in plutonium removal; and (4) the scrapers have a tendency to level the scraped area by filling in hollows which lie below the elevation of the scraper blade. In general, the scrapers appear to offer little advantage over conventional NTS practice, i.e., the

creation of windrows with graders, and removing the windrows with front-end loaders.

THE XCR SERIES GUZZLER VACUUM LOADER

The XCR Guzzler is a large truck mounted machine with tandem rear axles. It consists of a holding tank, a cycione separator, a filter bag house and a positive displacement air pump. The intake nozzle is located at the end of a flexible hose. It is an aluminum tube, approximately 20-cm diameter, cut at an angle, and manipulated by hand. Maximum guzzler uptake rates for granular material are 10 m^3/hour.

A Guzzler was demonstrated on June 26, 1990, in an area adjacent to the grid used for the profiler, grader, and scraper demonstrations. The area had been disk plowed and leveled. For this demonstration, the intake hose was connected directly to the cyclone, by-passing the 12 m^3 holding tank and its primary separation process.

In order to pick dry soil, the intake nozzle had to be placed in direct contact with the surface. The depth of soil removal was inconsistent, averaging approximately 2.5 cm. The resulting depth was more a function of machine performance rather than a change in soil texture. Undisturbed soil had to be manually broken loose and agitated before it was pulled in. Less than 0.5 m^3 of soil was picked up during an hour of actual vacuuming. Pressure drops greater than 250 mm Hg across the bag house indicated that neither the cyclone nor the reverse air jet system were effective keeping the filters clean.

Similar vacuum demonstrations utilizing a Central Engineering Model E5-16 Vac-All (2,5) and a General Resource Corporation Model 816L Haz Vac (J.R. Roberts, personal communication) encountered similar problems of inadequate intake force and soils clogging or passing through the separation processes. However, the possibility of incorporating an air vacuum as part of a soil removal and separation system has not been thoroughly evaluated.

CONCLUSIONS

Six soil removal machines were demonstrated: (1) a CMI Corporation Model PR-500FL pavement profiler, (2) a CMI Corporation Model 225B trimmer reclaimer, (3) a Caterpillar Model 623 elevating scraper, equipped with laser depth control, (4) a Caterpillar Model 14G motor grader, also equipped with laser depth control, (5) a Caterpillar Model 637 auger scraper, and (6) a Guzzler Series XCR vacuum truck. The primary conclusion of the soil removal demonstrations is that the CMI Model PR-500FL profiler is superior to the all other equipment tested. It achieves the most accurate depth control (within 1.3 cm of programmed cut depth). The profiler removes soil cleanly, with virtually no residue or downward mixing of the contaminated surface layer into uncontaminated lower layers. Its removal rate in the test area exceeded 90 m^3/hr. Under optimum conditions, it may produce more than twice that volume. Importantly, this machine also raised virtually no dust. The profiler was completely unaffected by the standing vegetation on the test plot. For minor work, such as removing spillage and cleaning small areas missed by the profiler, an industrial vacuum truck would be useful.

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M-AREA BASIN CLOSURE - SAVANNAH RIVER SITE (U)

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ABSTRACT

M-Area, on the Savannah River Site, processes raw materials and manufactures fuel and target rods for reactor use. Effluent from these processes were discharged into the M-Area settling basin and Lost Lake, a natural wetland. The closure of this basin began in 1988 and included the removal and stabilization of basin fluids, excavation of all contaminated soils from affected areas and Lost Lake, and placement of all materials in the bottom of the emptied basin. These materials were covered with a RCRA style cap, employing redundant barriers of kaolin clay and geosynthetic material. Restoration of excavated uplands and wetlands is currently underway.

INTRODUCTION

The Savannah River Site is a Department of Energy production facility constructed in the 1950's. This 780-square-kilometer (300 mi^2) site is located in western South Carolina, adjacent to the Savannah River. M-Area, located near the site's northern boundary, manufactures and produces aluminum clad, enriched uranium fuel tubes, and aluminum clad target rods for reactor use. Stringent nuclear reactor standards necessitate the use of cleaners and degreasers, more so than other commercial aluminum operations.

M-Area has three production buildings (313-M, 320-M, and 321-M) and two support laboratories (320-M and 322-M). These facilities generate wastewater similar to that produced by commercial aluminum-forming and metal-finishing industries. Initially, this effluent was discharged to the A-1 outfall and Tims Branch. The M-Area settling basin was constructed in 1958 to receive building 321-M effluent and to eliminate the release of enriched uranium to the surface streams and ecosystem.

The original basin was 100.9 m (331 ft) long x 85.0 m (279 ft) wide x 6.1 m (20 ft) deep, with a design capacity of 30.3 million liters (8 million gal). The basin had an outlet, channelling any overflow into a natural depression called Lost Lake. Discharge into the settling basin was terminated in July 1985, with the completion of the M-Area Liquid Effluent Treatment Facility.

During the 27 years of operation the basin received wastes containing primarily lead, nickel, magnesium, zinc, and uranium, with concentrations of nitrate, phosphate, sulfate, sodium hydroxide, and metal degreasers. Total uranium discharged to the basin between 1974 and 1985 was 1150 Mci. The influent ph varied, due to the use of both acids and caustics in the manufacturing processes. It is estimated that 30,000 kg of heavy metals and 2.0 million kg of volatile organic solvents were discharged to the M-Area basin.

The purpose of this paper is to briefly describe the characterization and the closure of the M-Area Basin. This closure was regulated by South Carolina Department of Health and Environmental Controls (SCDHEC).

CHARACTERIZATION

Geology. The generalized geology in the vicinity of the M-Area basin is that of interbedded sands and clay lenses. This marine environment was subjected to shoreline variation and stream meandering. The groundwater is located approximately 42.7 m (140 ft) below the ground surface and consists of three hydrostatic layers, each confined by clay layers.

Four groundwater monitoring wells were initially installed to identify any groundwater contamination. Determinations from these wells precipitated the closure and remediation activities. An extensive remediation program to remove organic solvents from the groundwater is associated with this closure. ough germane to the contamination problem, a thorough discussion of the groundwater remediation is not included in this paper.

M-Area Basins and Adjacent Areas

An extended characterization program was initiated to address the organic and inorganic constituents in four basic areas (1,2,3). These areas are the basin, the process sewer line, the overflow seepage area, and Lost Lake (Fig. 1).

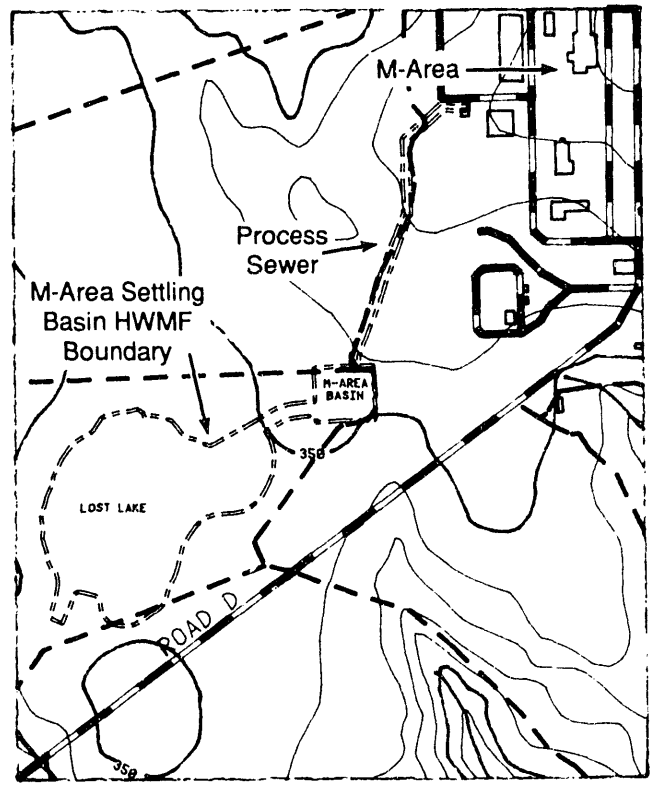


Fig. 1. Plan view of the M-Area Settling Basin Hazardous Waste Management Facility (HWMF).

The basin fluids were characterized by three distinct zones. The upper and middle zones were defined and separated by a chemocline, with both experiencing mixing induced by thermal heating and flow from the process sewer. The majority of the metals contained in the basin resided in the lower zone, a semiconsolidated sludge. High levels of chlorocarbon solvents were detected in the sludge in 1982, but they were not detected at significant levels when reanalyzed in 1984. Apparently they had volatilized or infiltrated into the soil.

The process sewer line was a 609.6 m (2000 ft), gravity flow system, constructed out of 76.2 cm (30 in) vitrified clay pipe (VCP). This pipe had been relined with a 30.5 cm (12 in) polyethylene liner to prevent leakage. The extent of contamination from leakage was partially characterized, but was indeterminate until excavation. At the time of excavation, heavy metals were found to a depth of 1.2 m (4 ft) below sewer grade. Low concentrations of volatile organic compounds were also found within this depth range.

The sludge composition in the overflow ditch and seepage area were similar to the basin, but at lower concentrations. Soils beneath the overflow ditch contained elevated levels of metals to a depth of 15.2 cm (6 in), with nickel and uranium ranging to depths of as much as 0.9 m (3 ft). Low-level organic contamination was also found in the top 15.2 cm (6 in) of these soils.

Slightly elevated concentrations of metals were found in the surface soils below the normal water line at Lost Lake. Only one soil sample from Lost Lake contained a measurable amount of tetrachloroethylene.

Figures 2 and 3, show the generalized concentrations for the different areas characterized relative to SRS background levels. These background concentrations area listed in Table I, and have been used to normalize the concentration levels displayed on Figs. 2 and 3.

EXCAVATION ACTIVITIES

The M-Area Basin Closure Plan identified the Hazardous Waste Management Facility (HWMF) as encompassing the M-Area basin, the process sewer line, the overflow seepage area, and Lost Lake (Fig. 1), (3). The strategy was to remove, treat, and release the fluids. The sludge from the bottom layer in the basin, together with sludge from the

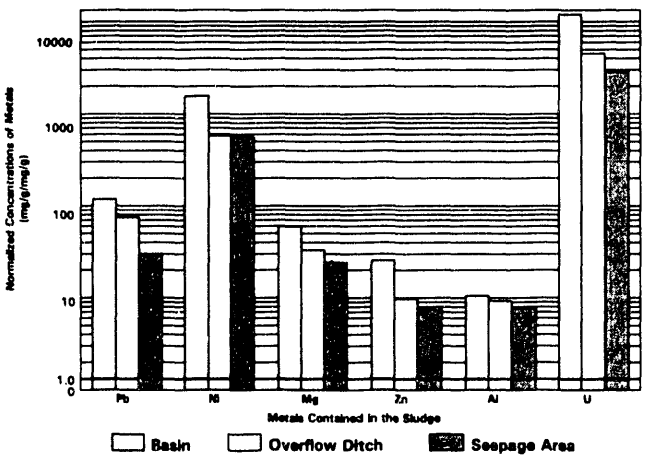


Fig. 2. Normalized semilog graph displaying heavy metal concentrations contained in the sludge (Pickett, July 1985). Includes areas within the HWMF where sludge was found.

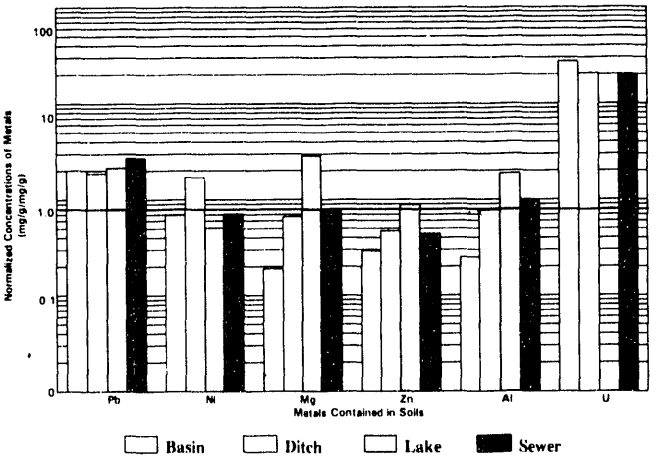


Fig. 3. Normalized semilog graph displaying heavy metal concentrations located in the HWMF soils (Pickett, July 1985).

overflow ditch and seepage area, were stabilized and placed into the bottom of the empty basin (Fig. 4). The remainder of the contaminated soils was excavated and placed on top of the stabilized material. These materials were then protected with a RCRA style cap, minimizing potential for constituent migration. The following discussions will briefly treat the closure activities for each element of the HWMF.

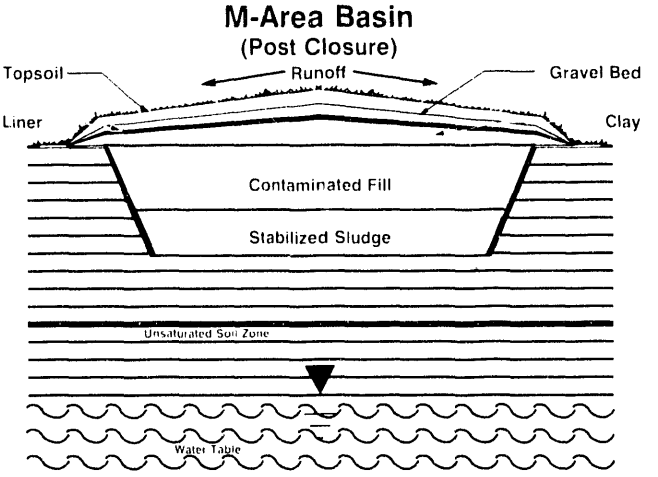


Fig. 4. Cross-section of the closure of the M-Area Setting Basin showing the deposition of stabilized materials and the RCRA style closure cap.

TABLE I

Savannah River Site Background Levels

Constituent	Concentration (ppm)
Pb	5
Ni	14
Mg	96
Zn	12
Al	13,000
U	2

Site Preparation

Site preparation included removing and disposing of the dense vegetation within the HWMF, and grading the laydown area for construction. These operations were done to facilitate access to contaminated soils and to preclude any spread of contamination that might be associated with the timber. Several options were contemplated for disposal of the grubbed vegetation. Among these were transportation off the site, constructing an incinerator, and open-air burning. After extensive negotiations with SCDHEC, the final decision was to allow open-air burning, with constraints on allowable wind speed and direction, after which the vegetation was grubbed, piled, and then burned.

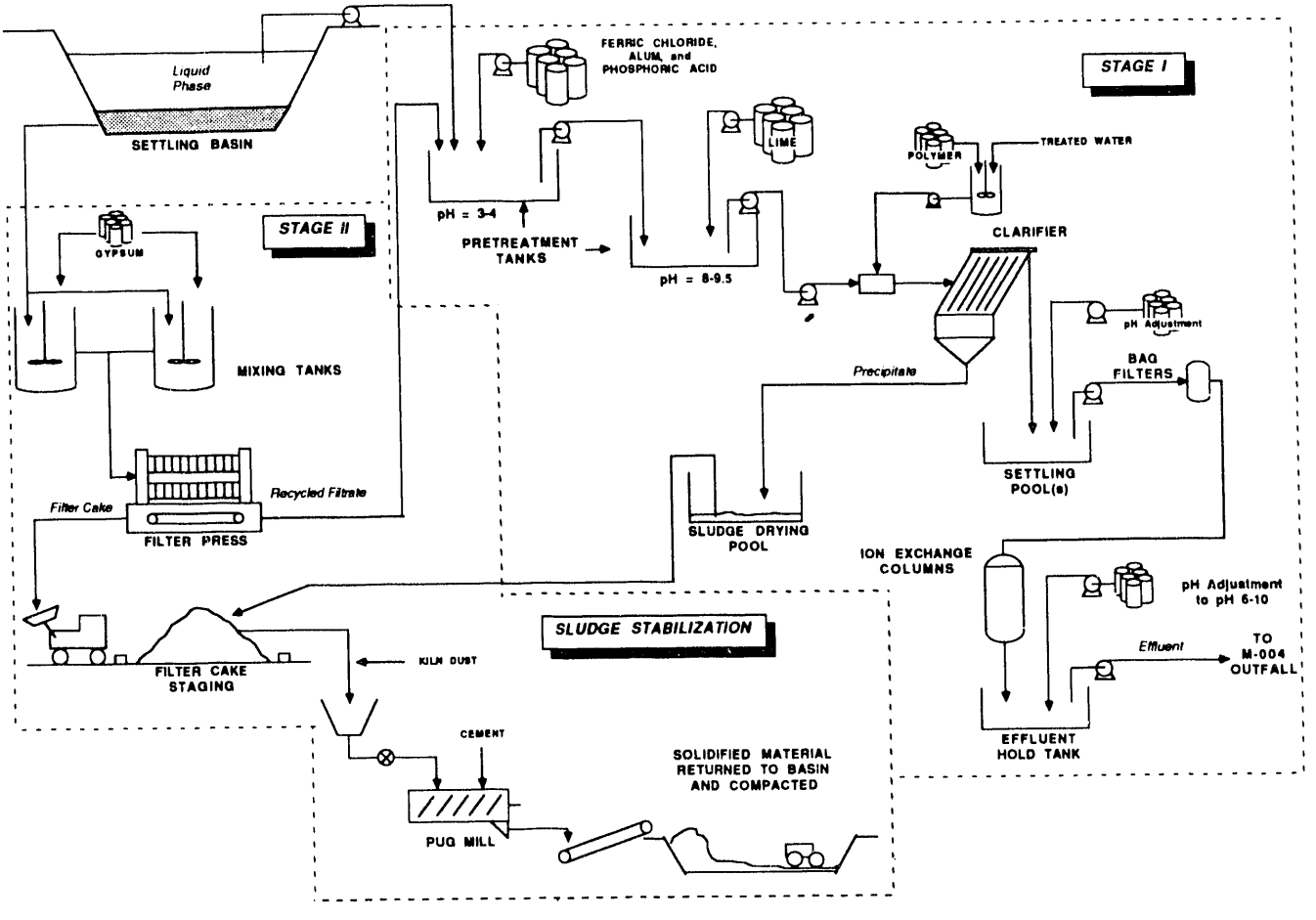
The area adjacent to the basin was grubbed and graded to facilitate construction of a temporary Wastewater Treatment Facility (WTF) and a laydown area for materials and equipment. The work area was diked, forcing any drainage to flow into the basin. Access to the area was restricted and a decontamination pad for equipment and personnel was constructed.

Settling Basin

The liquids contained in the basin were pumped to the temporary WTF, treated, and discharged to the NPDES-permitted outfall M-004A. The temporary WTF implemented both chemical and physical treatment stages. These treatment steps included ph adjustment, polymer addition, and clarification by precipitation and filtration (Fig. 5). Treated effluents were to the outfall through a 10.2 cm (4 in) sealed pipeline.

The fluids and sludge were removed from the basin using pumps and a horizontal auger-cutter and pump assembly, supported by a floating dredge. The dredge pumped the sludge into a mixing tank where diatomaceous earth was added to act as a flocculent and filter aid. The mixture was then pumped to and processed by a portable filter press, separating the liquids from the solids. The filtrates were sent to the WTF for processing and discharge to the outfall. The (clay-like) filter cake was staged and covered adjacent to the basin for later stabilization and deposition.

The filter cake was stabilized using a mixture of Portland Cement and flyash, at a ratio of 4 parts cement to 1 part flyash. This mixture was then blended with the filter cake at a ratio of 1:10. A pug mill was used to process the filter cake; however, at the initial mix ratio, the material was very difficult to work and impeded the pug mill operations. After iterative trial runs, the optimal mixture was determined to be a ratio of 1:6, cement and flyash to the filter cake. This ratio cost the contractor more in cement costs, but these costs were more than offset by the reduction in downtime and manhours to keep the pug mill operational. The pug mill was equipped with a conveyor system to deposit the stabilized filter cake directly into the basin, where it was mechanically spread and compacted.



Flow Diagram of the M-Basin Wastewater Treatment Facility

Fig. 5. Schematic of the temporary Wastewater Treatment Facility constructed at the M-Area Settling Basin.

Process Sewer

Excavation of the process sewer included the removal of piping and all contaminated soils that were within the range of normal excavation activities. The polyethylene pipe was withdrawn intact and cut up into workable 2.4 m (8 ft) lengths. These pieces were taken to the now empty basin, filled with concrete, and buried. The clay-tile pipe was also deposited in the basin and crushed by mechanical equipment to minimize void space.

Monitoring for heavy metals in the soil below the process sewer revealed contamination some 1.2 m (4 ft) below grade. Over 1530 cubic meters (2000 yds^3) of contaminated soil were removed and compacted into the basin. The uncontaminated overlying soils were staged for later recompaction after the removal of the process sewer line.

Monitoring indicated residual organic contamination in the deeper soils that were not within the range of surface excavation. This contamination is being addressed in Part B of the Post Closure Care Permit and as part of the corrective action program.

Overflow Ditch and Seepage Area

The natural seepage area (Fig. 6) allowed a portion of the basin overflow to dissipate into the ground by infiltration. Soils within this 1.5 ha (3.8 ac) drainage area were excavated to depths ranging from 10.2 to 61 cm (4 to 24 in). Nearly 13,006.9 cubic meters (17,000 yds^3) of soil were excavated and transported to the basin for deposition.

The sludge was removed from the bottom of the overflow ditch. The sludge was similar to that found in the basin, though at lower concentrations. This material was dewatered and stabilized with the basin sludge. The contaminated soil was excavated to a depth of 1.8 m (6 ft), and placed on top of the stabilized sludge.

Lost Lake

The Carolina bay, known as Lost Lake, is a naturally occurring wetland. This 11.7 ha (29 ac) wetland is a geomorphological anomaly, with no apparent outlet. Seasonal weather and rainfall fluctuations cause changes in water level, ranging from completely full to dry.

Prior to excavation, Lost Lake was pumped dry to facilitate excavation. Approximately 45.4 million liters (12 million gal) of water were removed and spread in areas outside the watershed. Prior to discharge, these waters were fully tested. Test result evaluation prompted SCDHEC to require monitoring only for total suspended solids (TSS) prior to discharge. The water was pumped into one of three 189,270 liter (50,000 gal) holding tanks, tested for TSS, and then discharged to a land disposal system.

Based on the levels of standing water, soil types, and the concentration of metals, the lake was divided into three distinct remediation zones (Fig. 6). The first zone, labeled C, encompassed all those areas below 102.4 m (336 ft) in elevation; 30.5 to 45.1 cm (12 to 18 in) of soil were removed, extending into the underlying hardpan. The second zone, labeled D, included those areas lying between 102.4 and 103.0 m (336 and 338 ft) in elevation; 15.2 to 30.5 cm (6 to 12 in) of soil were removed, depending upon characterization findings and supplemental monitoring. The third and last zone, labeled E, included those areas between 103.0 and 103.6 m (338 and 340 ft) in elevation; 5.1 to 10.2 cm (2 to 4 in) of soil were removed. All these soils were transported to and compacted in the basin.

Summary of Excavations

Table II presents the volumes of materials processed and deposited into the basin.

CLOSURE CAP

The closure cap is an integrated system employing redundant barriers (Fig. 4). The system used 61.0 cm (24 in) of kaolin clay, overlain with a 36-mil-thick geosynthetic material, embedded between two 15.2 cm (6 in) layers of sand. A 61.0 cm (24 in) gravel drainage layer was placed next, overlain by a geotextile filter material. Finally, the system was protected with 61.0 cm (24 in) of topsoil and a vegetative cover.

Kaolin Clay

Kaolin clay is the primary element in the moisture barrier and is locally available. In 1987-88, SRS initiated a study to prequalify local clay sources and to determine optimum construction methods. This study was conducted by Mueser Rutledge Consulting Engineers of New York (5,6). The evaluation parameters included clay workability, construction procedures and equipment, and final clay permeability. The

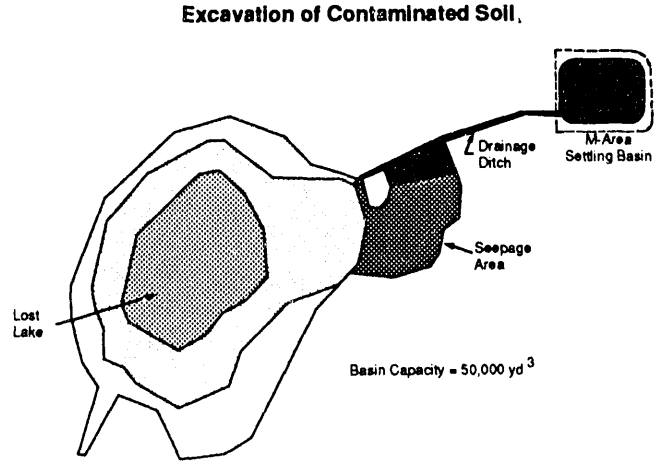


Fig. 6. Plan view of the excavation of contaminated areas of the M-Area Settling Basin HWMF, not including the process sewer line.

TABLE II

Summary of Exavated Volumes, M-Area HWMF

Name	Area	Volume
M-Area Settling Basin:		
Liquid Phase		3,000,000 gal
Sludge Phase		2,000,000 gal
Process Sewer		2100 yd^3
Overflow/seepage	3.8 ac	17,200 yd^3
Lost Lake:		
Area "C"	9.9 ac	16,000 yd^3
Area "D"	11.3 ac	9100 yd^3
Area "E"	8.2 ac	2200 yd^3

final report recommendations were implemented into the construction of the M-Area basin closure cap.

Construction of the clay cap was done using four, 20.3 cm (8 in) lifts, which were compacted to a depth of 15.2 cm (6 in). Each of the four separate lifts were placed and compacted, bringing the thickness of the clay to 61.0 cm (24 in). A total of 10,329.0 cubic meters (13,500 yds^3) of kaolin clay were incorporated into the closure cap.

Testing was performed on the clay material prior to, during, and after placement. Prior to placement, the clay was sampled and tested at delivery to verify quality and optimum moisture density. During placement, moisture content and density were checked using both the sand cone and nuclear testing equipment. After placement, several random samples were taken of the cap profile and bench tested for quality and permeability. Each of the holes was filled and sealed, using multiple lifts of compacted bentonite clay pellets.

Geosynthetic Material

After laying down a 15.2 cm (6 in) thick layer of sand, a geosynthetic material by the trade name of Hypalon was placed, covering the cap. Over 9290 square meters (100,000 ft^2) of the 36-mil material were used, providing a redundant barrier to the kaolin clay. The Hypalon panels were overlapped 15.2 cm (6 in), and bonded using a cold-applied Hypalon bonding adhesive. The geosynthetic cap was visually inspected for holes, and the seams were tested using an air lance, supplemented by laboratory seam testing. Any holes or faulty seams were patched and repaired. The edges of the material were secured using an anchor trench.

Drainage Layer

The cap drainage system overlying the geosynthetic layer, functions to preclude the development of a hydrostatic head over the more impermeable portions of the cap. Infiltrating rain water is channeled laterally by the permeable gravel to a perimeter drain and discharged into a bypass channel along the outside of the basin. The system consisted of three primary components:

- A 30.5 cm (12 in) thick layer of stone graded to ASTM C7 specifications.
- A perimeter drain consisting of a 15.2 cm (6 in) perforated collection pipe, embedded in crushed stone in the liner anchor trench.
- A protective cover of 90-mil-thick geotextile filter fabric. The filter fabric prevents the downward migration of the topsoil, which would clog the drainage layer.

Final Cover

The final protective cover consisted of 45.7 cm (18 in) of clean fill, covered with 15.2 cm (6 in) of topsoil. Compaction was minimized for the upper portion of the fill to facilitate plant growth. The surface of the cap was contoured to maximize runoff and minimize erosion potential. The topsoil was disked and seeded with a blended seed mix. The U.S. Forest Service (USFS), Savannah River Station and the U.S. Soil conservation Service (SCS) provided support to design the vegetative cover. The cap was fertilized and seeded with a comprehensive plant mixture that included perennial rye grass, kobe lespedeza, winter wheat, crimson clover, and bermuda grass.

REVEGETATION OF AFFECTED AREAS

The revegetation efforts are divided into two elements, the uplands and the wetlands. The uplands consist of all disturbed areas, excluding the Lost Lake wetlands. Final construction operations included grading and contouring the excavated areas. After construction was completed, the USFS and the SCS immediately disked and seeded the areas to prevent erosion. The long range revegetation plan was created and is being implemented by a multidiscipline task team consisting of personnel from the: U.S. Forest Service, Soil Conservation Service, Savannah River Lab, Savannah River Ecology Lab, Environmental Restoration Department (Westinghouse), NUS Corporation, and Department of Energy. Grasses were reseeded where necessary, and select hardwood trees were planted. The loblolly pine, predominant in the region, will be allowed to reseed naturally.

The revegetation plan also involved the restoration of the Carolina bay wetland. The wetland is being used as a study site, to optimize soil treatments and vegetative types to be used in future wetland restoration efforts at SRS.

CONCLUSIONS

The final cost to close this 1.0 ha (2.4 ac) basin and to restore approximately 10.1 ha (25 ac) of affected area was $5.4 million. Construction began in July 1988 and continued until January 1990. The basin was officially closed on January 1, 1991 and certified on February 26, 1991.

The closure of the M-Area settling basin was among the first mixed waste surface impoundments closed in the nation and at SRS. Hazardous and radioactive constituents contained in the basin and surrounding areas were removed, stabilized, and deposited back into the basin confines. This closure was then covered and protected with a state-of-the-art moisture barrier to preclude moisture infiltration. Those native areas adversely affected by closure activities are being revegetated and restored, enhancing the quality of the SRS environment.

The revegetation and restoration of the HWMF has been successful. Animal and bird life have returned to Lost Lake, and the wetland vegetation is thriving. The project has established a standard for all SRS restoration activities by demonstrating that not only can environmental cleanup be performed without further adverse environmental impact, but that it can also improve the ecological setting. Studies centered on the Lost Lake wetland and renewal of life in a Carolina bay will provide information to restore other disturbed areas.

ACKNOWLEDGMENT

The information contained in this article was developed during the course of work done under Contract No. DE-AC09-89SR18035 with the U.S. Department of Energy.

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DECOMMISSIONING OF A RESOURCE CONSERVATION AND RECOVERY ACT TREATMENT, STORAGE, AND DISPOSAL FACILITY: A CASE STUDY OF THE INTERIM STABILIZATION OF THE 216-A-29 DITCH AT THE HANFORD SITE

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ABSTRACT

The 216-A-29 ditch is located in the central portion of the Hanford Site within Operable Unit 200-PO-5. The ditch is classified under the Resource Conservation and Recovery Act of 1976 as a Treatment, Storage, and Disposal (TSD) Facility and as such, is to be removed from service in support of the Hanford Federal Facility Agreement and Consent Order Tri-Party Agreement (1) Milestone M-17-10, which states "cease all liquid discharges to hazardous land disposal units unless such units have been clean closed in accordance with the Resource Conservation and Recovery Act of 1976." (2) The 216-A-29 ditch is one stream feeding the 216-B-3 Pond system, and its removal from service was necessary to support the closure strategy for the 216-B-3 Pond system. Interim stabilization of the 216-A-29 ditch is the first step required to comply with the Tri-Party Agreement (2) and the eventual decommissioning of the entire B Pond system. Interim stabilization was required to maintain the 216-A-29 ditch in a stable configuration until closure actions have been determined and initiated.

INTRODUCTION

The Hanford Site covers approximately 560 mi^2 of semi-arid land owned by the United States Government and managed by the U.S. Department of Energy, Field Office, Richland. The Hanford Site is located northwest of the City of Richland, Washington, in the Columbia Basin. Richland adjoins the southernmost portion of the Hanford Site boundary and is the nearest population center. In early 1943, the U.S. Army Corps of Engineers selected the Hanford Site as the location for reactor, chemical separation, and related facilities and activities for the production and purification of plutonium. As a result of these activities, the 216-B-3 pond system was created, of which the 216-A-29 ditch is a part.

The 216-A-29 ditch is to be removed from service as part of the Tri-Party Agreement (2) Milestone M-17-10. Interim stabilization of the 216-A-29 ditch is the step required to comply with the Tri-Party Agreement (2), and the eventual decommissioning of the entire 216-B-3 pond system. Interim stabilization is required to maintain the 216-A-29 ditch in a stable configuration until closure actions have been determined and initiated.

FACILITY DESCRIPTION

The 216-A-29 ditch, was placed in service in 1955. It carries Plutonium-Uranium Extraction (PUREX) Plant chemical sewer liquid effluent to the 216-B-3-3 ditch which then flows into the 216-B-3 pond. Though it is used to transport liquid waste, it has some percolation capacity and is categorized as a surface impoundment treatment storage and disposal unit. The approximate flow rate of the 216-A-29 ditch is 3,790 L/min (1,000 gal/min) under PUREX Plant operating conditions and 946 L/min (250 gal/min) under shutdown conditions. Historically, chemicals were discharged from the PUREX Plant to the 216-A-29 ditch by several mechanisms:

- Acid fractionator condensate overflow
- Demineralizer regeneration
- Out-of-tolerance chemical batch disposal
- Accidental spills.

The majority of the known discharges are considered dangerous waste only because of their pH at the time of release. Since 1984, numerous administrative and engineering barriers have been implemented to prevent the disposal of dangerous waste to the chemical sewer line (3).

The 216-A-29 ditch (Fig. 1) has an overall length of about 1,098 m (3,600 ft). For the first 214 m (700 ft) from the outfall, the ditch is relatively level and shallow. The lower 884 m (2,900 ft) are confined within a steep-sided canyon averaging 24 m (80 ft) in width and dropping nearly 31 m (100 ft) in elevation. At two places in the upper portion of the ditch, earthen dams provide vehicle access to the opposite side. Each dam has a culvert running underneath it with a platform and slide gate at the upstream end. There is also a vehicle crossing where the ditch passes under the 200 East Area perimeter fence.

Because of the presence of water, there is moderately heavy vegetation along the ditch, including several hundred trees, approximately 100 are 10 cm (4 in.) dia. or greater. Willows and cottonwoods constitute the majority of the trees. Except for the immediate banks of the ditch itself, the area around the first 214 m (700 ft) is barren cobble. Along the lower reach, sagebrush, grasses, rabbitbrush, and other vegetation typical of the surrounding desert are growing on the slopes of the canyon and beyond.

A post and chain fence bearing warning signs (Caution Radiation Area Surface Contamination) surrounds the 216-A-29 ditch except for the three crossing points. The width of the posted zone averages over 73 m (240 ft) over the length of the ditch. The posting is necessary because of the potential for radioactive contamination.

OBJECTIVES

The interim stabilization of 216-A-29 ditch achieves two major objectives. The first objective was to place the ditch in a configuration that would maintain the environmental control of any radioactive or potentially hazardous sediments after the chemical sewer stream had been rerouted to another existing pipeline. Of primary concern was the period between the rerouting of the effluent and the initiation of closure actions for the 216-A-29 ditch.

The second objective is to reduce the size of the posted zone around the ditch as much as possible and reclassify the remainder as underground radioactive material. This reduces



the establishment of approximately a 92 m (100 yd) buffer zone around the nest. The size of the buffer zone was based on the facts that well drilling rigs were active within 92 m (100 yd) of the nest, and the hawks appeared to have taken up residence after the well drilling began and Swainson's Hawks are not easily disturbed by activity around the nest. The buffer zone allowed work to continue around the nest, while allowing the hawks to raise a successful brood. Ditch sediments in the buffer zone will be exposed after the chemical sewer has been rerouted. To ensure that no radiological surface contamination is present, the exposed stream sediments will be monitored radiologically. If contamination is found, corrective action will be taken. Any actions taken in this portion of the ditch will attempt to prevent disturbance of the hawks as much as possible. The buffer zone will be stabilized in early September after the birds migrate.

Eradication of Woody Vegetation

There were approximately 100 trees over 10 cm (4 in.) in dia. in the ditch. The largest tree was approximately 92 cm (3 ft) in dia. The predominant trees were willows and cottonwoods. All trees were sprayed with RODEO* herbicide and cut. Trees located in areas most likely to be contaminated were sampled to determine disposal requirements. Both core samples and actively growing portions of the tree were sampled. Analysis of the samples showed that the trees could be handled as nonradioactive and nonhazardous. All trees over 10 cm (4 in.) in dia. were removed from the ditch. The stumps were left in the ditch to decrease the chance of disturbing any underground contamination found in the ditch.

Spraying

All trees were sprayed with a 1.5-percent solution of RODEO herbicide. This herbicide was used because of the presence of water in the ditch during the spraying activities. Spraying was necessary to prevent resprouting of the trees after cutting had occurred. The largest trees were not killed by the initial herbicide application and required subsequent treatment after the trees were cut. One hole, 20 cm (2 in.) deep and 5.5 mm (1/2 in.) in dia., was drilled for each in. of stump dia. These holes were filled with RODEO herbicide and covered with grease to prevent evaporation. The herbicide was then absorbed into the roots of the tree, effectively preventing resprouting of the tree.

Sampling

Sampling of the trees was necessary to determine disposal requirements. In light of past waste disposal knowledge and vegetation sampling, it was believed that the trees could be handled as nonhazardous and nonradioactive. ten trees were selected for sampling from an area where contamination was most likely to be found. These areas were near the outfall, behind the earth dams, and at the confluence with the 216-B-3-3 ditch (which is more contaminated than the 216-A-29 ditch). The trees were core sampled by means of a large brace and bit, and the cuttings were collected and analyzed for gross alpha, beta, and gamma radiation. No radionuclides were found above background levels. In addition, 16 samples were taken from actively growing trees and other vegetation in the ditch. All of these results showed no detectable radiation.

Cutting

Trees were felled away from the stream channel, when possible. This minimized the chance of contamination because the stream channel is the most likely source of contamination. Trees were cut as low to the ground as possible.

Removal

Removal of the trees over 10 cm (4 in.) in dia. was necessary to reduce the potential for future voids and subsidence. Trees of this size and larger were chosen to be removed based on a size split in the ditch. The majority of the trees were this size. Smaller trees and other vegetation were readily incorporated into the soil by the mechanical action of the earth moving equipment.

Sampling showed that the trees could be handled as nonhazardous and nonradioactive. However, the trees were located in an area posted as surface contamination. To remove the trees from the ditch, careful monitoring by a Health Physics Technician was necessary. Each tree to be removed from the ditch was surveyed before being released from the ditch. Concern centered on the dragging of trees out of the ditch which activity disturbed soil to a depth of several in. Ground surveys of the area disturbed by the tree dragging found no contamination. In addition, all equipment and personnel were monitored for radiological contamination according to standard practice. Removal of the trees was accomplished by means of a bulldozer, winch, and a number of wire rope chokers. Because the trees were nonradioactive and nonhazardous, they will be burned later near the ditch.

Isolation and Dismantling of Structures

The PUREX Plant chemical sewer was routed from the 216-A-29 ditch to the PUREX Plant cooling water line by opening and closing two slide gates in a control box upstream of the outfall. The capability to reopen the gates was maintained until the stream sediments received the first layers of cover materials and no longer needed to be wetted. The slide gates located at the upstream side of each earth dam were also maintained in a operable condition until the stream sediments had received the first layers of cover materials. This allowed the option of running water down the ditch to prevent the stream sediments from drying out. Sediments were covered starting at the lower end of the ditch and proceeding upstream toward the outfall. As each slide gate was encountered, it was dismantled. Once the streambed received the initial layers of cover soil, the chemical sewer was permanently isolated from the 216-A-29 ditch.

To accomplish this, the outfall pipe was excavated to within 3.1 m (10 ft) of the control box. Excavation any closer to the control box would have endangered other buried pipelines in the vicinity. A sledgehammer was used to break a hole in the 37.5 cm (15 in.) vitrified clay pipe. An inflatable plug was placed at the outfall end of the pipe, and filled with high slump concrete.

* RODEO is a registered trademark of the Monsanto.

A wood platform and slide gate were located at the upstream end of each earth dam. After the slide was lowered to the closed position, the platform was tore down and disposed of in the ditch.

A small metal bridge located near the outfall was removed, radiologically surveyed, and disposed of as nonradiologic waste. Both ends of the culvert that passes under the 200 East Area perimeter fence were sealed with concrete.

Stabilization

Stabilization of the ditch took three phases: consolidation, stabilization, and revegetation (Fig. 2).

In the first phase, the top layers of soil adjacent to the ditch was scraped off and pushed into the streambed. This consolidated contaminated and potentially contaminated soil in the smallest possible area. The thickness of this layer was kept as even as possible.

In the second phase, the consolidated soils were covered with clean soil. In the upper section of the ditch, the fill was brought to the surrounding grade level. Clean fill came from a nearby spoil pile. Along the lower section, the clean fill was obtained from the upper banks of the canyon. The fill was placed in a series of tiers progressing down the ditch. Tiers were placed for each 1.6 m (6 ft) drop in elevation in the streambed. This minimized the gradient, and thus the erosion potential. The fill was a minimum of 0.61 m (2 ft) deep and a maximum of 2.4 m (8 ft) deep at the uphill end. The face of the tier had approximately a 4 to 1 slope. Rock was placed on the face to prevent erosion. The walls of the canyon were regraded to approximately 10 to 1 slope. This allowed radiological survey and revegetating equipment access to the stabilized ditch. This slope also reduced the erosion potential. See Fig. 3 for a artist representation of the stabilized ditch.

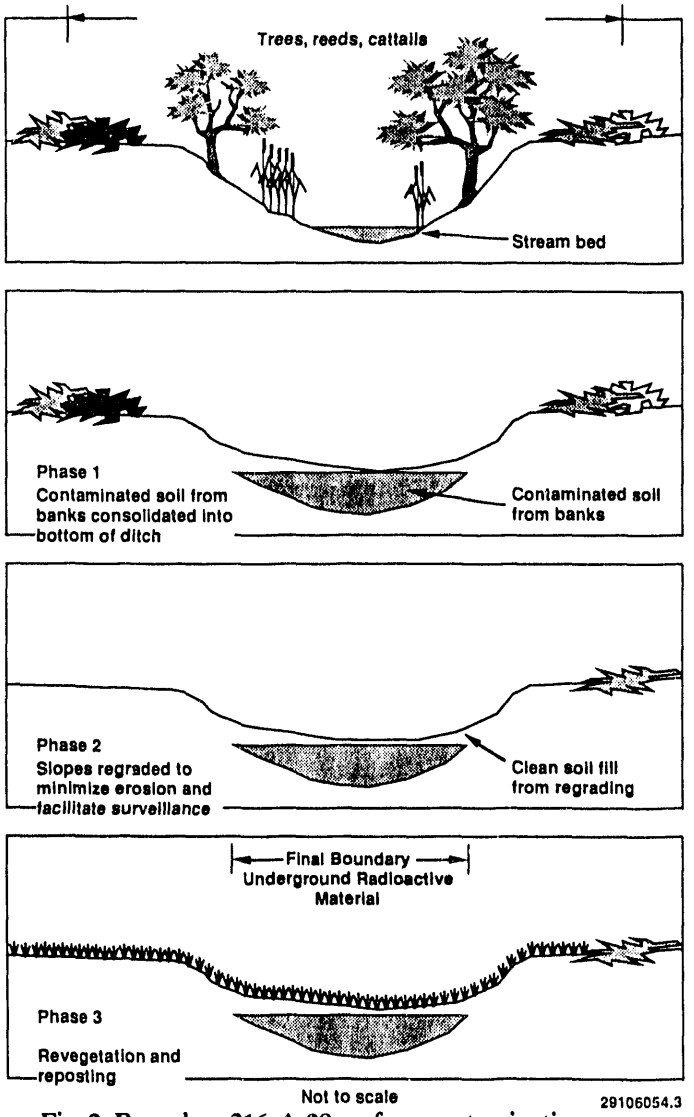


Fig. 2. Boundary 216-A-29 surface contamination area.

The third phase is revegetating and reposting the stabilized areas. A high nitrogen fertilizer will be spread over the area, and a mixture of Thickspike and Siberian perennial wheatgrass planted. The grass will be planted using techniques similar to contour farming. This will minimized the erosion potential. Straw mulch will be spread over and crimped into the soil.

Once the stabilization has been completed, the entire area previously enclosed by the "Surface Contamination" posting will be surveyed to confirm that no radioactive materials are present on the surface. The area will then be posted as underground radioactive material.

LESSONS LEARNED

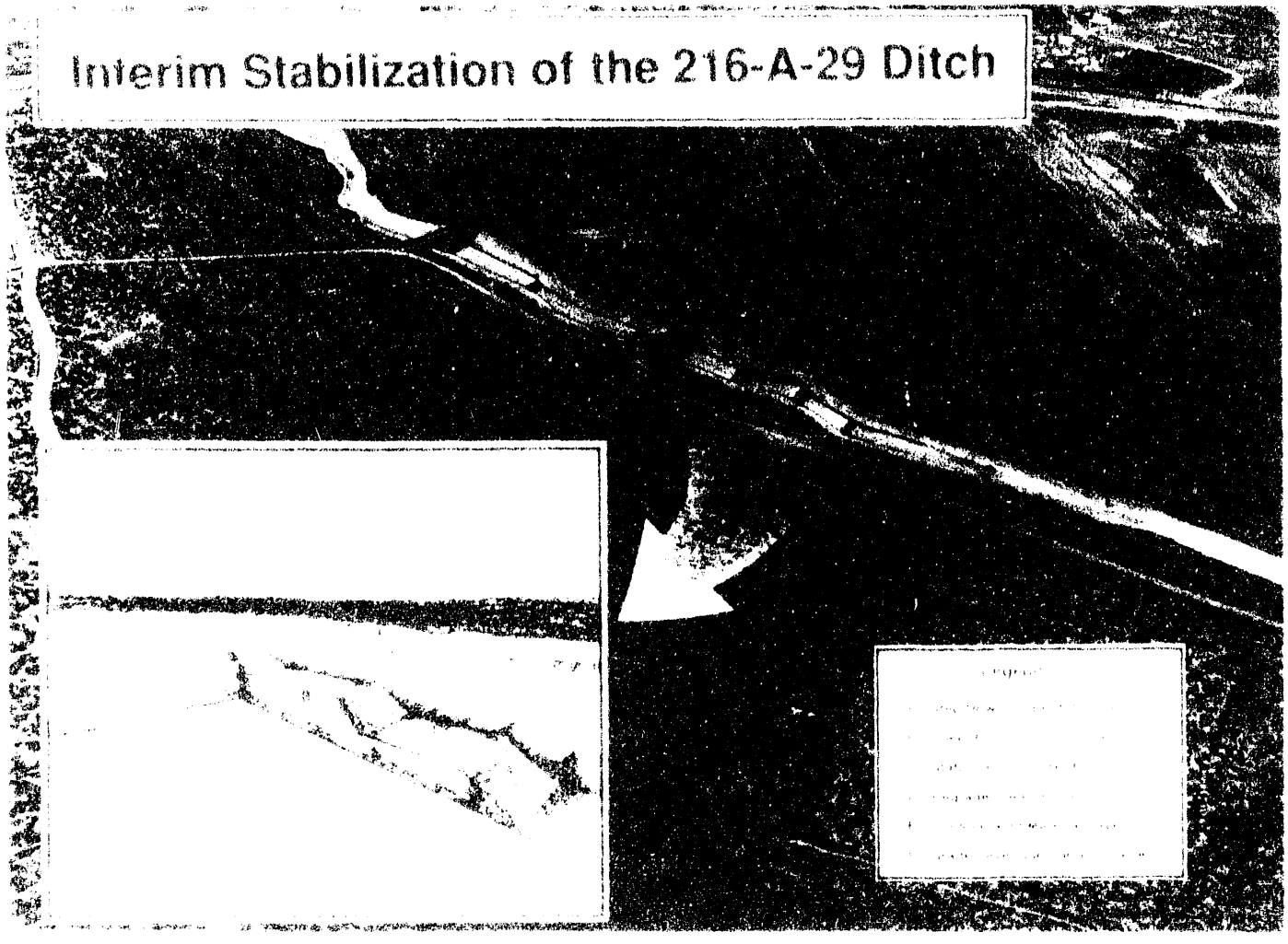
Problems observed during this project may be beneficial in planning future decommissioning actions for outdoor waste disposal sites.

- Initial herbicide application was ineffective in eradicating the larger trees and subsequent treatment of the stumps required. It would have been more efficient to spray the smaller trees by hand, cut all the trees down, and then treat the stumps of the larger trees. This would have saved considerable effort wasted on applying herbicide to the larger trees. This would have also minimized delays associated with weather, as herbicide application during moderate winds is not allowed. Weather restrictions delayed spraying for several months. In addition, problems associated with using the spray equipment in the steep topography of the ditch would have been minimized.
- The larger trees should have been removed in the late fall. This would have prevented the migratory Swainson's Hawks from taking up residence in the ditch the following spring. Although this would have destroyed the nesting site, other suitable nesting areas are available.
- More effective dust control methods were needed during the project. Because of the steep topography of the ditch, water trucks were not able to effectively apply water to the ditch. To control dust, the ditch was watered before, during, and after earth moving operations each day. A bulldozer was required to aid the water truck when it became stuck. A sprinkler system would have been more cost effective, but was not feasible due to the relative remoteness of the ditch.

CONCLUSIONS

Interim stabilization is expected to be completed by September 30, 1991. Work in the buffer zone around the Swainson's Hawks nest will begin as soon as the birds migrate. The closure plan for the 216-A-29 ditch is expected to be submitted to Ecology and EPA in May 1996, Milestone M-20-

Interim Stabilization of the 216-A-29 Ditch



A SUCCESSFUL ENVIRONMENTAL REMEDIATION PROGRAM CLOSURE AND POST-CLOSURE ACTIVITIES (CAPCA) Y-12 PLANT, OAK RIDGE, TENNESSEE

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ABSTRACT

The Resource Conservation and Recovery Act (RCRA) closure of eleven waste management units at the Department of Energy's (DOE's) Oak Ridge Y-12 Plant is nearing completion. The Oak Ridge Y-12 Plant is managed by Martin Marietta Energy Systems, Inc. for the U.S. Department of Energy under Contract DE-AC05-84OR21400. The Closure and Post Closure Program (CAPCA) has been accomplished on an accelerated schedule through the efforts of a dedicated team from several organizations.

This paper relates experience gained from the program that can be of benefit on other DOE environmental remediation projects. Technical design and construction aspects, as well as project management considerations, are discussed.

INTRODUCTION

Eleven waste management units, totaling over 80 acres (32 hectares), have been successfully closed at the Department of Energy's Y-12 Plant in Oak Ridge, Tennessee. The closures have been accomplished in accordance with the requirements of the Resource Conservation and Recovery Act (RCRA) and the Rules Governing Hazardous Waste Management in Tennessee. The basic closure plan has consisted of waste stabilization as required and installation of a multimedia cap with appropriate surface drainage improvements. Completed ancillary facilities have included two borrow areas, several miles of haul road, and a two and one half acre settling and spill catchment basin for the Y-12 Plant. Closure of one additional waste management unit is yet to be accomplished.

These waste unit closures, and associated projects, are being accomplished through the Closures and Post Closures Activities Program (CAPCA). The closures have been accomplished under an accelerated schedule and have required the coordinated efforts of many organizations. The estimated total cost of the CAPCA closures is $47,000,000.

The experience gained from this program can be of considerable value in further environmental remediation efforts at Y-12 and other Department of Energy installations. This paper will provide details of the closures and present technical and managerial features that led to the program's success.

MANAGEMENT ORGANIZATION

The scope of the CAPCA closure program has required the participation of many organizations. Coordination of the efforts of these organizations has been critical considering the large investment of funds expended on the program and extremely tight schedules mandated by agreements with regulatory agencies.

As owner of the Y-12 Plant, DOE has, of course, provided supervision of the program through its Oak Ridge Operations Office. Martin Marietta Energy Systems, Inc. (Energy Systems), is the facilities manager for the Y-12 Plant and has been responsible for management of the program. The Energy Systems' Health, Safety, Environment, and Accountability (HSEA) Division was tasked as the Program Manager and served as the point of contact with the regulatory agencies. Special consulting services were provided to HSEA by the following firms:

- Battelle Columbus
- Geraghty & Miller, Inc.
- H & R Technical Associates
- Oak Ridge National Laboratory Environmental Science Division
- Oceaneering, Inc.
- Roy F. Weston, Inc.

The design and construction activities were assigned to a Project Manager from the Energy Systems' Engineering Division who established a dedicated management team of managers, engineers, and construction professionals within that organization and from supporting organizations. This dedicated team was a key reason for the success of the CAPCA program. Energy Systems' Engineering was supported by the following consulting organizations:

• Lockwood Greene Engineers	Engineering studies Design plans and specifications Submittal review Construction inspection Record drawings Program support functions
• Lee Wan & Associates	Industrial Hygiene/Health Physics Quality Oversight
• Rust Engineering/ M.K. Ferguson	Construction (direct hire and subcontract)
• Dames & Moore	Independent Professional Engineer (closure certification)
• CH2M Hill	HAZWRAP Regional Subcontractor
• Eight specialty subcontractors	Geotechnical, surveying, hydrologic studies, etc.

Effective communication between the team members was another reason for the success of the CAPCA program. Communication was facilitated by daily team meetings involving current participants. The team meetings provided an opportunity for timely identification and resolution of problems, as well as organization interface and information transfer.

PROGRAM PLANNING

Site Descriptions

The scope of the CAPCA program included closure of the following waste units:

Bear Creek Burial Ground A	17.9 Ac (7.2 Ha)
Bear Creek Burial Ground B and Walk In Pits	6.5 Ac (2.6 Ha)
Bear Creek Burial Ground C	7.3 Ac (3.0 Ha)
S-3 Ponds	5.1 Ac (2.1 Ha)
Oil Retention Pond - 1	5.2 Ac (2.1 Ha)
Oil Retention Pond - 2	0.5 Ac (0.2 Ha)
Oil Landfarm	12.7 Ac (5.1 Ha)
Hazardous Chemical Disposal Area	3.5 Ac (1.4 Ha)
Chestnut Ridge Security Pits	7.6 Ac (3.1 Ha)
Chestnut Ridge Sediment Disposal Basin	5.0 Ac (2.0 Ha)
New Hope Pond	8.9 Ac (3.6 Ha)

The Burial Grounds consist of a series of trenches which have been used for disposal of solid wastes and, in some cases, liquid wastes. The first trench was excavated in August 1955 for the disposal of solid wastes. In 1959, the Y-12 Plant was authorized by the Atomic Energy Commission to begin using the facility for the disposal of certain types of liquid wastes. Since that time, several types of wastes have been disposed in the various burial ground areas including the following:

- Ferrous metals and uranium
- Salts
- Solvents
- Ethylenediamine Tetraacetic Acid (EDTA)
- Mop water
- Oils and coolants
- Debris
- Asbestos
- Material contaminated with radioisotopes

Burial Ground B has been used for disposal of depleted uranium chips, metals, and oxides. Organic and caustic chemicals, aged ethers, peroxides, thorium saw fines, and uranium saw fines have been disposed in the walk in pits. Closure of these waste units remains to be accomplished. Closure design is currently in progress which takes into consideration the potentially explosive and pyrophoric nature of the wastes. Utilization of remote controlled construction equipment is under consideration.

Oil Retention Ponds 1 and 2 were constructed in 1971 and 1972, respectively, to collect and contain oils leaching from Burial Ground A. The water, oils floating on the surface, and sediments were contaminated with polychlorinated biphenyls (PCBs).

The Oil Landfarm disposal plots were in operation from 1973 to 1982. As part of an Environmental Protection Agency (EPA) approved research project, the facility was used for the biological degradation of waste oil and machine coolants via landfarming, a process involving the application of waste oils and coolants to nutrient adjusted soil during dry months of the year. After application, the plots were cultivated frequently to maintain aerobic conditions to enhance biodegradation. Between 1973 and 1982, approximately one million gallons of uranium and PCB contaminated waste were applied to the Oil Landfarm disposal plots.

The Hazardous Chemical Storage Area was used to treat wastes that posed safety hazards within the Y-12 Plant. In general, these were wastes which exhibited the characteristic of reactivity. The material came from two sources: gas cylinders with leaking or damaged valves and lab chemicals considered to be reactive or explosive. Gas cylinders containing corrosive gases were bled through neutralizing slurries. Bottled chemicals were broken under water spray in a concrete vessel. After the explosion or chemical reaction had taken place, the effluent was discharged into a small unlined surface impoundment and allowed to percolate through the soil.

The S-3 Ponds were built in 1951 as a disposal site for liquid wastes. The site consisted of four unlined impoundments covering an area of roughly 400 feet by 400 feet (122 meters by 122 meters). The ponds were approximately 17 feet (5.2 meters) deep and contained 2 to 5 feet (0.6 to 1.5 meters) of sludge each. The water in the ponds was neutralized and denitrified and allowed to settle with the supernatant pumped to a treatment facility. The ponds were subsequently closed with waste in place as a landfill per 40 Code of Federal Regulations (CFR) Part 265 Subpart K - Surface Impoundments.

The Chestnut Ridge Security Pits were used for disposal of solid and liquid wastes associated with the production, use, or supply of materials, processes, or products of the Oak Ridge Y-12 Plant. The facility was closed as an interim status hazardous waste landfill because removal and treatment of the waste was not possible.

The New Hope Pond waste unit was an unlined, man-made settling basin constructed in 1962. The pond, with a surface area of 5.2 acres (2.1 Ha), received surface flow and some process water from the Y-12 Plant. The purpose of the pond was to remove suspended sediments and to modify fluctuations in pH prior to discharge to East Fork Popular Creek. Analysis of pond sediments indicated that the sediments did not exhibit the characteristics of a RCRA waste. However, due to the presence of uranium, PCBs, and mercury, the pond was closed in a manner equivalent to a RCRA closure with the wastes in place. Accumulated sediments were dredged from the New Hope Pond on several occasions beginning in 1973 and placed in the Chestnut Ridge Sediment Disposal Basin. This facility was, therefore, also closed in accordance with RCRA standards.

The closure of these waste management units required design and construction of ancillary facilities. Two borrow areas were identified and developed. Each was on the top of Chestnut Ridge which lies adjacent to the Y-12 Plant to the south. Several miles of new haul roads were constructed as it was determined that the volume and nature of equipment used to transport the soil for cap construction could not be accommodated by existing roads. A two and one-half acre surface water detention pond was also constructed as a replacement for the closed New Hope Pond.

Closure Plans

Closure plans were prepared for each waste management unit and submitted to the Tennessee Department of Health and Environment for approval. The closure plans specified

the construction of engineered caps to minimize migration of liquids to streams and groundwater, to promote drainage around the capped areas, and to minimize erosion, subsidence and maintenance. A closure schedule was stipulated in each closure plan.

Engineering Study

The CAPCA program has been a very large design and construction undertaking. The total program has involved installation of 390,000 tons [354,000 metric tons] of structural stabilization rip-rap, 660,000 cubic yards [502,000 cubic meters] compacted clay, and 285,000 square yards [237,000 square meters] flexible membrane liner. Initial planning of the effort was critical to the success of the program.

An early activity was preparation of an engineering study that addressed the logistics of the required materials and equipment based upon closure plan provisions. One conclusion was that it was not feasible to procure the volume of sand that would be required for the sand drainage layer in the various caps. The recommendation was made to substitute a geonet and filter fabric for the sand layer. This was subsequently approved by the Tennessee Department of Health and Environment resulting in considerable savings of funds and construction time.

The engineering study also evaluated the existing road system at the Y-12 Plant in relation to the expected volume of construction traffic. It was determined that a new system of haul roads would be required to prevent adverse impacts on plant operations and worker safety.

Both cost estimates and proposed schedules were presented in the engineering study for planning purposes.

DESIGN FEATURES

Structural Stabilization

Structural stabilization of pond sludges was required prior to cap construction. Adequate structural stabilization was critical to minimize subsequent settlement and resultant damage to the integrity of the caps. This was accomplished by dumping limestone rip-rap into the sludge and tracking in with dozers. Stabilization geotextiles were also used in soft areas that did not require installation of rip-rap. All areas that were structurally stabilized were proofrolled with a loaded dump truck prior to further construction.

Below Cap Fill

Fill material was required to level the sites and to bring the surfaces to specified grades. This fill was initially specified to be installed to 95 percent Standard Proctor Density. The specification was changed as the closure program progressed to be equivalent to the impermeable clay layer. It was found during early construction work that it was advantageous to install all fill over existing grade to impermeable clay specifications to minimize difficulties associated with construction documentation [i.e., thickness verification and compaction records].

Gas Collection Layer

One site required installation of a gas collection layer and venting system. The gas collection layer consisted of a one foot [0.31 meter] thick layer of crushed limestone covered by filter fabric. The venting system was assembled from polyvinyl chloride pipe.

Impermeable Layer

Construction specifications required installation of a minimum of 24 inches [0.61 meters] of clay from the borrow area with a moisture content and density within a zone of acceptance shown on a graph contained in the project specifications. Extensive tests were previously conducted relating moisture and density of the materials from the borrow area to impermeability. The resultant charts of moisture content versus density indicated ranges of acceptability assuring a resultant permeability of 1×10^{-7} cm/seconds or less. Approval of this method of impermeable clay installation by the Tennessee Department of Health and Environment was a significant factor in the timely success of the program.

Flexible Membrane Liner

The closure plans included installation of a 30 mil polyvinyl chloride liner. The liners were factory assembled in large panels which were seamed together on the site. Extensive destructive and nondestructive testing of the materials and seams were performed and documented to assure liner integrity.

Drainage Layer

As previously discussed, a geonet and filter fabric was approved by the Tennessee Department of Health and Environment as a substitute for the sand drainage layer as specified in the closure plans. This installation proved to be both effective and efficient and was also a significant factor in the timely success of the CAPCA program.

Vegetative Layer

The final 18 inches [0.46 meters] of soil was placed to support vegetation. Early projects specified 90 percent Proctor Density compaction, but such compaction was subsequently found not to be necessary. The requirement was deleted and compaction by steel drum rolling was specified resulting in cost savings for both construction and testing.

Grassing

Due to the unavailability of adequate topsoil, extensive use of soil amendments was required. The seed bed was prepared by tilling in lime and fertilizer. Ammonium nitrate was applied approximately 60 days following seeding. Seed mixtures were specified taking into consideration the season of the year.

CONSTRUCTION

Organization and Responsibilities

Closure construction was accomplished by subcontract to the Y-12 Construction Manager, Rust Engineering, during the initial projects and M.K. Ferguson during the latter projects, all under the direction of the Energy Systems' Project Manager. Title III inspection and preparation of record drawings was the responsibility of Lockwood Greene Engineers working through the on-site Architect/Engineer (A/E) contract with DOE. Soil and liner testing was provided by Westinghouse Environmental and Geotechnical Services.

As previously mentioned, a dedicated team and effective communication using daily team meetings were key factors in the success of the CAPCA program. The emphasis was always placed upon rapid recognition and resolution of problems, as well as refinement of specifications and procedures based on "lessons learned".

Documentation

Hazardous waste site closures are unique construction projects in that the success of the project is determined by certification of the closure, rather than the existence of a useable facility as is normally produced by a construction project. For that reason, documentation of the process of construction was of extreme importance. A frequently used statement was, "If it wasn't documented, it didn't happen."

Record drawings and summary reports were prepared at the conclusion of each project for review by the Independent Professional Engineer as a part of his/her certification.

Quality Assurance

The closure program was subject to the requirements of ANSI/ASME NQA-1. A project specific quality assurance (QA) program was prepared and implemented for the Title III inspection effort. The program addressed job responsibilities, inspection procedures, construction change design control, corrective actions, QA records, document control, and audits.

During the construction process, the primary areas of quality assurance attention involved:

- Soil density and moisture content testing,
- Flexible membrane liner testing, and
- Soil layer thickness verification.

Health and Safety

The hazardous waste site closures were subject to the requirements of The Occupational Safety and Health Administration (OSHA) as specified in 29 CFR 1910.120. Each construction contractor was required to prepare a Site Safety Plan including on site control responsibilities, hazard evaluation, personal protective equipment requirements, monitoring, decontamination procedures, and emergency procedures. All personnel entering the sites received a minimum 40 hours of site safety training. Medical monitoring programs were also mandated of all participant organizations.

Environmental Protection

Any construction program of the magnitude of CAPCA requires a concerted effort to protect the natural environment. An emphasis was, therefore, maintained on prevention of soil erosion and sedimentation. Specific requirements such as silt fencing and ditch check dams were required of the earthwork contractors. Sedimentation ponds were also constructed at each borrow area. Additionally, an Environmental Compliance Standard Operating Procedure was prepared and enforced for the CAPCA program. This program included a preventive measures checklist making each team member responsible for participation in erosion control monitoring efforts.

Best Management Practices Plans were also prepared for each closure site and the borrow areas. These plans specified employee training, spill prevention and control measures, water quality monitoring, good housekeeping practices, erosion control measures, and hazardous material release response guidelines.

PROGRAM MANAGEMENT SUPPORT

Scheduling

Each site closure plan included a schedule for closure including milestone dates for submission of detailed engineering plans and specifications, construction completion for the various cap layers, and submission of closure certification. A program schedule was initially prepared based upon the standard DOE project regime. It was found that this regime would not satisfactorily meet the mandated schedule. An aggressive "fast track" schedule was, therefore, adopted. Tactics such as starting design activities without complete or final information, bidding construction packages using 90 percent design issues with subsequent construction issues incorporated by amendment, and overlapping cap construction activities were employed. This aggressive plan resulted in a reduction of the program schedule by approximately one and three fourth years.

Lockwood Greene Engineers was tasked early in the program with preparation and maintenance of detailed project schedules to assist the project team in schedule compliance. Schedule update meetings were regularly held and revised schedules issued. Logic changes, "what if" alternative schedules, and "work around" schedules were often employed.

Verification Matrices

As previously discussed, the hazardous waste site closures required certification of closure in accordance with the closure plans by a registered independent professional engineer. The Energy Systems' Project Manager developed a tool for assuring that closure plan requirements were incorporated in the design documents and that necessary documentation was prepared during construction. The tool was termed a "Verification Matrix" and included the following sections:

- Closure Plan Requirement - Each specific closure plan requirement was identified and listed
- Implementing Document - A document was identified for each requirement that caused compliance (i.e., plan or specification reference)
- Responsible Organization - An organization responsible for monitoring and documenting compliance was identified (i.e., Title III inspector, soils engineer)
- Performance Documentation - The specific documentation that could be used to prove compliance was noted (i.e., daily construction report)
- Summary Report - Documentation of specification compliance was compiled in Summary Reports and appropriate references recorded.

Lockwood Greene Engineers was tasked with preparing the verification matrices during individual project design and for updating as the project progressed. The matrices were considered "living documents" and were frequently updated.

Certification

Certification of closure plan compliance by an independent professional engineer was provided by Dames and

Moore. The firm's representatives participated in program progress review meetings and provided valuable input concerning interpretation of closure plan requirements. They performed periodic on site inspections during construction, and all closure documentation was made available for their review.

SUMMARY

The CAPCA program has been challenging for all involved. The program involved a very large design and construction effort using "fast track" procedures. A very large organization was employed and many technical issues presented challenges. But perhaps the greatest challenge involved educating all involved that the closures were not just another "dirt job". Closure certification required construction with nuclear industry quality assurance and documentation standards.

The program has been a success due to the following key reasons:

- A dedicated team,
- A decisive Project Manager who solicited input from all appropriate participants and made decisions without delay to the work in progress,
- Constant communication between the program team, and
- Cooperation from the Tennessee Department of Health and Environment.

Success of the closure program has been recognized. The East Tennessee Chapter of the Project Management Institute gave its "Project of the Year" award to the Project Team.

AN EVALUATION OF ALTERNATIVE REACTOR VESSEL CUTTING TECHNOLOGIES FOR THE DECOMMISSIONING OF THE EXPERIMENTAL BOILING WATER REACTOR AT ARGONNE NATIONAL LABORATORY

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ABSTRACT

This paper will detail 1) a brief overview of the current status of the EBWR D&D Project, and 2) the results of a study performed to evaluate the metal cutting technologies available to size reduce the EBWR reactor vessel.

The techniques evaluated were:

- Plasma arc
- Arc saw
- Oxyacetylene
- Electric arc gouging
- Mechanical cladding removal/flame cutting
- Exothermic reaction
- Diamond wire
- Water jet
- Laser
- Mechanical milling
- Controlled explosives
- Electrical discharge

After a detailed review of these 12 techniques, the decision was made by ANL that the most appropriate method for segmenting the EBWR reactor vessel would be to lift the vessel from the vessel cavity and use an abrasive water jet positioned on the main floor to perform the cutting of the reactor vessel.

INTRODUCTION

The EBWR was built as a test reactor to demonstrate the feasibility of operating an integrated power plant using a direct cycle boiling water reactor as a heat source. The reactor was designed to produce 20 MW of heat which was fed directly to a turbine-generator producing 5 MW of electricity. Construction was initiated in 1955 and full power operation was first achieved in December 1956. The total construction cost was $1.9 million U. S. dollars.

Following intermittent operation at power levels up to 62 MW, the EBWR was modified in 1962 to increase its power output capability to 100 MW. The modifications included the addition of a reboiler plant to utilize the additional 80 MW of thermal energy, in addition to the 20 MW used by the turbine-generator.

The EBWR was later loaded with a core containing plutonium and operated in support of the Atomic Energy Commission's (AEC) Plutonium Recycle Program. The role of the EBWR in the DOE/AEC programs was completed in July 1967, and the plant was permanently shut down and placed in a dry lay-up condition.

The facility was placed in DOE's Surplus Facilities Management Program (SFMP) in 1976. It is currently undergoing D&D which will allow the facility to be reused by other DOE research programs.

FACILITY DESCRIPTION

Argonne National Laboratory currently occupies a 1,700-acre reservation in DuPage County, Illinois, approximately 22 miles southwest of downtown Chicago. Laboratory structures and support facilities occupy approximately 200 acres of the site, with the remaining acreage devoted to landscaped areas and forest. The location of EBWR is in the 300 West area of the ANL-East Site.

The reactor pressure vessel is contained within a shielded cell which extends from the main floor downward approximately 25 feet to the region of the pump floor. The vessel is made of carbon steel, clad with stainless steel on those surfaces which were in contact with reactor water or steam. It is approximately 7 feet 5 inches in outside diameter, 24 feet 8 inches in length, and has a nominal wall thickness of 2 1/2 inches. Nine control rod drive tubes and four forced circulation inlet pipe stubs extend downward from the bottom of the vessel, penetrating the cell's bottom shielding plug. Two 12-inch diameter forced circulation outlet pipes also extend from the pressure vessel through the cell's 4-foot thick bottom shield. The vessel is closed by a forged steel cover plate approximately 9 inches thick which is retained by the reactor vessel stud bolts.

A radiation survey of the inside of the reactor vessel was performed in February 1989. The results of this survey showed that the radiation fields ranged from 2 R/hr (0.02 Sievert/hr) to a maximum of 100 R/hr.

Corings into the reactor vessel wall indicate radiation levels in the range of 10-20 mR/hr. This indicates that the primary source of radiation is from the reactor internals, not the primary vessel. Therefore, removal of the reactor vessel will pose a minimal concern during dismantling and the removal of the reactor vessel internals will pose the greatest occupational radiation exposure risk during the D&D work.

TABLE I

Summary of Cutting Technologies

				Approximate Capital Costs ($1000)			
Cutting Technology	Cutting Speed for 2.5" Steel	Auxiliary System Requirements	Development Required	Cutting System	Manipulation and Viewing	Contamination Control	Approximate Consumable Costs ($10000
Plasma-Arc Cutting	13"/min.	Ventilation, water processing	No	40	148-278	45-82	1.8
Arc-Saw Cutting	60" min.	Ventilation, water processing	Yes	160-280	148-228	45-82	1.2
Flame Cutting from OD	10"-14" min.	Ventilation	No	1.7	148-228	20-47	1.0-1.7
Arc Gouge/Flame Cutting	20"/min. for gouge; 10"-14"/min for cutting	Ventilation	No	31	148-228	20-47	1.1-1.9
Mechanical Cladding Removal/Flame Cutting	2"-4"/min.	Ventilation, vacuum	No	2-5	148-278	23-50	1.2-3.4
Exothermic-Reaction Cutting	6"/min.	Ventilation	Yes	0.6-1	Not feasible	20-47	1.7-3.0
Diamond-Wire Cutting	1"-2"/min.	Ventilation, water processing	No	35	98-178	45-55	660.0-990.0
Water-Jet Cutting	3"/min.	Ventilation	No	150	44	45-55	1.8
Laser Cutting	5"-10"/min.	Ventilation	Yes	1,200	228-378	20	0.250
Mechanical Milling	3"/min.	Ventilation	Yes	0.1	98-178	20-47	99.0-186.0
Controlled Explosive Cutting	Instantaneous	Ventilation	Yes	0.1	98-178	20-47	90.0-186.0
Electronic Discharge Machining	4"/hour	Dielectric fluid supply, containment and processing	Yes	61	228-378	25-35	0.321

CUTTING TECHNOLOGIES

A study was performed for ANL (1) by the subcontractor Nuclear Energy Services, to evaluate different cutting technologies available to segment the EBWR reactor vessel. The study reviewed 12 techniques determined to be feasible from a technical standpoint (Table I). These techniques were evaluated based upon the following five criterion:

- Cutting Principle and Method
- Performance and Physical Characteristics
- Site Specific Impacts
- Radiological, Safety and Environmental Impacts
- Schedule and Costs

Additionally, three other factors were evaluated for each:

- Remote Cutting Equipment Positioning
- Type of Ventilating Equipment Needed
- Best Cutting Approach: in place or cut at main floor elevation.

A brief description of each of the 12 techniques follows.

Plasma-arc Cutting

The plasma-arc cutting process utilizes a direct-current (DC) arc established between a tungsten electrode and the conductive workpiece. This arc is created within a gas flow of nitrogen or argon combined with hydrogen that flows through a constricting orifice in the torch nozzle. The constricting effect of the orifice on both the gas and the arc results in very high current densities and high temperatures in the stream. The plasma is ejected from the torch nozzle at a high velocity and in combination with the arc, melts the contacted workpiece and blows the molten metal away. Nozzle life is greatly increased with a water-injection system that insulates the nozzle from the intense heat of the arc.

The speed expected from the plasma-arc system in cutting the 2.5-in.-thick material of the EBWR vessel is 13 in./min. The estimated cost for the plasma-arc cutting equipment is $40,000, which includes the torch assembly, power supply, control panel, and cooling-water system. The remote manipulation and viewing system to support the plasma-arc system is estimated to cost between $148,000 and $278,000. The lead time required for delivery of a plasma-arc system is estimated to be 6-8 weeks, with additional time needed for design and fabrication of the remote-handling system.

This process would require supplementary equipment, such as an atmospheric-containment envelope, an air-filtration system, and, if a water-injection system is used, a liquid-waste-processing system at a total cost of between $45,000 and $82,000.

Arc-Saw Cutting

The arc saw is a circular, toothless, rotating blade that produces a cut in conductive materials by means of a high-current electrical arc between the blade and the material being cut. Blade rotation removes the molten metal generated by the arc in the kerf of the workpiece. Water cooling (5-20 gal/min) of the saw blade) during in-air cutting is recommended. The depth of the cut is limited only by blade diameter. For 2.5-in.-thick carbon steel with a 0.1-in.-thick stainless steel cladding, a single-pass cut using a 20-in. blade is recommended. Cutting rates of up to 280 $in.^2$/min have been achieved with stainless steel and high-alloy steels; however, carbon steel cutting is impeded by slag buildup in the kerf, reducing the cutting rate. A cutting rate of 60 in./min might be expected.

Arc-saw cutting equipment, including the remote manipulator and associated hydraulics, is estimated to cost between $300,000 and $500,000. Additional costs are represented by supplementary equipment, such as the required atmo-spheric containment and air-filtration system, as well as processing and disposal of the 5-20 gal/min blade cooling water.

Flame Cutting

Flame cutting, also known as oxyacetylene cutting, typically cannot be used to cut nonferrous or ferrous/high-percent alloy metals. This is due to the formation of refractory oxides that have high melting point temperatures and form an insulating coating on the workpiece, thus hindering progress of the cut. These metals can be cut if the torch flame temperature can be increased above the melting point of the refractory oxides, or if the formation of these oxides can be prevented. Otherwise, the vessel must be jacked up to permit flame cutting from the outside diameter (OD).

One method of eliminating the formation of refractory oxides for inside diameter (ID) cutting is to remove the stainless steel cladding before flame cutting. This can be done with the electric-arc gouging process or by mechanical methods, such as machine cutting or abrasive cutting. Another method is to increase the oxyacetylene flame temperature through the introduction of a fine iron or iron/aluminum powder. In addition to raising the flame temperature, this powder assists the cutting action by producing an increased mass flux in the torch flame and oxygen stream. For flame cutting 2.5-in. mild steel plate in air, cutting speeds of 10-14 in./min are considered optimum. In this range, 10-20 ft^3 of oxygen and 2-3 ft^3 of acetylene would be required per linear foot of cut. Therefore, considering the expected 600 linear feet of cut necessary to section the EBWR vessel, the estimated cost of the oxygen is $450-$900, and the estimated cost of the acetylene is $500-$800. Equipment for the oxyacetylene flame cutting process would include the cutting torch, gas lines, counterweight, and a heat shield. The estimated price for this equipment is $1,700. Total estimated cost of this cutting system, including consumables and remote manipulation equipment, is $160,000 to $278,000. Since flame cutting cannot perform a complete cut of the reactor vessel wall from the inside diameter without preliminary removal of the stainless steel cladding, the additional cost of either supplementary processes or vessel jacking must be taken into account.

Electric-Arc Gouging

The combination of electric-arc gouging and flame cutting utilizes two separate metal-removal operations to cut through carbon steel plate with a stainless steel cladding. When cutting is performed from the clad surface of the plate, the arc gouge technique is used to remove a strip of the stainless steel cladding. This exposes the carbon steel plate beneath for flame cutting.

In air, electric-arc gouging can achieve travel speeds of 20 in./min for removal of 1/4-in. stainless steel cladding at an electrode feed rate of 1-2 in./ min. Standard electric-arc electrodes are available in 12- to 20-in. lengths. Mild steel strip electrodes have been developed to allow continuous operation without the need to replace consumed electrodes. Cutting of the EBWR vessel would be limited by the flame cutting rate of 10-14 in./min.

Capital costs for the electric-arc gouging equipment are $31,000. The standard electrodes (consumable) used with this equipment cost $150 per 100 electrodes. It is estimated that 100 electrodes would be needed to complete the job. Since this process produces large amounts of smoke, a high-efficiency particulate air (HEPA) filtration system and an atmospheric-containment tent would be required.

Mechanical Cladding Removal/Flame Cutting

Flame cutting (oxyacetylene cutting) as a method for reactor vessel sectioning from inside the vessel requires the removal of the 0.1-in. stainless steel cladding to a width of 1 in. to expose the carbon steel base metal. This allows the use of the flame cutting process without the buildup of refractory oxides that would be present with the cladding in place. This building would hinder progress of the cut.

Abrasive cutting would be an effective method for mechanical removal of the cladding. A pneumatically operated abrasive scarfing wheel with a diameter of 16 in. is estimated to be able to cut through the 0.1-in. cladding at the rate of 20 linear feet per hour. An electrically operated abrasive belt is also an effective means of mechanical manipulator unit that carries the oxyacetylene torch.

Pneumatic, right-angle-drive, scarfing wheels (2.5 hp, 5/8-in. arbor) are commercially available at $275-$575 each. Resin-bonded scarfing wheels (16-in. x 1-in.) are available at approximately $85 each. It is estimated that eight wheels would be required to perform 600 linear feet of cutting. A collective price of $955-$1,255 is estimated for the abrasive equipment. The cost of the electric belt drive system ranges from $750 to $3,000. These costs do not include supplementary equipment, such as the necessary air compressor and associated equipment and hoses. Use of this system would require an atmospheric-containment envelope and filtration system to contain airborne radionuclide particulates generated during cutting.

Exothermic-Reaction Cutting Processes

The exothermic-reaction cutting process utilizes hand-held equipment and is classified as a gross cutting technique. The two such cutting techniques examined in this document are the thermite-reaction lance and the exothermic cutting rod. The cutting speeds of the two processes are not continuous and are further limited by the burn time of the rods. The equipment cost for the exothermic cutting rod system is $1,000. The estimated cost of consumables to complete cutting operations on the EBWR vessel (based on 600 linear feet of cut) is $1,000 for the exothermic cutting rods and $1,000 for the necessary industrial oxygen. The cost for the thermite-reaction lance is $5 per lance. The lance-holder and oxygen supply valve cost $55. Welding supply wholesalers can provide the remaining equipment necessary for approximately $500. The feasibility of developing a remote manipulation system for the exothermic-reaction cutting process would need to be evaluated. A ventilation system and an atmospheric-containment tent would be required because this cutting process produces large amounts of smoke.

Diamond-Wire Cutting

Diamond-wire cutting is a relatively new technique that is typically used to cut through concrete and stone. Use of this method to cut through 2.5-in. carbon steel would be at a cutting speed of 1-2 in./min, but the diamond wire would have an extremely low life expectancy. The diamonds might fracture or lose their sharpness, or the bonding between the diamonds and the wire might fail when cutting through metal. The diamond wire is successful in cutting through reinforcing steel present in concrete because the aggregate tends to resharpen the diamonds that have been blunted by the steel rebar. In addition, a clearance of 24 in. on both sides of the vessel wall is required to use wire cutting. Diamond-wire cutting is a wet cutting technique that uses water (3-5 gal/min) to cool the wire and flush the debris from the cut. Based on a cutting requirement of 600 linear feet, this system would require a total of 18,000 gallons of water for cutting. The capital cost for the necessary equipment is $35,225. Diamond wire, available at $110/ft, would cost between $660,000 and $990,000 to complete the job.

The diamond-wire cutting system described here has been designed for cutting concrete. Another diamond cutting system that has been designed for cutting metals is available. It employs high-tensile-strength wires that range in size from 0.003 to 0.015 in. and have diamonds embedded on their surface. Information on exact cutting rates for those wires currently is not available, but the rates are known to be low. It is possible that the cutting rates can be significantly increased through the use of appropriate acids.

Water-Jet Cutting System

The water-jet cutting system, when combined with the use of abrasives such as crushed garnet, can produce a cutting speed of 3 linear inches per minute of travel in a 2.5-in.-thick carbon steel plate. The water-jet cutting system is easily adapted to remote manipulation, as the nozzle head assembly can be located (piped) remotely from the intensifier pump and abrasive supply systems. The working tolerance between the workpiece and the carbide nozzle is not critical, and adequate cutting can be performed with a gap as large as 1.5 in. The equipment cost for the water-jet system, abrasive supply system, control panel, and a one-year supply of spare parts is estimated to be $90,000. The estimate cost of crushed garnet, sapphire orifices, and carbide nozzles required to complete cutting operations on the EBWR vessel (based on the estimation of 600 linear feet of cut) is $1,800. An estimated 3,500 gallons of water would be required for this process. Processing, transport, and disposal costs of the spent garnet, water, and reactor vessel particles (fines) represents an additional expenditure.

Laser Cutting

By exposing a material to a focused laser beam, the energy transferred to the region directly below the beam is so high that it cannot be dissipated fast enough by conduction. This energy forms a cavity on the surface of the workpiece, and if the laser beam is powerful enough, this cavity will completely penetrate the workpiece. By directing a high-velocity gas stream into this cavity, the molten material will be ejected through the back of the workpiece. The cutting action is obtained by moving the laser-induced cavity and the assist-gas nozzle along the desired path of the desired cut. With a 25-kw laser system, a cutting speed of 5-10 in./min is achievable for 2.5-in. steel.

The CO_2 laser cutting system consists of the following components: a laser-beam generator with associated controls, pumps, high voltage supplies, gas supply and cooling system; beam-handling optics; focusing optics; and cutting nozzle assembly. Estimated cost for the equipment is over $1,200,000, and robotic remote manipulation equipment required for the

application is estimated to cost an additional $228,000-$378,000. Additional equipment required to support the laser-beam cutting process would consist of a contamination-control containment and a HEPA filtration system to remove potential airborne particulates generated from the small amount of smoke created during the cutting.

Mechanical Milling

The outside diameter pipe milling machine is a portable, hydraulically powered unit designed to be strapped onto a pipe or vessel with twin mounting chains. The blade is a rotating, multiple-tooth, circular cutter designed to remove metal from the workpiece. Cutting speeds of 3 in./min are possible in 3-in.-thick stainless steel with this mechanical milling system. Supplementary equipment, such as atmospheric containment and filtration systems, would be required because this process has the potential to generate airborne radioactivity. The estimated cost for mechanical milling equipment adapted to the dimensions of the FBWR vessel is approximately $60,000, with an additional $20,000 needed to develop a machine to cut from the inside diameter. Neither inside nor outside diameter cutters are capable of making vertical cuts; however, a linear track could be developed. The costs for containment construction and air and water purification systems are additional.

Controlled Explosive Cutting

Explosive cutting is a method of segmenting metal or other materials with an explosive that is formed into a geometric shape especially designed and sized to produce the desired separation of the workpiece.

To cut 2.5-in. metal, approximately 0.5 lb of explosives is required per foot of cut (4000 grains/ft). This translates to an estimated materials cost of $150/ft. The total cost for shaped charges to complete the cutting requirement of 600 linear feet is about $90,000.

Additional equipment to support controlled explosive cutting would consist of an atmospheric-containment tent and a HEPA filtration unit to remove the airborne radioactivity generated during the blasting/cutting operations. Some of the charges could be placed on the EBWR vessel wall through the use of an articulating inside circular cutter (estimated to cost $96,000). The remaining charges may be placed either manually or remotely at additional cost.

Assuming that a more cost-effective method of placing the charges could be found, the amount of charge required to fracture the vessel might be reduced by two orders of magnitude if the vessel could be locally chilled below the null ductility temperature. Because of the amount of research and development that would be required, this method was not pursued further.

Electrical-Discharge Machining

Electrical-discharge machining (EDM) is a precise cutting process used in machining operations with critical tolerances. Applications of the EDM process generally require the workpiece to be of a limited size (small parts) because the workpiece is placed within a dielectric fluid container for processing. The tolerance between the workpiece and the EDM electrode must be controlled from 0.0005 to 0.002 in. Remote manipulation of the EDM equipment as applied to dissection of the EBWR vessel could necessitate a specifically designed system requiring 6 months of engineering time to produce, if it were even feasible to do so. The capital cost for the EDM equipment is approximately $61,000, which does not include manipulation or contamination-control systems.

Contamination-Control Measures

For most of the cutting methods described in this report, an atmospheric-containment system and a filtration system would be required to control airborne radioactivity and high concentrations of smoke and gases.

Atmospheric-containment tents can be constructed from various materials to facilitate the use of specific cutting technologies. Herculite and metal frame containment tents can be used with cutting technologies that do not produce fire hazards. Herculite material is available at prices from $5.00/ft^2. Assuming that 2,000 ft^2 of Herculite would be required, the cost of material, excluding the structural framework, would be about $10,000. The aluminum framework would cost an additional $3,000.

Fire-retardant, modular containment enclosures constructed from Lexan or stainless steel could be used with cutting technologies that include inherent fire hazards. The average cost of such a containment is about $600 for a 4 ft x 8 ft panel and slightly more for special panels, such as doors and windows. A fire-resistant contamination-control envelope would cost from $30,000 to $40,000.

Filtration systems such as HEPA filters are used in conjunction with cutting technologies that may produce airborne radionuclides or generate large amounts of smoke. The HEPA filter system should effect at a minimum 10 air changes per hour within the containment envelope. A typical HEPA filter unit that would meet this requirement costs approximately $7,100.

ANL Selection Process

After a detailed study of 12 proposals, the decision was made by ANL that the most appropriate method for sectioning the EBWR reactor vessel would be to jack the vessel up and use an abrasive water-jet system located on the main floor to cut rings off the vessel. The decision was based on the following considerations:

1. Abrasive water-jet cutting causes very little spread of airborne contamination;
2. ANL has a treatment facility to handle contaminated water;
3. Work would start on the least radioactive portion of the vessel first;
4. Abrasive water-jet cutting does not create a fire hazard;
5. The abrasive water jet can be used to decontaminate or scabble concrete and steel; and
6. Abrasive water-jet cutting is estimated to be one of the least expensive approaches.

REFERENCE

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SRS WASTE REMOVAL AND D & D PROGRAM FOR UNDERGROUND WASTE TANKS (U)

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ABSTRACT

Removal of radioactive waste from 51 large underground storage tanks at Savannah River Site (SRS) has been planned. Waste removal equipment and techniques were demonstrated in one tank (Tank #16) in 1980. Remote inspection techniques were used to monitor the demonstration. This demonstrationprovided the basis for planning waste removal fromthe remaining tanks. Waste removal will allow decontamination and decommissioning (D&D) of the tanks. Some alternatives for D&D have been evaluated. Facilities are being installed on other tanks with completion of waste removal from problem tanks scheduled for 2001.

INTRODUCTION

At the Savannah River Site, high-level radioactive liquid waste resulting from fuel processing in the Canyon Buildings is stored in large underground storage tanks. The process is illustrated in Fig. 1. The waste consists of supernate, soluble salts and insoluble sludge. The waste is stored in these tanks, some for over 38 years, until it can be processed through in-tank operations (in-tank precipitation and sludge washing) that prepares the waste as feed for the Defense Waste Processing Facility (DWPF) which includes the Vitrification and Saltstone Facilities. The Vitrification Facility is designed to convert the high-level liquid waste into a stable form for disposal. The high-activity sludge and the precipitated radionuclides will be immobilized in borosilicate glass and encased in stainless-steel canisters in the Vitrification Facility for interim storage at SRS until a future Federal repository is available. The decontaminated salt solution remaining after precipitation will be combined with a specially formulated cement to form saltstone which will be stored in vaults at SRS.

A key step in this operation is waste removal from the underground tanks, which will eventually permit D&D of the SRS waste tanks.

Waste Tank Description

At SRS the 51 large subsurface tanks that are used for handling aqueous high level radioactive waste consist of four different designs as shown in Fig. 2. All of the waste tanks are below ground and are built of carbon steel and reinforced concrete. Three designs (designated Types I, II and III) have double steel walls and forced water cooling systems. The Types I and II tanks only have a five-foot high secondary wall height while the Type III secondary wall extends to the tank top. The fourth design (Type IV) has a single steel wall directly supported by the encasing reinforced concrete and has no cooling coils. The Type III design was developed after leaks occurred in the primary walls of the Type I and II tanks. It was concluded that the primary leak producing mechanism was stress corrosion cracking at sites near the seam welds, and that stress relieving after fabrication should eliminate the cracking. The Type III tanks were stress relieved and chemical controls implemented. No cracks have occurred in these tanks.

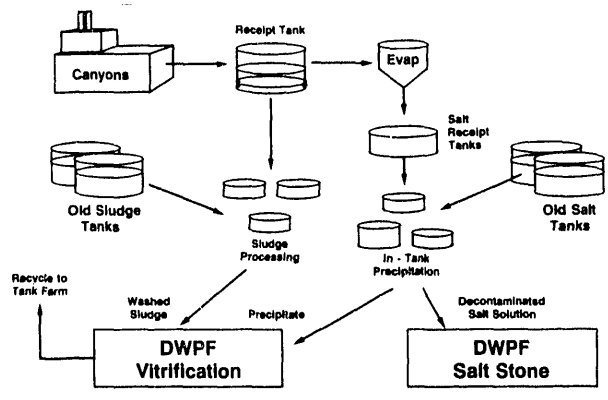


Fig. 1. SRS High-Level Waste Management System.

Waste Removal at SRS

A means of waste removal from these underground tanks is essential because:

- The Type I and II Tanks are susceptible to leaks due to wall cracks.
- The Type IV Tanks do not provide multiple barriers against leakage.
- Processing the removed waste through DWPF results in a stable waste form for permanent disposal.
- Removal of waste from the Type III Tanks allows reuse of the tanks and eliminates the need to construct additional tanks.

In the mid-seventies the Savannah River Laboratory developed a process to slurry waste using long-shafted centrifugal pumps to slurry waste sludge. Supernate and other radioactive liquid was used as the slurry medium to minimize waste volume. The same pumps were also used to provide mixing for salt dissolutions. This operation had been simulated by slurrying kaolin clay in water in a full-scale mockup. However, a demonstration in an actual waste tank was needed to ensure applicability and to evaluate actual waste removal performance. Waste Tank 16 at SRS was selected for this demonstration. The results of this successful demonstration (1) were used to plan the current SRS Waste Removal Program and should also provide useful information for other facilities requiring waste removal from underground tanks.

Tank 16 History

Tank 16 was constructed in 1955 but did not receive high activity waste until May 1959. In September 1959 waste spilled

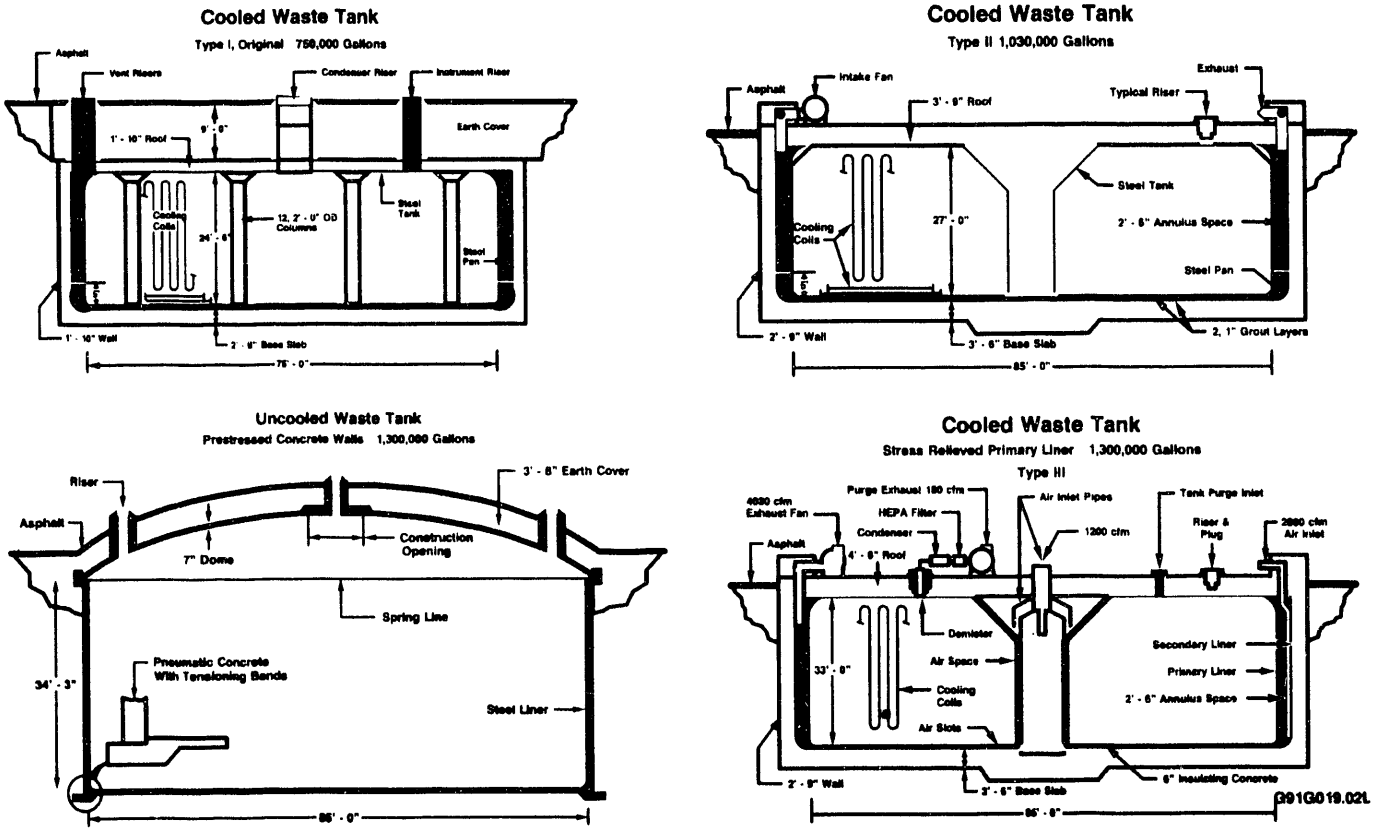


Fig. 2. SRS Waste Tank designs.

into the annulus through cracks in the primary tank wall. The annulus pan was overfilled and some waste (estimated to be a few tens-of-gallons) leaked into the soil and has been studied extensively (2). Most of the remaining high-activity waste was removed from the tank. The tank was removed from even low-activity waste service in 1972 but about 75,000 gallons (22-inch height) of sludge remained. Most of the salt that had leaked into the annulus was removed during a test demonstration in 1978. Figure 3 is a photograph of the tank interior prior to the demonstration of waste removal.

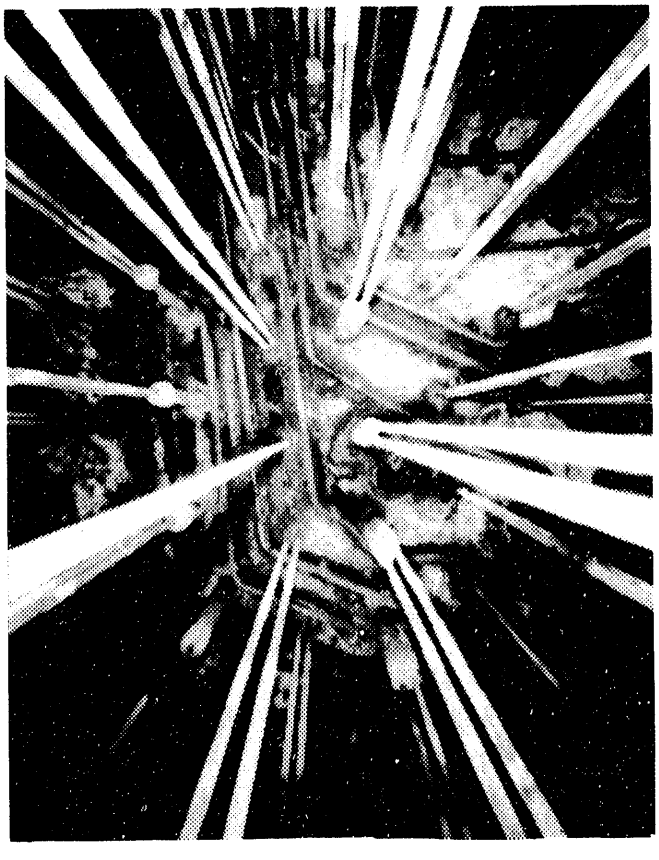


Fig. 3. Tank 16 interior before sludge removal.

Tank 16 Waste Removal Equipment

Figure 4 is a diagram of Tank 16. For the demonstration, structural steel platforms were constructed over the tank to support the slurry pumps and other equipment and prevent overloading the tank top. The slurry pumps were driven at 1800 rpm by 150-hp motors. The pump-motor-casing assembly rotated on a turntable at 0.2 rpm. Arrangements were provided for installation of up to five slurry pumps, but only three were ever installed. Special inspection equipment was inserted into the tank. The inspection techniques will be described in more detail.

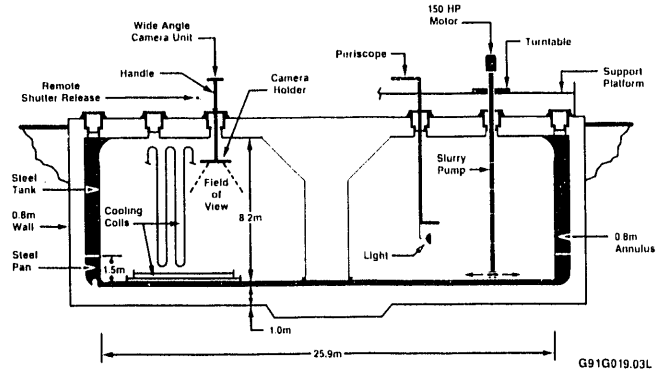


Fig. 4. Tank 16 dimensions and equipment arrangements.

Waste Tank Inspection

Special equipment has been developed at SRS to allow visual and photographic inspection of the tank interiors including the annular space. The techniques used are:

- Periscopic - visual and photographic
- Direct photography
- Direct wide-angle photography
- Closed circuit television

These techniques are normally used for tank inspection related to waste storage to help ensure tank integrity. However, tank interior inspections were invaluable in planning, monitoring and evaluating the results of the Tank 16 demonstration and subsequent waste removal operations performed in other SRS waste tanks. The tank interior photographs in this report were made by these techniques. Figure 5 shows a periscope being used for a tank interior inspection. Figure 6 shows the equipment used for direct photography in a tank. Figure 7 is a photograph of a salt deposit on the primary tank exterior wall due to leakage into the annulus. Again, Fig. 3 was a photograph of the interior of Tank 16 prior to the waste removal demonstration. Other photographs will be shown later illustrating how tank inspection was used to monitor progress and evaluate the effectiveness of waste removal.

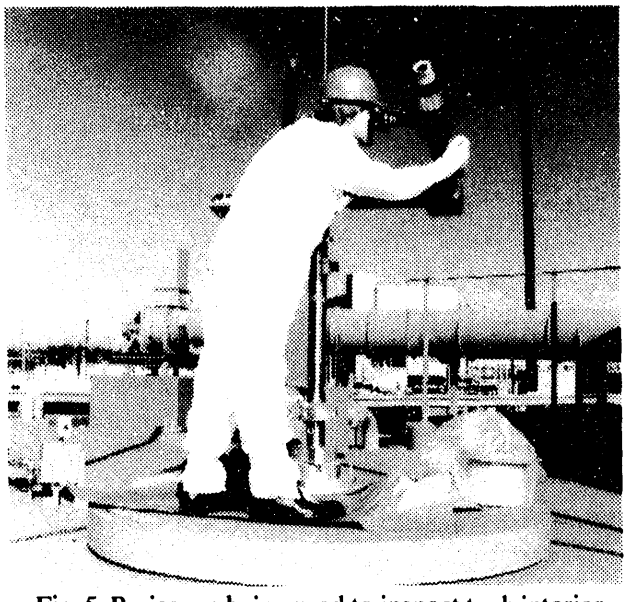


Fig. 5. Periscope being used to inspect tank interior.

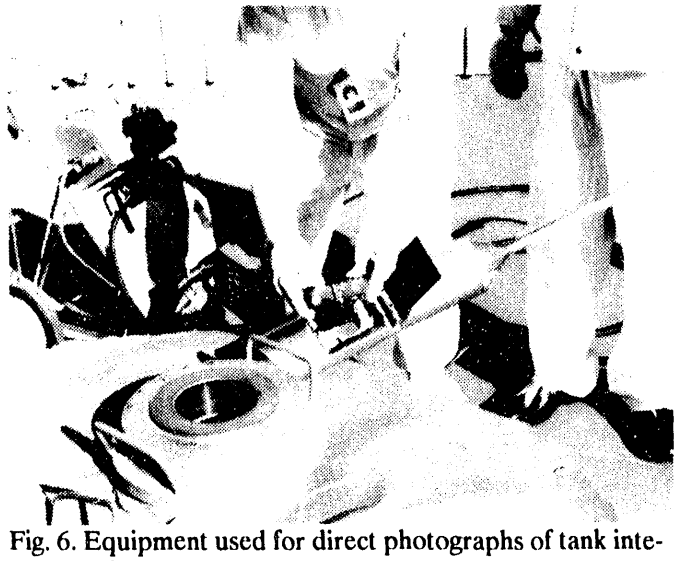


Fig. 6. Equipment used for direct photographs of tank interior.

Tank 16 Demonstration

The Tank 16 waste removal demonstration consisted of sludge removal followed by tank cleaning. For sludge removal, supernate from other tanks was added to Tank 16. Using three pumps, 98% or 76,000 gallons of the sludge was slurried and transferred from the tank. Five rotary spray jets were installed in the tank through risers and the tank interior was sprayed with water containing corrosion inhibitors. This was followed by three washes with 4% oxalic acid. Afterwards, the tank interior was rinsed with water. Essentially all of the waste was removed from the tank. Figure 8 shows the bottom of the tank after chemical cleaning. The residue on the tank bottom is from chemicals left after the liquid heel evaporated. Analysis indicated only 4100 Ci remained in the tank versus approximately 5 million Ci transferred from the tank. The dried solids remaining on the floor were estimated at 1.67 grams per square foot or 9.5 kg total.

Tank 16 D&D Plans

In 1989, United Engineers and Constructors in Philadelphia, PA was contracted by SRS to evaluate alternatives for D&D of Tank 16 (3). General criteria for the D&D were as follows:

- The tank (primary and annulus) will be entombed with suitable backfill (grout) to remain stable over 300 years.
- An Intrusion Barrier/Radiation Shield was to be placed on top of the tank with an effective life of 500 years.
- The tank was to be isolated from all other tanks and systems.



Fig. 7. Tank 16 primary wall by periscope.

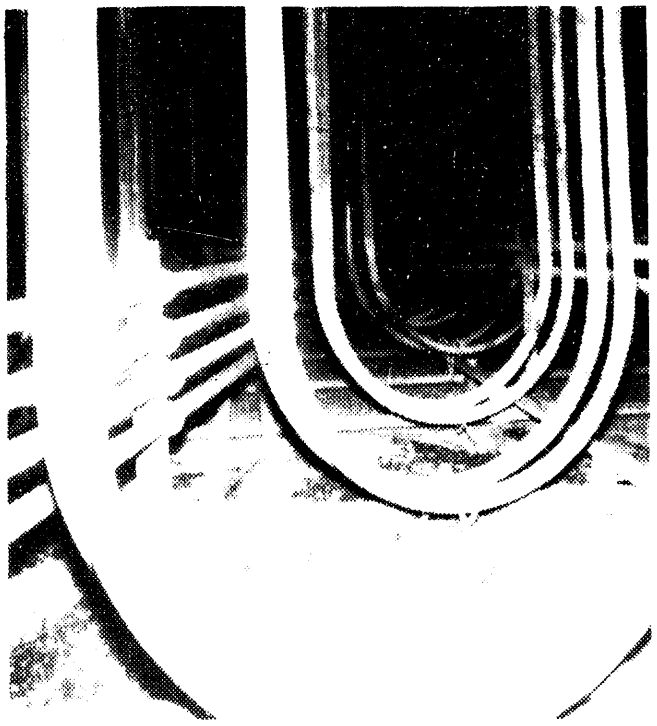


Fig. 8. Floor of Tank 16 after chemical cleaning.



Fig. 9. Interior of single-wall tank after waste removal.

- Decommissioning was to be in accordance with Class C waste, as defined in 10 CFR 61.

The selection of Class C criteria is a conservative implementation of the regulations as the remaining waste curie levels in the tank qualified for Class B criteria. Evaluation of options for removal of the radioactive/hazardous material above the tank indicated significant cost variation in the total D&D costs. Cutting larger openings in the tank top for equipment disposal inside the tank resulted in the highest D&D Venture Guidance Appraisal (VGA) estimate of $20.4 million. However, entombment of equipment in-place on the tank top to an elevation of 6'-6" reduced the estimate to $10.5 million.

Because some liquid waste escaped from Tank 16 into the ground, the area was made a RCRA Facility Investigation/Remedial Investigation (RFI/RI) site. Assessment of data from monitoring wells in the Tank 16 vicinity is underway and is scheduled for completion in 1992 and a proposed plan will be submitted for regulatory review in 1994. Further planning for D&D of Tank 16 was put on hold until the RFI/RI results are known.

Waste Removal Other SRS Tanks

Since the Tank 16 waste removal demonstration, all high level waste has been removed from the eight SRS single-wall tanks using long-shaft slurry pumps. Figure 9 shows the interior of one of the Type IV tanks (single wall) after most of the waste was removed. Additional cleaning will be required to remove the residual waste, such as zeolite, from these tanks. Space was not available in Type III tanks to receive the contents of the waste remaining in all the older type tanks. Additional waste removal has been delayed until DWPF is operational, which is now predicted to be in 1993. During this time, projects were underway for the installation of equipment to remove waste from an additional 35 tanks. Figure 10 is a photograph of the typical equipment that must be installed on



Fig. 10. Structural steel to support waste removal equipment from single-wall tanks.

a tank top for waste removal. Additional projects will be required to provide facilities for other tanks. By the latest SRS project estimates, about $15 million is now required per tank for waste removal facilities. By current schedules (4), waste removal from all but the Type III tanks is to be completed by 2001.

In summary, techniques have been successfully demonstrated for waste removal and cleaning of the large underground tanks used to store radioactive waste at SRS. Facilities for waste removal and processing of this waste have been constructed. Planning is in progress for D&D of the empty tanks.

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DECOMMISSIONING OF A GROUT- AND WASTE-FILLED STORAGE TANK IN THE 200 EAST AREA OF THE HANFORD SITE

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ABSTRACT

A self-concentrating waste tank located at the Strontium Semiworks Facility in the 200 East Area of the Hanford Site will be decommissioned following waste removal. During a previous decommissioning phase, the tank, thought to be empty, was filled with grout to prevent it from collapsing over time. Several years later, an agitator rod was pulled from within the tank and found to contain significant amounts of radiation, indicating there was still radioactive waste in the tank. Several alternative waste-removal options have been researched and evaluated. It is concluded that before the waste is to be disposed, the grout must be removed. This paper addresses that effort.

INTRODUCTION

Tank 241-CX-72 was installed at the Strontium Semiworks Facility in 1955 to be used as an experimental tank for determining characteristics of self-concentrating waste from pilot plant studies for the plutonium and uranium recovery by extraction solvent extraction process.

The tank is an upright cylindrical vessel 1.02 m (40 in.) in diameter and 10.9 m (35.67 ft) in length, as seen in Fig. 1. The 0.9-cm (3/8-in.) -thick vessel wall is constructed of ASTM A-7-52T carbon steel and reinforced with five stiffener rings. A cylindrical electrical heater is mounted just above each ring. Three rows of vertical guides connect the stiffener rings.

The tank wall extends beyond the bottom plate of the tank, which is reinforced by additional stiffeners. A 7.6-cm (3-in.) -diameter drywell is mounted on the inside of the tank. Two 20.3-cm (8-in.) -diameter access pipes, a 20.3-cm (8-in.) -diameter instrument diptube, a 7.6-cm (3-in.) -diameter vapor header pipe, and a 5.1-cm (2-in.) -diameter fill pipe are mounted to the tank lid near the center of the tank. The instrument diptubes were used for liquid level monitoring and density measurements. The drywell and the diptubes still remain in the tank.

Paddles were mounted concentrically on the agitator rod to assess the height of the sludge level within the tank. The paddles were manually operated by the agitator assembly. A sparger system was also mounted near the bottom of the tank to enhance agitation of the tank contents. The agitator assembly and sparger-system pipes remain in the tank.

The tank is set inside a caisson, a cylinder fabricated from 1.3-cm (0.5-in.) carbon steel plate. The caisson is 1.8 m (6 ft) in diameter and 10.9 m (35.7 ft) deep. The bottom of the caisson is a 30.5-cm (12-in.) thick reinforced concrete pad supported by reinforcing bars welded to the inside. Support pads, which are welded to the bottom of the tank, rest on the caisson's concrete base. The top of the tank is welded to a plate that extends over and acts as a seal for the caisson. The tank was lifted by two lugs welded onto the plate.

Records indicate that this tank was in operation for less than 1 yr. In June 1974, material level measurements indicated that 1.9 m (73.5 in.) of sludge and 2.5 cm (1 in.) of liquid were present in the tank. A sample of the liquid showed it to be a clear, light brown solution with a pH of 9.5 and a trace of solids. The solution contained the following concentrations of radionuclides:

Pu	1.3×10^{-8} g/gal
U	2.43×10^{-3} g/gal
^{137}Cs	none detected
$^{89,90}Sr$	4.33 nCi/gal

In November of that year, a level of 1.9 m (75.75 in.) was measured. Sampling was then discontinued.

In November 1976, sludge measurements and a ground-level visual inspection indicated that no sludge was present in the tank. At this time, it was planned to obtain optical equipment that would allow a more detailed visual inspection from inside the tank; however, this equipment was apparently never obtained.

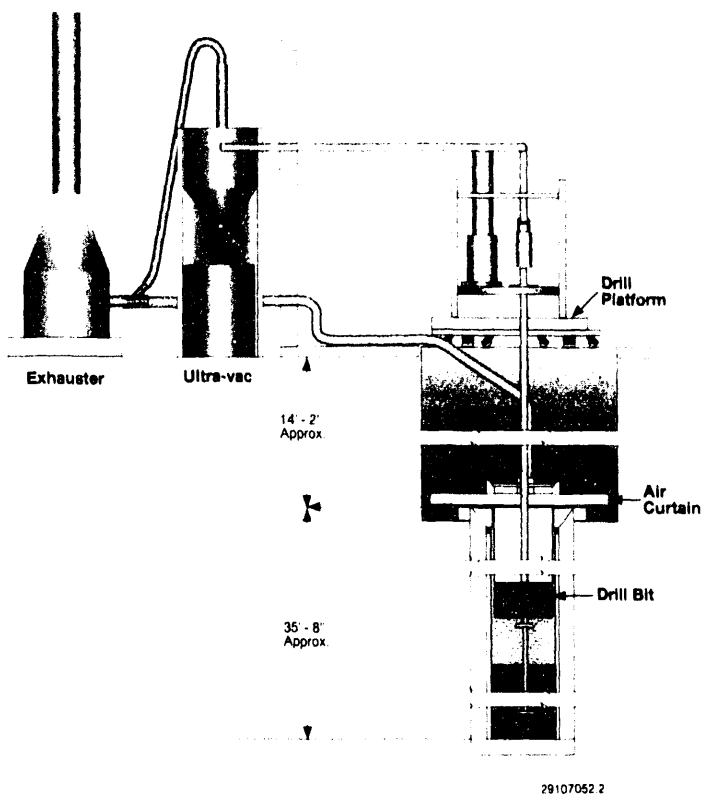


Fig. 1. Tank 241-CX-72.

Records from June 1977 indicate a discrepancy between the tank volume and level:

Volume (gal)		Levels	
Liquid	Solid	Liquid	Solid
5	325	1.9 m (74.5 in)	2.5 cm (1.0 in.)

In March 1978, the tank was recorded as empty. In 1986, a liquid level measurement indicated the tank was empty. Based on this information, the tank was decommissioned and filled with grout.

Two years later, 4.6 m (15 ft) of the actuator rod were accidentally pulled from the tank and found to be radioactively contaminated. Subsequent analyses of the tank contents using nondestructive testing methods indicated the tank may contain transuranic (TRU) wastes. Radiation measurements taken through the drywell indicate that three distinct regions exist in the tank. The bottom 3 m (10 ft) of the tank probably contain a dry waste that contains most of the TRU material and 0.6 m (2 ft) of contaminated grout, which may be TRU waste. The intermediate layer probably consists of grout, which may contain small amounts of cesium between the grout fill and vessel walls. Little or no radioactivity was detected in the upper 1.5 m (5 ft) of the tank. This analysis has been plotted and is shown in Fig. 2.

The tank is believed to contain a waste layer approximately 3.1 m (10 ft) deep. The 1986 inspection failed to indicate the presence of sludge either because the inspection was made in the drywell or the dryness of the waste made it appear that the tank was empty.

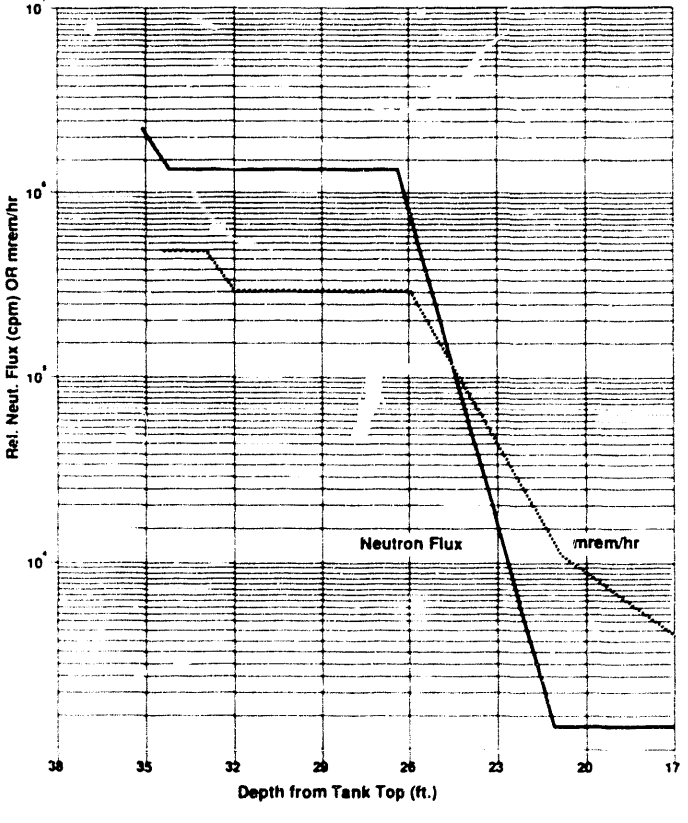


Fig. 2. Intermediate layer analysis.

PRELIMINARY ALTERNATIVES

Three basic alternatives are available for decommissioning Tank 241-CX-72: (1) further stabilize the waste and leave it where it is, (2) remove the tank and treat/dispose of the waste, or (3) remove the waste from the tank in place. Each of these alternatives and some of the subalternatives are briefly discussed below.

In Place Disposal

In place disposal is considered an alternative based on the *Final Environmental Impact Statement* (EIS): *Disposal of Hanford Defense High-Level, Transuranic, and Tank Wastes*, DOE/EIS-0113[1]. This EIS includes the in place disposal of several kilograms of plutonium in liquid waste sites (cribs) based on a risk-benefit analysis. In place disposal of Tank 241-CX-72 would require a valid characterization of the waste and a similar risk-benefit analysis.

Tank Removal and In-Vitro Waste Removal

This alternative consists of three basic suboptions: (1) storage of the waste for eventual disposal in a deep geological repository, (2) dissolution of the waste and pumping it to Tank Farms, or (3) direct transfer of the waste to Tank Farms. Each of these suboptions would require the tank to be lifted out of its caisson and sectioned to separate the high-level waste portion from the concrete-filled portion. Sectioning can be done using a diamond-wire rope-cutting technique. Sectioning would be accomplished by lifting the tank partially out of its caisson with a crane and cutting approximately 3.1-m (10-ft) -long pieces off until only 3.1 m (10 ft) remained. This would require a remotely operated grapple for the crane and a grapple or alternative for the bottom portion of the tank.

In Place Waste Removal

In place waste removal would require the removal of the grout covering the waste. Once the grout was removed, the waste could be sampled and characterized. After waste characterization, the appropriate waste removal operation would be developed, based on the contents and the consistency of the material. Several options for waste removal may be sluicing the waste to a double-shell tank (DST), removing the waste as a solid and then sluicing to a DST, or removing the waste as a solid for burial as a solid TRU waste.

The in place disposal of the tank is not considered practical because of perceived difficulty. It would require an extensive characterization effort and a complete revision of the project environmental assessment. Because no valid characterization of the waste exists, this alternative is not considered.

The preparatory steps for each of the three suboptions of tank removal and in-vitro waste removal are considered viable, but involve a relatively high level of risk in moving and sectioning the tank. In addition, the radiation exposures are all considered higher for these suboptions.

The in place waste removal is considered viable and is recommended based on relative ease of operation, relatively

low radiation exposure, and perceived cost in comparison with the other possible alternatives.

Because of the relative ease of operation and the low radiation exposure expected for the in place waste removal, this directive is being pursued.

CURRENT CONFIGURATION

An engineering study was performed to find the most effective way of sampling and disposing of the waste. The study concluded that the decommissioning of Tank 241-CX-72 would occur in three phases as follows:

I. Grout removal

II. Waste layer sampling and analysis

III. Waste removal and disposal as determined by analysis

The most effective technique found for Phase 1 was to dry mine the grout down to a level at which the waste could be sampled and analyzed (dry mining is using a drilling bit without using a liquid for cooling and material removal). Because of potential airborne particles migrating from the tank as the grout is removed, an elaborate air curtain and containment building have been designed to ensure that no radioactive particles are released to the atmosphere. The air curtain is a hollow steel barrier located at the top of the tank, which is 4.3 m (14 ft) below grade. It will draw approximately 57 m^3/min (1900 ft^3/min) of air from the building down the hole to the tank, at which point the air will be routed to a filtering vacuum and then through an exhauster. This will ensure that no particles migrate into the building, causing a contamination problem. The overall component setup is diagrammed in Fig. 3.

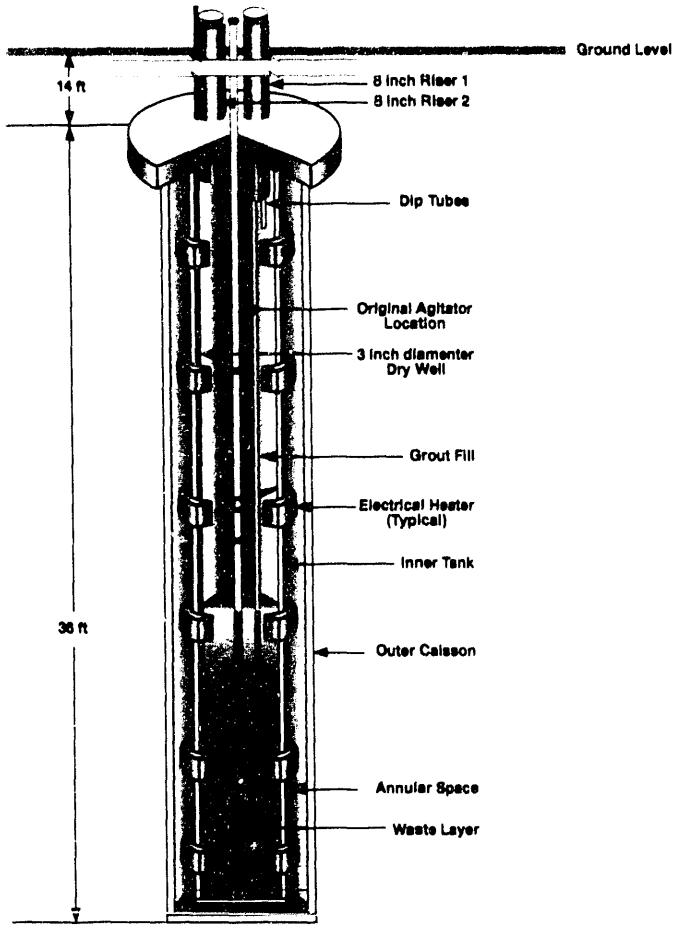


Fig. 3. Dry Mining Component Setup.

The drill bit designed for the grout removal is 0.9 m (36 in.) in diameter and weighs approximately 1,085 kg (2,400 lb). The bit will remove all the grout except for a 5.0-cm (2-in.) ring along the tank sidewall. The drill face has 10 steps toward the middle, each step housing several diamond-imbedded inserts, for a total of 96 inserts. The bit center is a 10.2-cm (4 in.) -diameter by 15.2-cm (6-in.) -long nose used as the pilot for the bit. This pilot will direct the motion down the center of the tank with minimal movement toward the tank sidewalls. The overall length of the bit is 2.2 m (7 ft 3 in.), which helps ensure that if the bit does encounter the tank sidewall, it will not breach the wall and cause a potential contamination.

The drill string is made of two concentric pipes for compressed and vacuumed air flow. The compressed air flows down the volume between the two pipes and supplies air for cooling. It also forces the grout and steel grindings toward the center of the drill bit. Once the particles are within the area near the center of the drill bit, the vacuum will draw the debris up the interior pipe to the filtering system.

The drill bit and string are operated by a large Shimpo drive motor, which is mounted to a platform with the necessary gearing and vertical motion for operating the drill. The vertical motion is controlled by a Compumotor servo controller and motor, which drive the drill platform either up or down by four ball-screw jacks. Once the drill platform reaches the lower limit of its ball-screw jacks, the drill string is disconnected, the platform is raised, and a new drill string section is connected for further drilling.

Preliminary off-site testing shows that the drill bit grinds the grout, the steel pipes, and the center rod into a very fine dust, which is easily removed by the vacuum system. Although the rate is slow, the process is very effective.

PRESENT STATUS

The soil has been excavated to the top of the tank, and the hole has been shored for safety. A 7.3-m (24-ft) by 14.63-m (48-ft) concrete pad has been poured around the excavated hole to provide the foundation for a greenhouse. The greenhouse has been constructed over the tank area for secondary containment of the system. Vacuum and exhausting systems have been purchased and tested, as well as the compressor, which is used for providing the compressed air down the tank. These components are all at the tank site and ready for use.

For safety reasons, the drilling platform will be tested in a radioactively clean area over a test pit. This test will serve a dual purpose, providing input into how the operation will take place once over the actual tank and giving the operators a chance to become familiar with the system. By testing over a test pit, minor changes can take place without the need for contamination control. This gives personnel involved in the final operation of the drilling platform a better understanding and a reassurance toward the final operation of the platform.

Also, by performing the test, several final supporting documents can be written toward the final operation of the platform, such as the decommissioning work plan, the operability test procedure, and the radiation work permit.

Once the testing is complete and the necessary changes have been made, the drilling platform will be moved and fixed above the tank.

FUTURE WORK

The drilling operation will proceed at the rate of 0.6 cm (0.25 in.) per hour, or at the optimum speed developed through testing. This will continue until the drill bit is 0.6 m (2 ft) above the waste layer or the radiation monitoring indicates that the waste layer is nearing. The drill will then be removed from the tank and placed on the air curtain for storage. The drill platform will be wheeled away from the pit and placed in the west end of the greenhouse. This will be the end of Phase I and the start of Phase II. A core sampling truck will be brought in from the east side of the greenhouse and will sample through the 0.6-m (2-ft) grout cap into the waste layer. The grout cap will help provide shielding while the air curtain continues working to prevent any airborne particles.

The samples will be analyzed and, from this analysis, Phase III will be developed: the removal and disposal of the waste. Several options are available at this time for various types of waste, but until the waste is analyzed, none of these options can be incorporated into the final design. One of the options is to continue using the drill bit, but this is only possible if the waste layer is of a dry consistency.

When the waste has been removed and disposed of properly, the tank will be decommissioned and the Strontium Semiworks Facility decommissioning can be finalized.

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SAFE STORAGE OF DEACTIVATED RADIOLOGICAL CHEMICAL PROCESSING PLANTS IN THE 200 WEST AREA OF THE HANFORD SITE

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ABSTRACT

This paper describes the surveillance and preventive maintenance actions that are implemented in the retired chemical processing plants (S Plant and U Plant) for the U.S. Department of Energy Field Office, Richland (RL). These actions are intended to keep the facilities in a safe storage configuration until final decommissioning, scheduled to begin in 2007, can be accomplished.

INTRODUCTION

Initial design-life parameters for the S Plant [Reduction Oxidation Plant (REDOX) facility] and U Plant facilities were 20 years. Currently, the building structure and equipment required to keep the U Plant facility in a safe storage configuration are 46 yr old and are required to be maintained for at least an additional 16 yr. The REDOX facility is 39 yr old and is also required to be maintained for at least an additional 16 yr. Design-life ratings of up to three times original parameters require the building structures and operational equipment to be carefully monitored under an ongoing surveillance and preventive maintenance program.

Background

The U Plant facility is located in the 200 West Area of the Hanford Site (Figs. 1 and 2). The reinforced concrete canyon building (221-U) was originally constructed during 1944 and 1945 as an integral part of the U Plant fuel separation facility, but it was never used for that purpose. From 1950 to 1952, the U Plant facility was extensively modified for a uranium metal recovery program. Modification included all new cell process equipment in the canyon building.

The 221-U Canyon Building, from 1952 to 1958, recovered uranium from high-level waste underground storage tanks containing liquid from the bismuth phosphate process fuel separation plant (B Plant). The process involved solvent extraction with tributyl phosphate (TBP) for the separation and decontamination of the uranium.

The REDOX facility is also located in the 200 West Area, directly south of the U Plant facility on the Hanford Site (Figs. 1 and 2). This facility was constructed between 1950 and 1952 and became the first large-scale, continuous flow, solvent extraction process plant built in the United States for the recovery of plutonium from irradiated uranium fuel. The process, which replaced the batch precipitation methods first used at the Hanford Site, was designed to separate uranium, plutonium, and neptunium as individual product streams from the fission products with which they are associated in the irradiated fuel. This separation was accomplished by controlling the relative distribution of the activated components between aluminum nitrate-salted aqueous solutions and an immiscible organic extractant, hexone (methyl isobutyl ketone).

Physical Description

The main building associated with the U Plant facility is the 221-U Canyon Building. This building is built in 20 sections, with expansion joints between each section (Fig. 3). The sections, numbered 1 through 20, are each 12.2 m (40 ft) long and house the cell equipment used in the batch precipitation method. The building is divided lengthwise into the gallery side and the process canyon side. These two sections are separated by a wall that runs the full length of the building and is typically 1.5 to 2.7 m (5 to 9 ft) thick. Other typical thicknesses are as follows: the floor, 1.8 m (6 ft); the roof, 0.9 to 1.2 m (3 to 4 ft); outside wall (process side), 1.5 to 2.7 m (5 to 9 ft); and the outside wall (gallery side), 0.9 m (3 ft).

The gallery side has four floors which are all 4.3 m (14 ft) wide. From the bottom to the top, these are the electrical gallery, pipe gallery, operating gallery, and crane maintenance platform. The crane cabway is open to the top of the canyon with a concrete wall separating the cabway from the canyon for shielding purposes. The remaining galleries contain all the cold piping, electrical, control, and instrumentation for the process cells.

The 271-U Building is a four-floor office/storage complex associated with the U Plant facility. The building is directly attached to the north side of the 221-U Canyon Building and was used to house personnel whose responsibility was to support the facility.

The 276-U Solvent Handling Facility was used for bulk storage of the TBP. This solvent was used for recovery of uranium from the underground storage waste tanks. The facility is located on the outside southwest wall of the 221-U Building. It is an aboveground concrete basin, 20.1 m (66 ft) by 16.5 m (54 ft) by 2.4 m (8 ft), with 1.5 m (5 ft) aboveground.

The 291-U Exhaust Fan Facility contains the exhaust ventilation equipment for the 221-U Canyon Building, which maintains the radiologically contaminated areas of the 221-U Building under negative pressure with respect to the atmosphere and adjacent noncontaminated areas of the building. There are two stainless steel, direct-driven blowers of identical design, installed in parallel, both of which are driven by a 60-hp electric motor. The building's ventilation load is carried by an individual fan at a rate of 566 m^3/min (20,000 ft^3/min). The standby fan provides backup capabilities resulting from a malfunction or scheduled maintenance of the primary exhaust fan. The 291-U sand filter, which is 25.9 m (85 ft) by 25.9 m (85 ft) by 3 m (10 ft), is comprised of gradient layers of acid-resistant rock and sand that remove radioactive particles from the exhaust ventilation air before discharge to the atmosphere. The 291-U process stack, which is 61 m (200 ft) high, provides a discharge point for the exhaust air to ensure that the velocity and altitude are sufficient to eliminate hazards to personnel.

The REDOX Canyon Building, 202-S, is a reinforced concrete structure consisting of two main architectural features, those being the canyon and silo areas (Fig. 4). The building is 142.6 m (468 ft) long and 49.1 m (161 ft) wide. The canyon portion contains all the equipment for handling

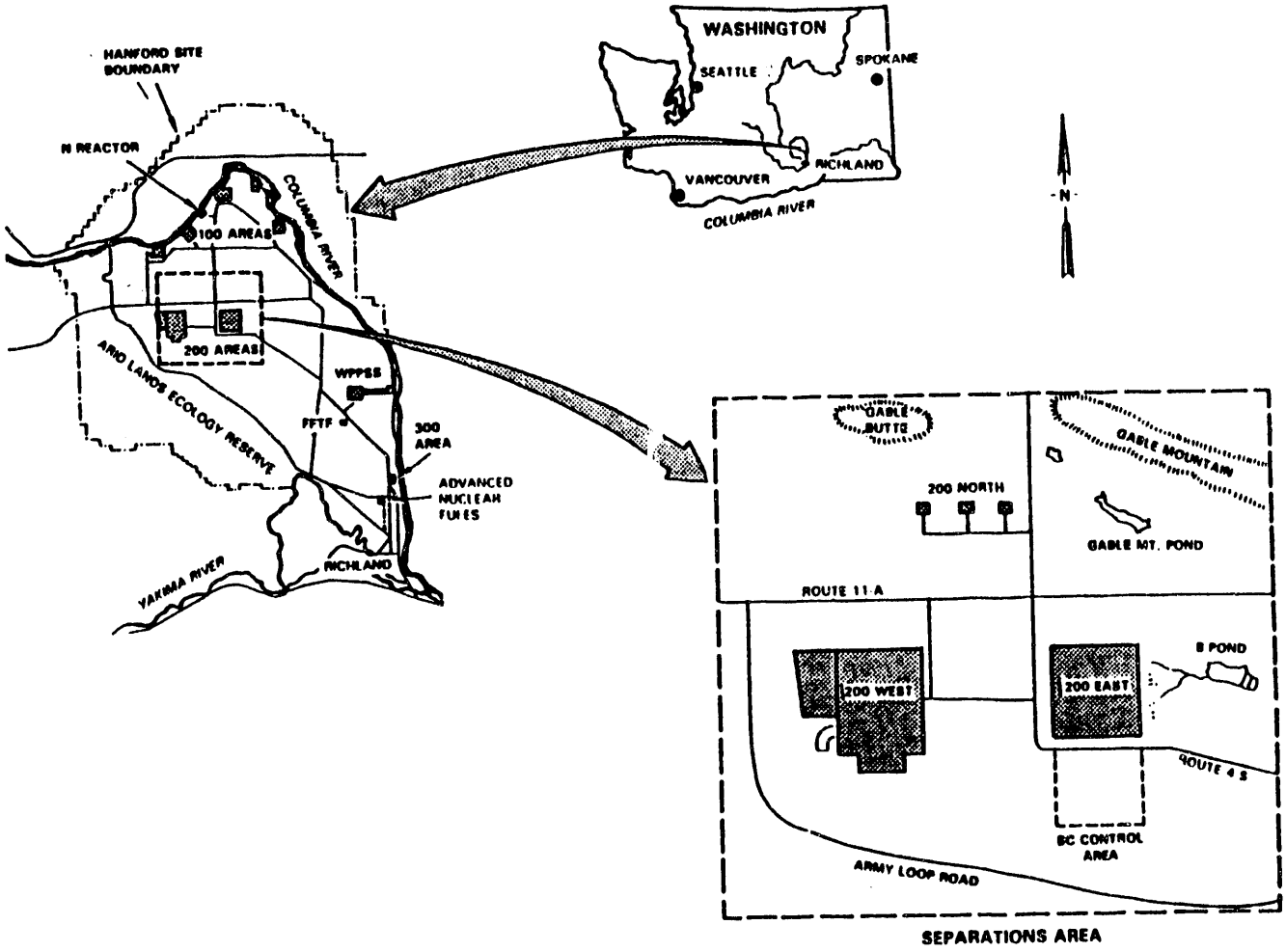


Fig. 1. Hanford site.

radioactive materials, such as fuel dissolution, feed preparation, solvent distillation, and waste concentration and neutralization. The silo area, located at the west end of the canyon, houses the solvent extraction columns and aqueous make-up vessels.

Operating, pipe, and sample galleries are located on the north and south sides of the canyon area (Fig. 4). A storage gallery is located under the south sample gallery. The silo section is made up of five chemical makeup levels, column maintenance level, column operating gallery, sample gallery, and column chemical feed tank level.

All service portions of the REDOX Building are shielded from the radioactive processing areas by concrete walls nominally 1.8 m (6 ft) in thickness. The location of cell equipment behind massive concrete shielding required the operations to be done by remote control. Chemical, steam, and water additions to the process vessels were made from the service areas through pipes penetrating the concrete shielding (referred to as the "cold" side of the piping). Transfers of radioactive solutions between process vessels were made by steam jets, gravity flow, and electrically operated pumps via piping contained in the pipe tunnel, which is located in the canyon section. This piping was referred to as the "hot" side of the transfer lines. Agitation of solutions was accomplished by remote operated recirculating steam jets or electrically driven agitators. This equipment, plus monitoring and control assemblies, comprise the majority of deactivated equipment which is presently located within the canyon cells and building galleries.

The 233-S Plutonium Concentration Facility, located directly north of the 202-S Canyon Building, was built in 1954 and 1955 and placed into operation in March 1955. During the initial process, a dilute plutonium nitrate solution was transferred from the 202-S Building to the 233-S Building. Within the 233-S Building, the plutonium solution was concentrated and loaded into product removal cans for transportation to other facilities for further processing. The facility is a reinforced concrete and corrugated metal structure consisting of eight rooms plus five air locks. A 9.7-m- (32-ft-) high bay area is divided into two sections. One is a process zone and the other is a viewing bay partitioned by vertical transparent plastic panels. These panels provided very little shielding in the event of a criticality incident; therefore, all the process vessels were designed with a critically safe geometry. In 1962, the operations of the facility were expanded to include neptunium concentrations and loadout process, along with an ion-exchange purification process.

The 276-S Solvent Handling Building was used for bulk storage of raw hexone and chemical treatment of new and recycled hexone. The facility is located west of the 202-S Canyon Building. It is an aboveground concrete building 13.1 m (43 ft) wide by 17.7 m (58 ft) long.

The exhaust ventilation equipment for the 202-S Canyon Building is contained in the 291-S Exhaust Fan Facility. There are three stainless steel, direct-driven blowers of identical

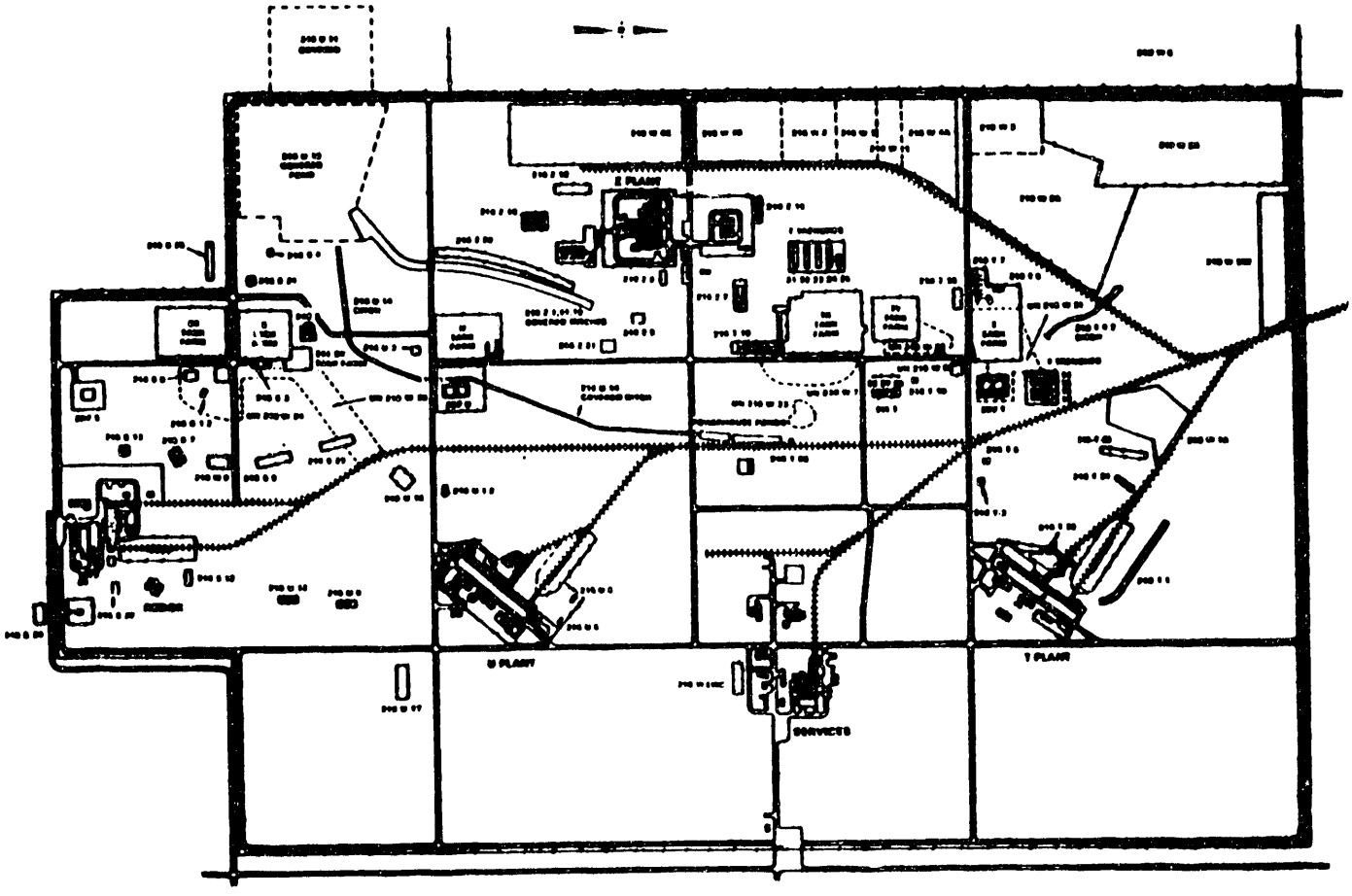


Fig. 2. 200 West Area.

design that are installed in parallel. Two blowers are powered by 60-hp electric motors, and the third is driven by a steam turbine. A single exhaust fan creates the 566 m^3/min (20,000 ft^3/min) flow rate up the process stack. The standby electrically driven fan provides backup capabilities in the event of a malfunction or scheduled maintenance of the primary unit. The steam turbine driven exhaust fan is used in emergency situations and will automatically begin operation if electrical power fails, supply air falls, or differential pressure across the air tunnel to atmosphere decreases below established standards. The 291-S sand filter, 25.9 m (85 ft) by 25.9 m (85 ft) by 33 m (10 ft), is comprised of gradient layers of acid-resistant rocks and sand which remove radioactive particles from the exhaust ventilation air before discharge to the atmosphere. The 60-m- (200-ft-) high process stack provides a discharge point for the exhaust air which ensures that the velocity and altitude are sufficient to eliminate hazards to personnel.

Since deactivation of the U Plant and S Plant facilities in 1967, all identified critical systems have been maintained under an on-going surveillance and maintenance program. The critical systems included in these programs are the building structure and ventilation systems, which maintain radiological confinement, and instrumentation, which monitors tank sumps in the canyon cells.

SURVEILLANCE

The surveillance frequency of the buildings that compose the REDOX facility are listed in Table I, and those of the U Plant facility are listed in Table II In consideration of the potential for contamination migration within the 202-S, 233-S, and 221-U buildings, efficient surveillance of the operational systems is vital to protect the environs and occupied areas of these buildings. Any off-standard condition noted during the performance of the surveillance procedure must be reported to the manager of the facility to provide prompt evaluation of the condition and initiate appropriate corrective actions.

PREVENTIVE MAINTENANCE

Several preventive maintenance systems are used at the REDOX and U Plant facilities which ensure the calibration of active instrumentation and the reliable operation of confinement systems. The Plant Instrumentation Surveillance, Calibration, and Evaluation System (PISCES) is a program that uses a computer database to document and forecast plant-installed instrument and equipment calibrations and verifications. The PISCES system is used for calibration of the following: (1) all Continuous Air Monitors (CAM) that are used for personnel safety and air effluent discharge point monitoring, (2) the differential pressure gauges which measure liquid levels in tanks and sumps, and (3) all operational

TABLE I

REDOX Surveillance Interval Schedule

Bldg. No.	Section of Building	Surveillance Interval: Once a day	3 times week	Once a week	Every other week	Once a month	Every other month
202-S	Galleries/office						
	North & south pipe gallery	X					
	North & south operating gallery			X			
	Storage gallery			X			
	Aqueous makeup levels 1-8				X		
	North & South sample gallery					X	
	Remote shop/decon					X	
	General offices			X			
202-S	Record sump levels			X			
202-S	Record tank levels			X			
202-S	Pressure reading						
	Canyon to atmosphere	X					
	Canyon to Sample	X					
	Sample to atmosphere	X					
	Wind tunnela		X				
202-S	Area surveillance			X			
202-S	Satellite storage			X			
233-S	Rooms/office/lobby						
	Cotaminated area						X
	All other areas			X			
276-S	Hexone storage			X			
291-S	Exhaust fan building	X					
292-S	Exhaust jet house			X			
293-S	Acid recovery building			X			
211-S	Chemical storage			X			

[a] Surveillance frequencies are specified to occur on Monday, Wednesday, andFriday; sometimes higher priority requirements may preclude this. In this event, three surveillances must be made during the week not to exceed 3 days between surveillances.

TABLE II

U Plant Surveillance Interval Schedule

Bldg. No.	Section of Building	Surveillance Interval: Once a day	3 times week	Once a week	Every other week	Once a month	Every other month
221-U	Canyon/galleries						
	Operating gallery	X					
	Pipe gallery	X					
	Electric gallery	X					
	Canyon			X			
	Gallery stairwell				X		
	General areas				X		
271-U	Office building						
	Basement			X			
	1st floor			X			
	2nd floor			X			
	3rd floor			X			
221-U	Area surveillance					X	
276-U	Satellite storage			X			
276-U	Solvent storage					X	
291-U	Exhaust fan building	X					

instrumentation which provides a visual, audio, or control function output.

The Preventive Maintenance System, which presently is a nondatabase recall system, is used in the REDOX and U Plant facilities to document and forecast preventive maintenance actions required to maintain the operational exhaust systems, inspect the architectural features of the building's confinement structures and provide general inspection and lubrication of all rotational equipment used to support the facility in its surplus status.

NONROUTINE MAINTENANCE

Nonroutine maintenance items are identified during the surveillance activities and require special consideration in the overall scope of maintenance for the retired facilities. This type of maintenance is required when equipment failures occur or building structures require repair to maintain the integrity of the confinement system. The design life, initial and preventive maintenance, and overall quality of workmanship that is used to repair operational systems or maintain original-construction structures is the basis for overall life expectancy. Without proper care and maintenance, the nonroutine maintenance items will continue to degrade operational effectiveness to the point where only replacement of entire systems will eliminate the potential failure mode.

SUMMARY

The initial nonroutine maintenance items completed thus far on the operational systems at the REDOX and U Plant facilities have greatly improved their overall operational reliability and durability. Efforts to continue this trend will ensure reliable operation until final decommissioning.

Replacement of existing systems with present day models must also be considered before rebuilding. Several factors which must be considered are component failure replacement interval and cost, availability of repair parts, and technical availability of personnel to maintain the equipment, to name only a few.

In addition, PISCES and Preventive Maintenance recall programs must be continued to provide the operational equipment with an environment which maintains the integrity of these critical systems.

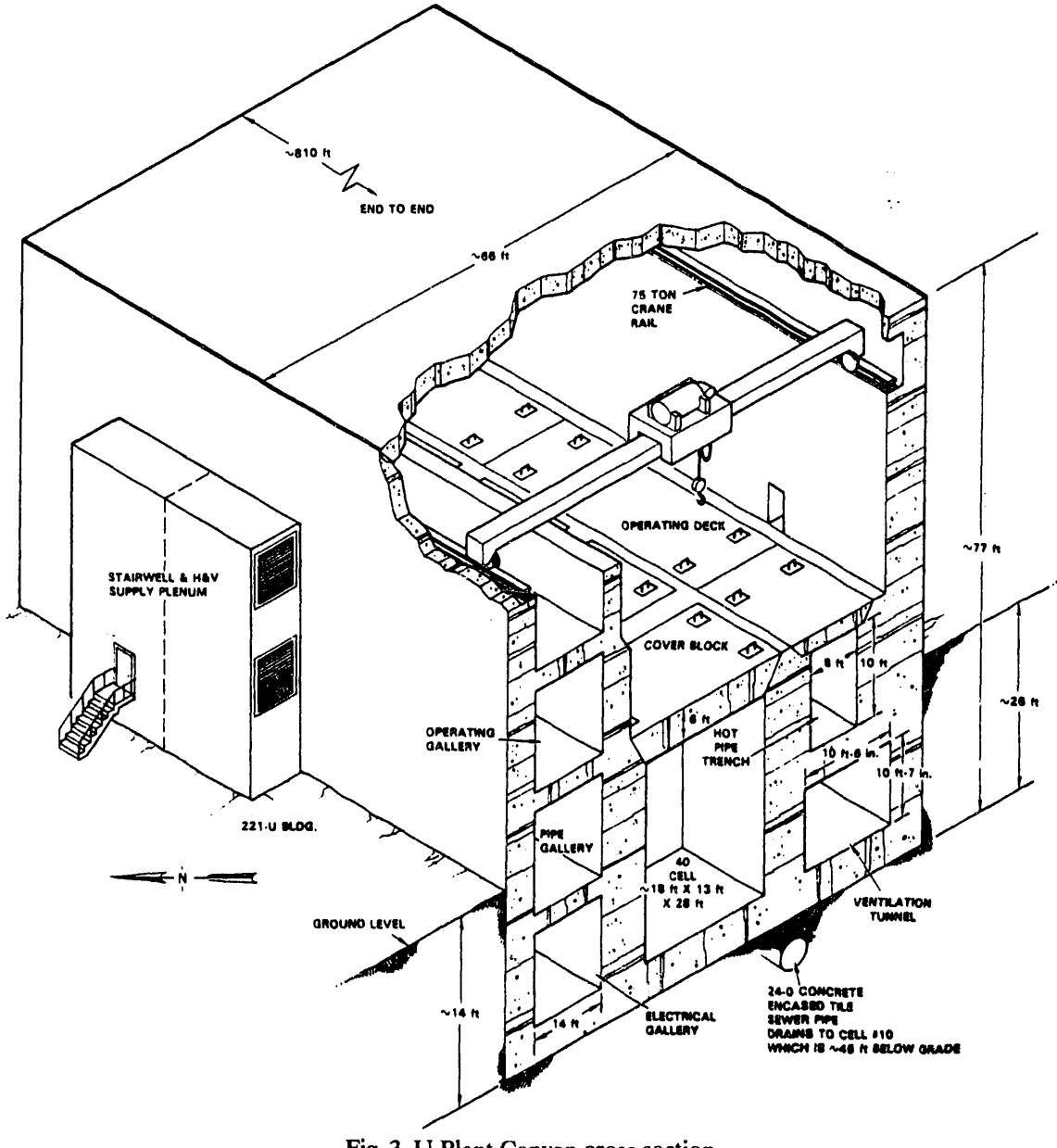


Fig. 3. U Plant Canyon cross section.

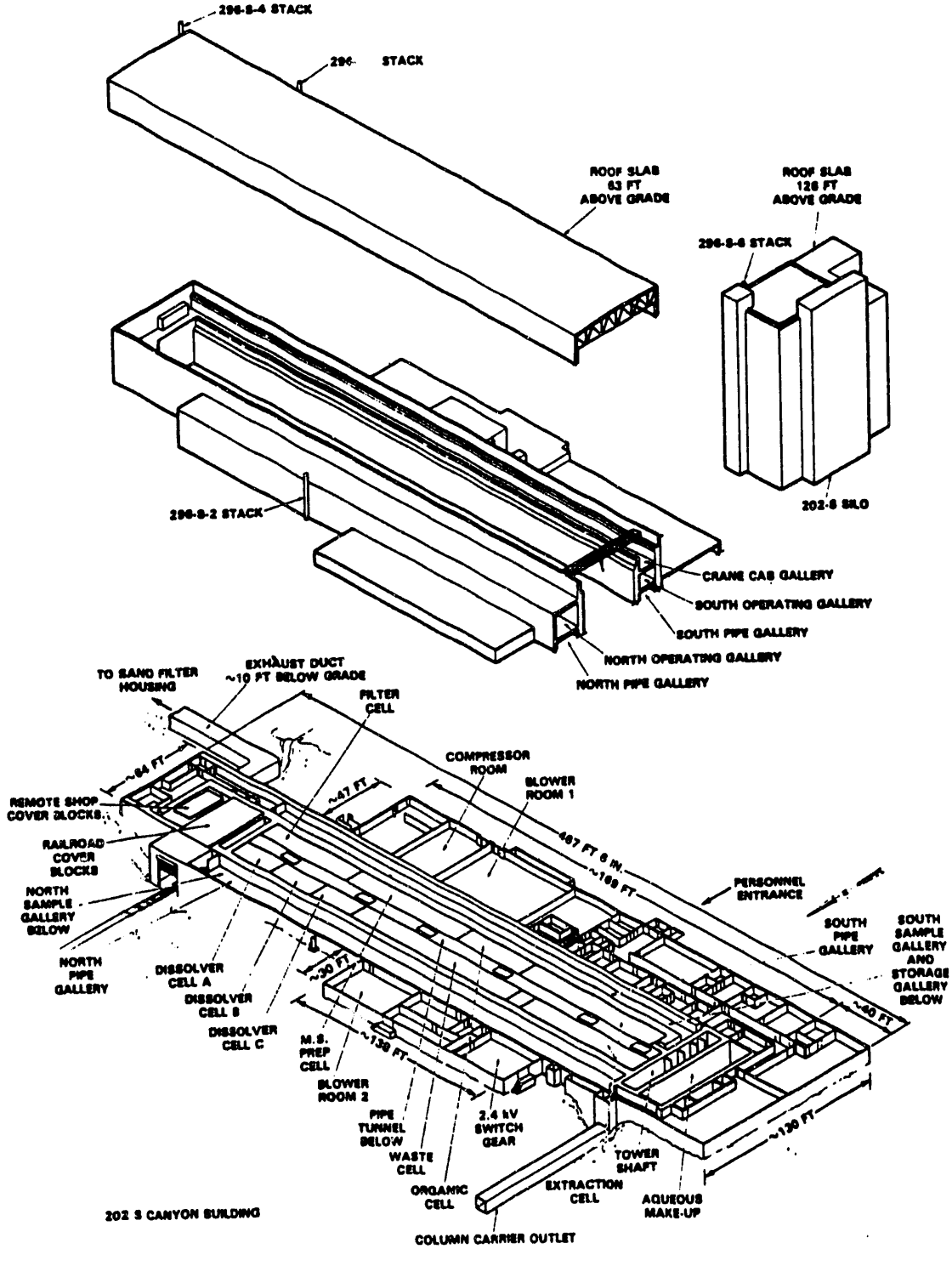


Fig. 4. Reduction Oxidation Plant Canyon cross section.

DECOMMISSIONING A NUCLEAR REACTOR

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Los Alamos National Laboratory

ABSTRACT

The process of decommissioning a facility such as a nuclear reactor or reprocessing plant presents many waste management options and concerns. Waste minimization is a primary consideration, along with protecting personnel and the environment. Waste management is complicated in that both radioactive and chemical hazardous wastes must be dealt with. This paper presents the general decommissioning approach of a recent project at Los Alamos. Included are the following technical objectives: site characterization work that provided a thorough physical, chemical, and radiological assessment of the contamination at the site; demonstration of the safe and cost-effective dismantlement of a highly contaminated and activated nuclear-fueled reactor; and techniques used in minimizing radioactive and hazardous waste.

BACKGROUND FOR THE WATER BOILER REACTOR PROJECT

Decommissioning a nuclear reactor is one of the largest and most complex tasks in waste management. A recent project at Los Alamos National Laboratory was the decommissioning of the Water Boiler Reactor.

Los Alamos National Laboratory was established in 1943 to build the world's first nuclear weapon. Today, the Laboratory is a multiprogram national laboratory of the US Department of Energy, still operated by the University of California. Although weapons activity has always been and remains the largest single activity, the Laboratory has become a versatile and broadly based multiprogram research and development institution. For more than 30 years, the Water Boiler Reactor was part of that effort.

The Laboratory is located in north-central New Mexico about 60 air miles north of Albuquerque. Physical facilities include 50 sites, or technical areas, spread over 43 square miles.

History

Enrico Fermi advocated construction of what was to become the world's third reactor, the first homogeneous liquid-fuel reactor, and the first reactor to be fueled by uranium enriched in uranium-235. Eventually three versions were built, all based on the same concept. For security purposes, these reactors were given the code name "Water Boilers." The name was appropriate because, in the higher power versions, the fuel solution appeared to boil as hydrogen and oxygen bubbles were formed through decomposition of the water solvent by the energetic fission products.

The first Water Boiler was assembled late in 1943 in a building that still exists in Los Alamos Canyon. Fuel for the reactor consumed the country's total supply of enriched uranium. To help protect the material, two machine-gun posts were located at the site.

The reactor was called LOPO, for low power, because its power output was virtually zero. This feature simplified its design and construction and eliminated the need for shielding. The liquid fuel was contained in a 1-ft-diameter stainless steel sphere shell surrounded by neutron-reflecting blocks of beryllium oxide on a graphite base (Fig. 1). The day in May 1944 that LOPO reached criticality, Fermi was at the controls.

LOPO served the purposes for which it had been intended: determining the critical mass of a simple fuel configuration and testing a new reactor concept. LOPO was dismantled to make way for a second Water Boiler, HYPO (high power), that could be operated at power levels up to 5.5 kilowatts and thus could provide the strong source of neutrons the Laboratory needed for various measurements and studies. A massive concrete shield was built to surround the core and the large graphite thermal column that radiated from it. The reactor became operative in December 1944. Many of the key neutron measurements needed in the design of the early atomic bombs were made with HYPO. Figure 2 is a simplified cross section of HYPO.

By 1950 higher neutron fluxes were desirable. Consequently, extensive modifications were made to permit operation at power levels up to 35 kilowatts. This version of the

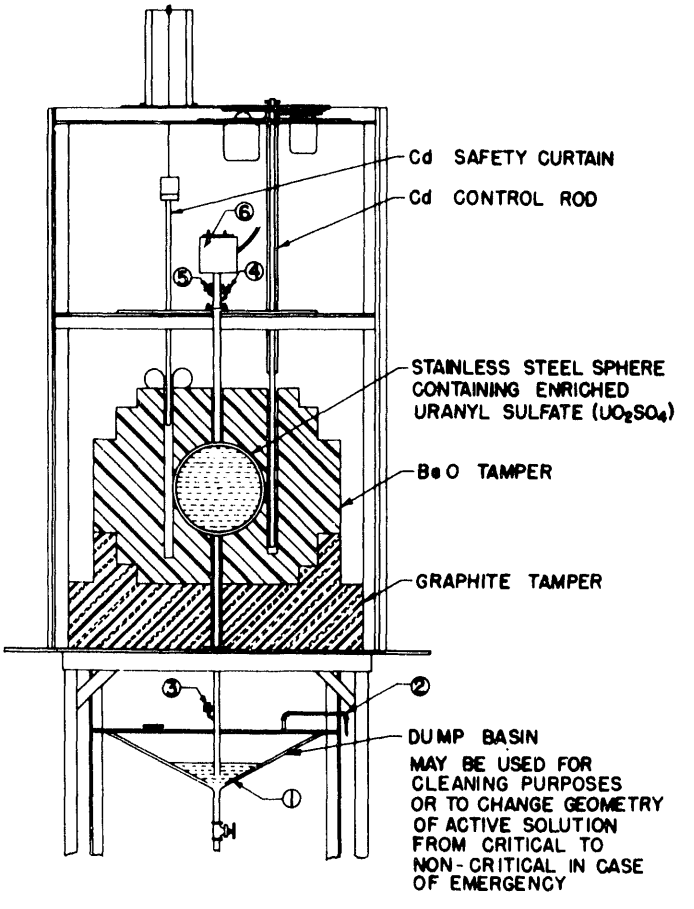


Fig. 1. LOPO Reactor.

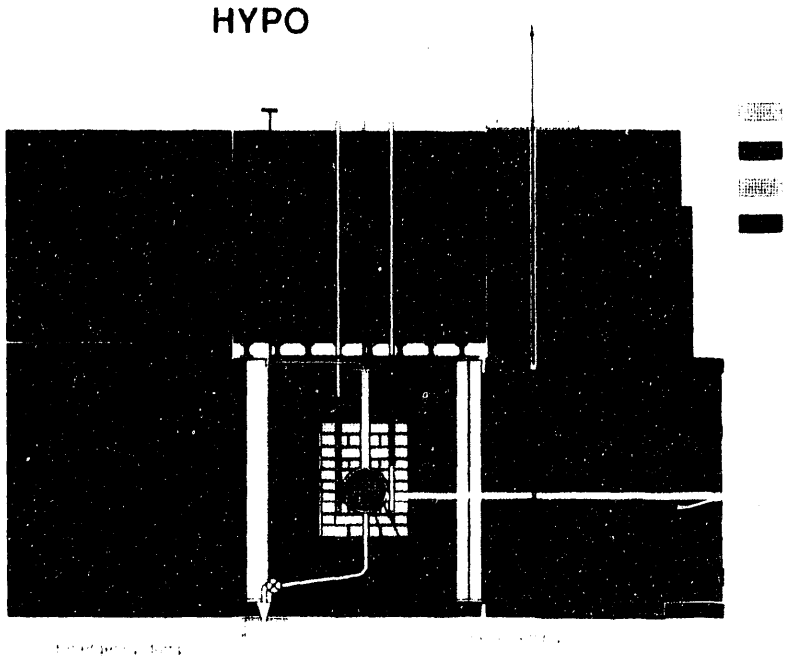


Fig. 2. HYPO Reactor.

Water Boiler was named SUPO, for super power. Completed in March 1951, the conversion from HYPO to SUPO included the following modifications.

- Three 20-ft-long stainless-steel cooling coils were installed in the 1-ft-diameter fuel vessel.
- The enrichment of the uranyl nitrate soup was increased from 14% to 88.7% ^{235}U.
- The beryllium oxide portion of the reflector was replaced with graphite to permit a more rapid and complete shutdown of the reactor.
- A gas recombination system was connected to the fuel vessel.

SUPO was operated almost daily until its deactivation in 1974.

Purpose

The Laboratory had to decontaminate and decommission the reactor inside Room 122, which housed the reactor, to provide reusable space at the site and to eliminate the hazard of accidental intrusion into a contaminated structure.

The reactor was used primarily as a source of neutrons rather than as an experiment in reactor design. The Water Boiler was an 88.7% enriched uranium homogeneous reactor consisting of a 1-ft-diameter stainless steel sphere filled with a water solution of uranyl nitrate and surrounded by a graphite neutron reflector. Other major components included various shielding materials, a concrete biological shield 15 ft x 15 ft x 11 ft high, two thermal columns, various access ports, and a gas recombination system (Fig 3-6).

Technical Objectives

The project had the following technical objectives:

- demonstrate the safe and cost-effective dismantlement of a highly contaminated and activated nuclear-fueled reactor;
- optimize the use of a dedicated subcontractor labor crew to induce a transfer of decommissioning experience; and
- provide for technology transfer by generating project performance data and documenting the decommissioning experience for use in future decommissioning projects.

Laying the groundwork for the physical decommissioning for the project took almost a year. World Services is the on-site subcontractor to the Laboratory and was therefore the subcontractor for decommissioning operations. The Waste Management Group and the Radiation Protection Group provided site-specific health and safety indoctrination training and specific training on all reactor-related components. Physical decommissioning began in June 1989.

The general decommissioning approach was to do site characterization work that provided a thorough physical, chemical, and radiological assessment of the contamination at the site. This step was followed by removing the contaminated filter plenum and unstacking the graphite thermal columns and the removable shielding, including an 8-1/2-in. bismuth pier in both the north and south thermal columns; 1/2-in. boron carbide $(B_4C)^+$ concrete, and borax paraffin cans; paraffin; and 4-in. lead shielding. Next the recombiner assembly, reactor vessel, and remaining shielding materials, including the concrete biological shield, were removed. Remedial action activities and final restoration were then completed.

Physical decommissioning was completed in April 1990 and the room released to the Isotope and Nuclear Chemistry Division.

Description of the Site

The reactor was isolated from the rest of the Laboratory because of its location in Los Alamos Canyon. No direct access to the site from other technical areas was available except through the Los Alamos Canyon Road. Room 122 housed the Water Boiler Reactor. The reactor and its



Fig. 3. South face of the water boiler reactor.

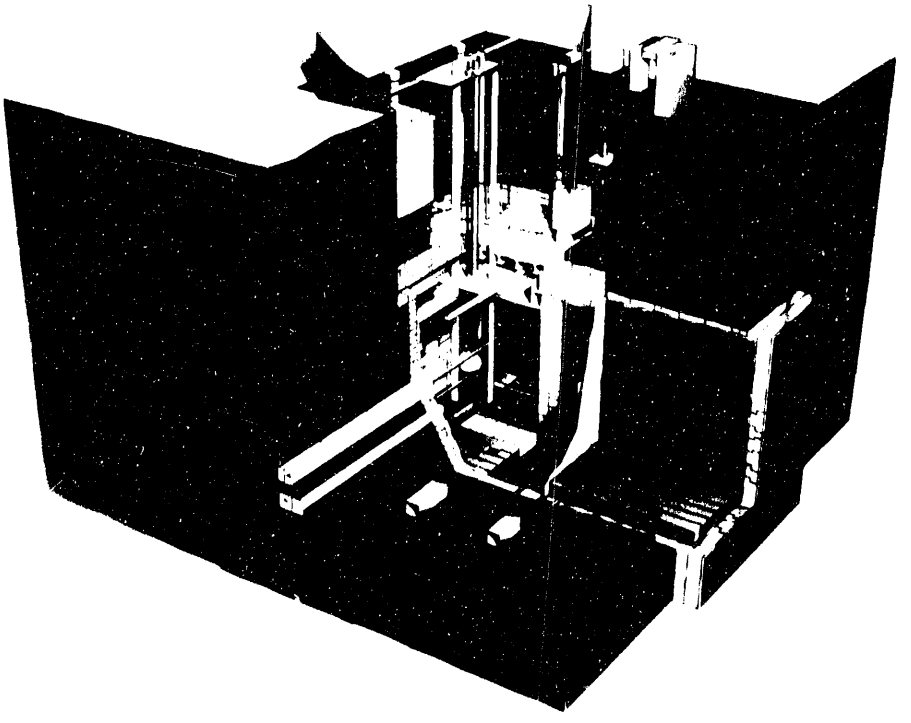


Fig. 4. Cutaway view looking northeast.

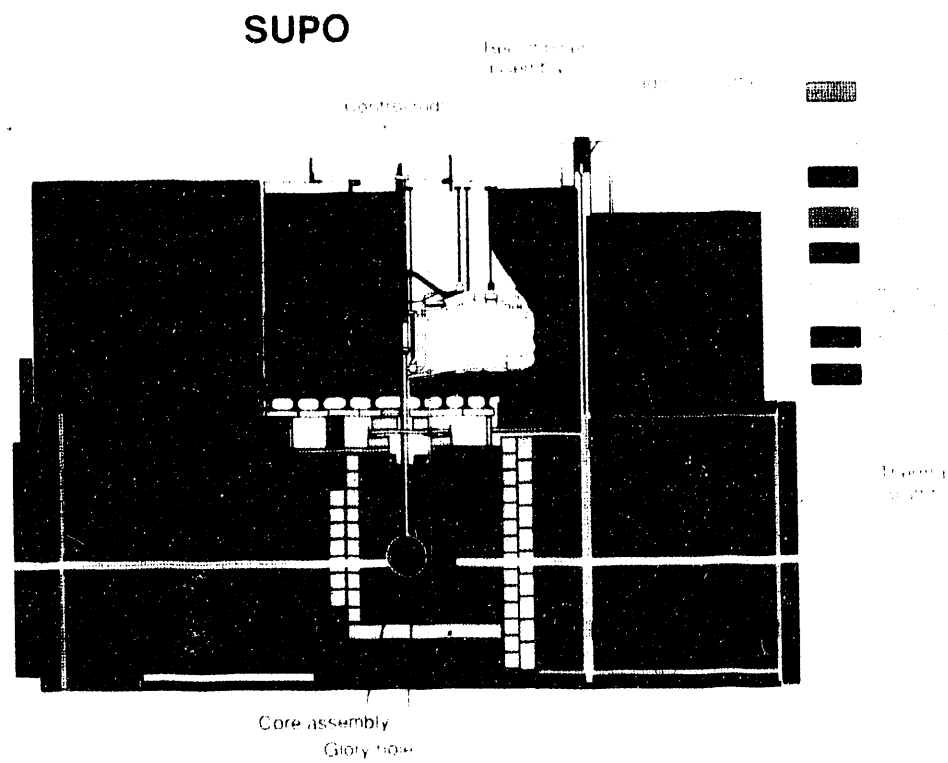


Fig. 5. North-south cross section of the reactor.

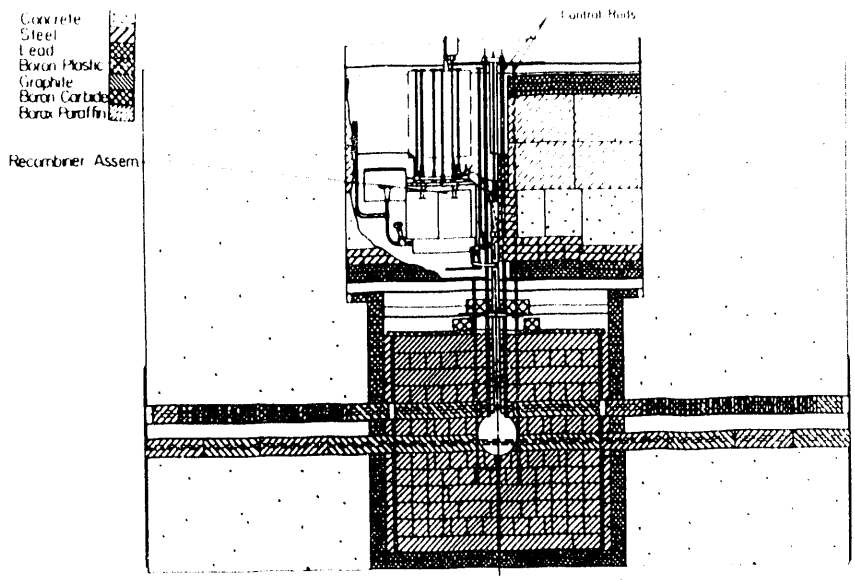


Fig. 6. East-west vertical cross section.

biological shield structure and control room were housed in a frame building approximately 60 ft x 60 ft x 26 ft.

Hazards

Contamination from fission products was distributed throughout reactor-related systems. Neutron activation of the reactor vessel and nearby components ranged from 1 R/h to 150 R/h. Radiation surveys of floor tunnels indicated radiation fields to be less than 1 mR/h in accessible areas.

In addition to the common industrial hazards of fall, electrical shock, crushing, rotating machinery, and the like, another hazard in the facility was lead. Lead shot, brick, and plates were used for radiation shielding. A waste regulated under the Resource Conservation and Recovery Act, the lead was disposed of under regulations of the state and the Environmental Protection Agency.

Radiological Controls

Strict compliance with radiological control procedures were essential to minimize occupational radioactivity exposure to levels as low as reasonably achievable (ALARA) and to prevent spreading contamination to adjoining rooms, which remained occupied.

A trained health physics technician from the Radiation Protection Group provided continuous surveillance of all decommissioning activities associated with the reactor.

Special requirements for radiation protection of workers were specified under the Laboratory practice of issuing a Special Work Permit for radiation work.

Work was monitored to ensure that the procedures were followed. Health physics technicians surveyed and monitored the materials generated during the work. Exposure records, surveys, and work conditions were reviewed daily. The need for changes in procedures or radiological controls were evaluated on the basis of these reviews.

The health physics technicians used portable survey instruments to measure loose surface contamination, the general area and contact radiation levels, and airborne contamination concentrations. They also ensured that personnel from World Services worked in a radiologically safe manner.

All personnel doing contaminated work wore protective clothing: rubber gloves, cloth coveralls, shoe covers, and hoods. When levels of contamination were high, a second set of protective clothing was required and supplemented with plastic or rubber apparel.

Personnel also wore full-face respirators when exposure to airborne activity was possible. The Industrial Hygiene Group fitted each worker with respirators. Engineered systems, such as HEPA-filtered ventilators and/or enclosures, kept airborne concentrations below limits established by the Laboratory's health, safety, and environment policies.

Personnel monitoring included monthly radiation badge dosimetry, pocket and finger ring dosimeters, bioassay analysis of urine specimens, and annual *in vivo* counting. Air in the work area was continuously sampled because of the significant potential for airborne contamination. Daily air samples were sent to the Health Physics Analysis Laboratory for analysis of gross alpha and gross beta/gamma activity.

Nasal smears were taken after operations involving removal of any reactor-related component and were checked for beta/gamma activity.

The project was completed without a release of radioactive material from the operations area or any worker overexposure.

No significant radiological impacts to the environment were caused by decommissioning work. Key factors in these achievements were the following:

- management overview,
- strict procedural controls,
- prudent deployment of radiation work permits,
- ongoing surveys,
- employee training,
- using dosimetric devices for exposure controls, and
- daily task planning.

The Project Management Plan estimated a total dose over the life of the project of 27.3 man-rem. The actual total dose over the life of the project was 4.35 man-rem.

Preplanning

Preplanning of work tasks by the project management team and World Services included detailed work procedures with estimates of personnel exposures. The project management team reviewed critical operations. Observations by management personnel and health physics technicians ensured that procedures were followed, that radiological control practices were followed properly, and that changing conditions were properly addressed. Post-work reviews tracked accumulation of exposure for various activities to ascertain where improvements could be made and where experience obtained could be applied to related work. Work in potentially high exposure areas was preceded by several classroom and simulation training sessions so that workers became familiar with their predetermined tasks before entering the exposure area.

DECOMMISSIONING THE REACTOR

Site Preparation

The first step in decommissioning the reactor was to prepare the site. The work included the following:

- setting up the World Services office;
- installing support facilities for site workers;
- establishing emergency readiness according to the Omega Site Emergency Plan; and
- addressing safety concerns (alarms, paging system, ventilation, etc.).

The room next to the reactor was modified to provide temporary office space and support facilities to World Services.

A self-contained mobile decontamination unit accommodated the various crafts personnel involved. The unit was a change-out and showering area. A dining trailer was also acquired for all crafts personnel assigned to the decommissioning project.

A craft entry structure was provided as an access control point near Room 122. The area was a radiation monitoring checkpoint for all crafts personnel leaving the facility.

Because the site was occupied and the Omega West Reactor was still operating, the Omega Site Emergency Plan was posted and in effect during all decommissioning activities. The objective of the plan was to minimize personnel injury and property damage in an accident or other emergency, such as fire, explosion, excursion by the Omega West Reactor, or radioactivity release. The evacuation route and assembly point were well marked.

Safety concerns in health physics and industrial safety required ongoing dialogue between project management and subcontractor personnel. Radiation and fire alarms were tested as part of the regular building maintenance program.

To control employee exposure to airborne contamination, fresh, clean air was circulated by a portable HEPA-filtered blower to replace the area's stale or contaminated air. The Industrial Hygiene Group determined the ventilation needs for the workers assigned to the project.

Steps in Decommissioning

The scope of the project was quite large. The decommissioning of the reactor consisted primarily of removing the FE-22 filter housing; the reactor vessel and its associated recombiner assembly and plumbing; two thermal columns; and various shielding materials, including bismuth, paraffin, steel, lead, and concrete, which were contained in a 5-ft-thick concrete biological shield. The contaminated concrete and soil beneath the biological shield and related utility tunnels were also removed.

Excess gas that appeared in the recombiner system, whether internally generated or externally injected, was automatically bled into an exhaust (or "stack") line that ran underground to the top of an adjacent mesa and terminated in a 150-ft-high stack. Small amounts of radioactive gas escaped

the reactor's biological shield and stack line and were collected and filtered with an exhaust arrangement (FE-22) that discharged the gas into the atmosphere above the reactor building. The filter housing was removed and disposed of at the Laboratory's solid waste disposal site.

These shielding materials were also removed and disposed of:

- limonite cans;
- the 8-1/2-in. bismuth pier in the north and south thermal columns;
- 1/2 in. of B_4C^+ paraffin; and
- steel, lead, and a 5-ft thick steel reinforced concrete biological shield structure.

The graphite neutron reflector was also unstacked. Smears from shielding materials, primarily from ^{137}Cs, were > 100,000 dpm/100 cm^2. To contain contamination on shielding materials that were being removed, special plywood-silicone, airtight sealed containers were fabricated.

The catalyst was a stainless steel rectangular can with inside dimensions of 6-1/8 in. x 6-7/8 in. x 5 in. (Fig. 7). Its primary function was to improve heat distribution, which in turn reduced radioactive off-gas velocity and kept both the reactor and stack line below the explosive concentration of gaseous fission products. The dose rate at contact in this component was 30 R/h. Removal was difficult because all the shielding materials encompassed the disconnection points.

Personnel used lead blankets as spot shielding and long-handled tools so that they could work for extended periods. The recombiner was then placed inside a 20 in. x 20 in. x 13 in. "suitcase cask" that contained 2 1/2 in. of lead shielding and weighed approximately 3 tons. Contact reading after packaging was 10 mR/h. The recombiner was taken into a hot cell where lead shielding was removed remotely before final disposition.

Also removed was the circulating blower, which kept static pressure negative to the stack to prevent radioactive gas leaks into the reactor room (Fig. 8). The dose rate at contact on the blower was 20 R/h. The blower was placed inside a 55-gallon drum and encased in concrete for disposal. Contact reading after packaging was 900 mR/h.

Next, the entrainment wool trap was removed. The wool trap was located ahead of the blower to stop any entrained liquid carried over (Fig. 9). It consisted of a 3-1/2 in. x 3-1/2 in. x 17 in. rectangular stainless steel box filled with stainless steel wool. The wool trap had a contact dose rate of 150 R/h. Each step of disassembly was done quickly, and, with lead shielding and specially designed long-handled tools, personnel exposure was not a problem.

A disposal container measuring 6 in. x 8 in. x 32 in. was fabricated. The container was constructed of 3/8-in. steel plate, in box form, and lined with 4 in. of lead to reduce the exterior contact reading to approximately 15 mR/h.

Then the after-condenser was removed. The design requirements of the after-condenser were that it should simultaneously reduce the temperature of gas flowing through it and condense water (Fig. 10). The contact dose rate on the condenser was 20 R/h. The container for the condenser and related piping was constructed of a corrugated metal pipe (CMP), measuring 3 ft in diameter by 6 ft long, with a CMP insert 2 ft in diameter by 4 ft long as the cavity. The outer CMP was filled with a 6-in. cold plug of concrete and 6-in. walls

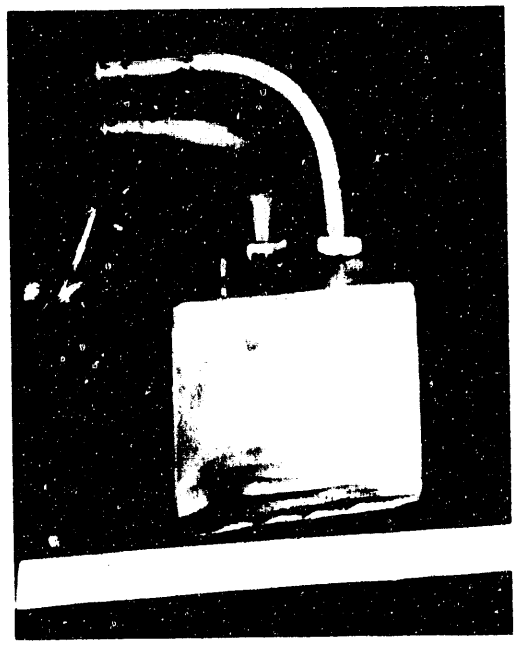


Fig. 7. Stainless steel recombiner.

filled with concrete for shielding. The outside contact reading was 200 mR/h.

The next step was to remove the reactor vessel. The 1-ft-diameter sphere was formed by welding together two hemispheres of type 347 stainless steel. Inside the sphere were cooling coils where cooling water passed. The vessel also had a glory hole that enabled an operator to optimally measure the neutron flux.

The contact dose rates were 17.5 R/h on the top side, and 22 R/h on the bottom.

A battery magnet with a load capacity of 5000 lb. was used to remove large sections of steel shielding around the vessel area. Two 6-ft extensions for a drill bit and screw shank, which were welded to one end of each extension, were designed and fabricated for remotely removing graphite that completely encircled the reactor vessel. The extensions were operated with a 1/2-in. variable speed drill. This procedure demonstrated a useful technique in reducing unnecessary personnel exposure.

The vessel was transported to the Laboratory's solid waste disposal site in a 6 ft x 6 ft x 8 ft 35-ton steel cask.

Next, the 15 ft x 15 ft x 11 ft concrete biological shield was removed. Workers tried to remove the 5-ft. thick steel-reinforced concrete biological shield without creating unnecessary dust. They used a star drill to bore holes at regular intervals; holes were filled with "s-mite," an expanding medium, so that the concrete would be broken. This attempt failed because of the amount of reinforced steel used in the concrete at the time of construction. The alternative was to use three jackhammers to break up the concrete shield (Fig. 11).

Airborne contamination was kept at a minimum by painting all accessible surfaces inside the biological shield and using a light spray of water during the jackhammering. This method was labor intensive and time consuming but the only alternative. A major cleanup of contaminated dust and debris followed.

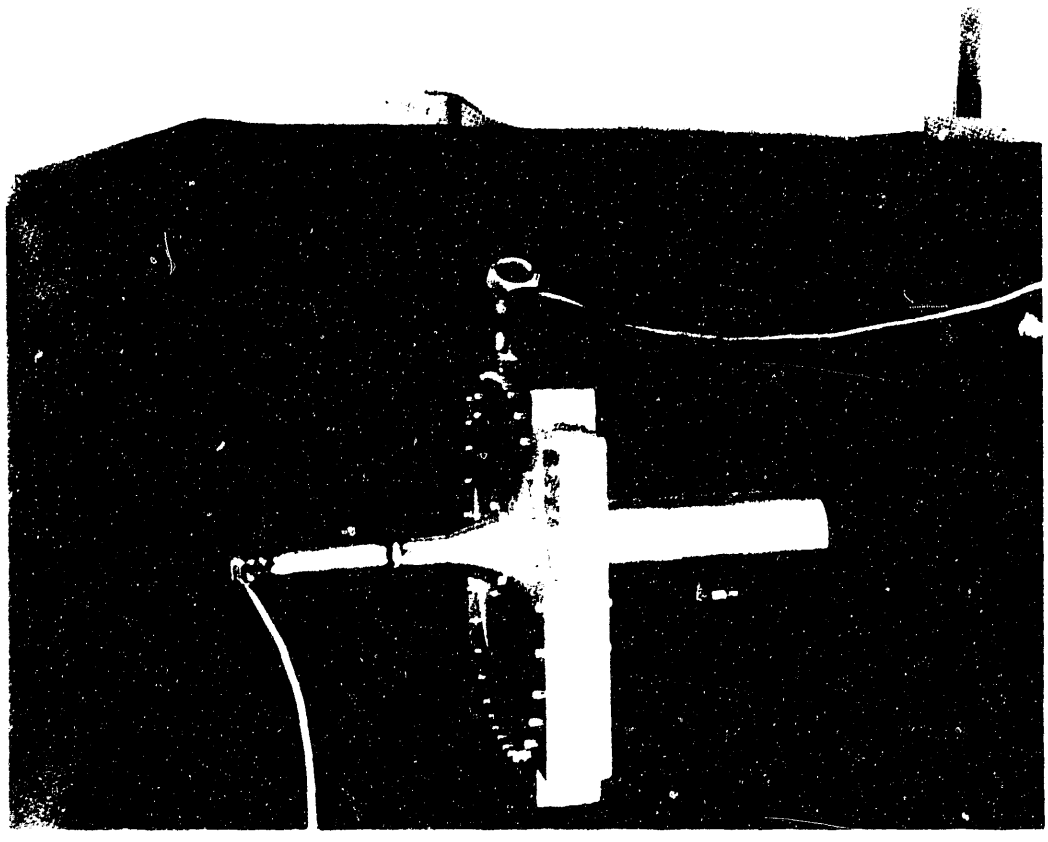


Fig. 8. The circulating blower.

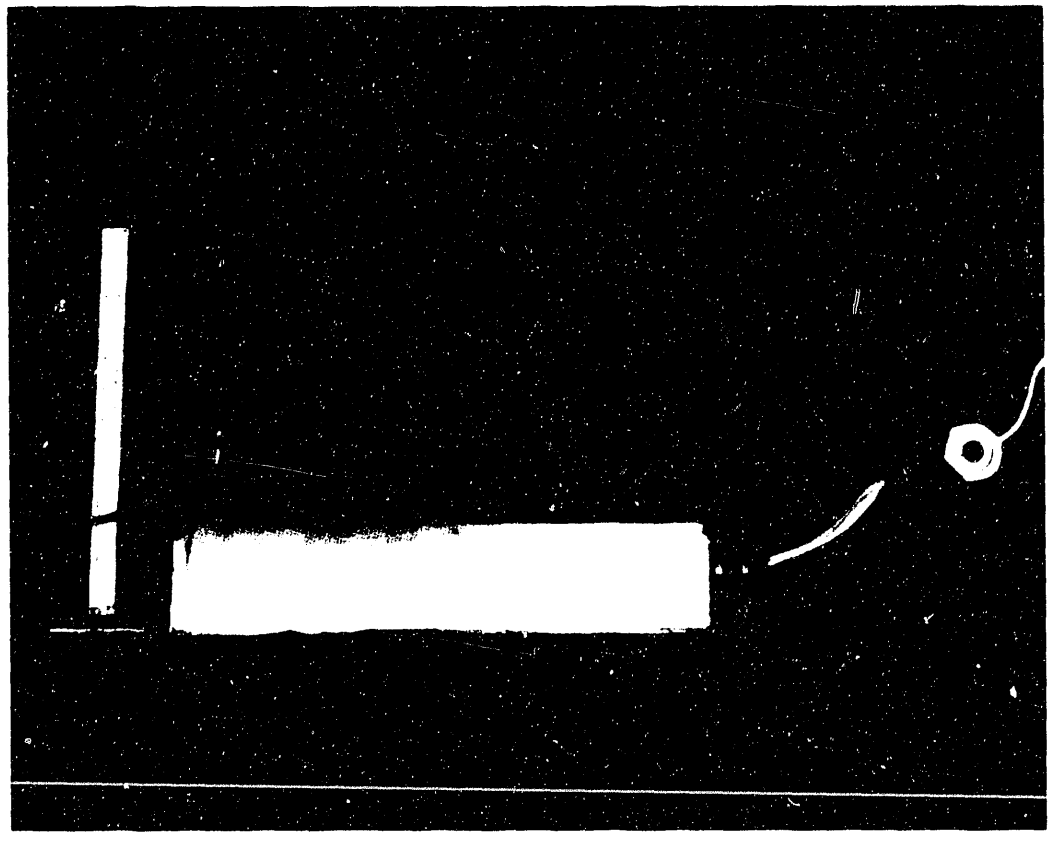


Fig. 9. The entrainment wool trap.

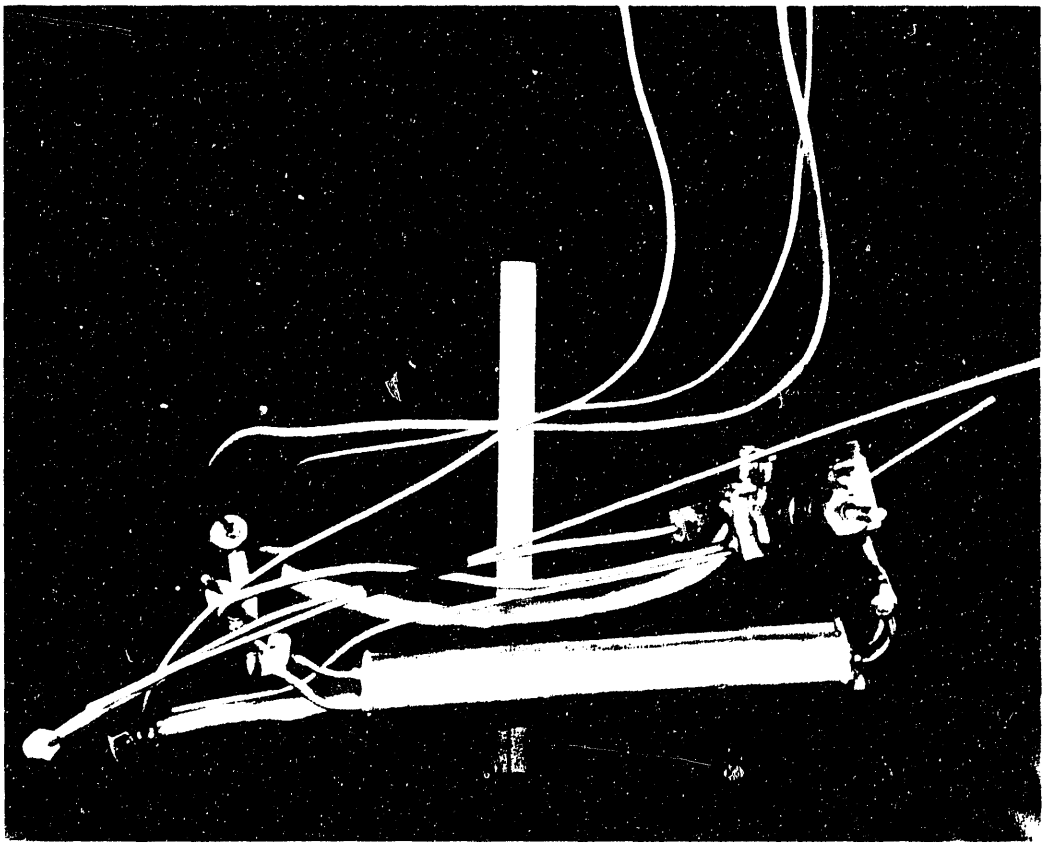


Fig. 10. The after condenser.



Fig. 11 Concrete biological shield broken with jackhammers.

Then the asbestos floor tile was removed; approximately 2000 ft^2 of asbestos floor tile was removed as part of the activities for post-remedial action. The subcontractor provided all site-specific training of personnel in asbestos removal.

Special Tools and Techniques

Several specifically designed tools and techniques were used to safely and remotely remove highly activated components. The tools were fabricated on-site. Workers also used conventional tools with extensions for remote operation. The tools enabled craft personnel to work for greater periods without unnecessary exposure from the high radiation field. Portable lead shielding was used when the recombiner assembly was removed.

Packaging and Transportation

All radioactive solid wastes were packaged and transported to comply with Laboratory requirements.

The project limited contact-handled waste packages to a maximum surface dose rate of 200 mR/h. The project got special approval from the Safety and Risk Assessment Group to package the highly activated components, up to 150 R/h. The radiation limits were raised to 1 R/h at contact with packaging.

Highly activated components, such as the recombiner assembly, reactor vessel, and associated piping, were placed inside specially fabricated metal containers consisting of either steel, lead, or concrete or a combination of these.

All waste loads were secured and covered for shipment to the waste disposal site, TA-54, Area G. The health physics surveyor from the Radiation Protection Group signed the Radioactive Waste Disposal Form only after approving the loading and securing of the waste load. Waste was sent to TA-54 only during hours when traffic was not expected to be heavy. An official escort vehicle from the Radiation Protection Group was used when transporting highly activated components to the waste disposal site.

Disposal of the Wastes

Low-level radioactive solid waste generated by the Water Boiler Reactor Decommissioning Project (WBRDP) was either buried in pits or placed in shafts at TA-54, Area G. Burial in pits consisted of covering the waste in the pits with a meter of uncontaminated soil and revegetating the disposal area. Disposal in shafts consisted of lowering the waste package down a 65-ft shaft.

All mixed waste was stored at TA-54, Area G, in accordance with applicable regulatory requirements.

Site Release Program

To release a successfully decommissioned facility or site from the Surplus Facilities Management Program (SFMP), it is necessary to verify and, in some cases, certify that the decontamination has been completed according to the criteria established for the project.

After the determination that the Water Boiler Reactor should be decommissioned and decontaminated, the reactor was designated for remedial action. Because the reactor was known to be contaminated with radioactive materials because of program activities by the Office of Nuclear Energy (NE), the facility was accepted into the SFMP.

Radiological surveys determined that Room 122 had isolated areas that would require remedial action. Surface contamination was heavy on the floor surface where the biological shield was removed, an area of approximately 250 ft^2. The soil in one area, the utility trench (sand trap), was found to be contaminated with ^{137}Cs in concentrations greater than 850 pCi/g. Furthermore, a utility trench inside Room 122 was found to contain many lead plates and required the removal of approximately 2 m^3 of soil.

Three types of remedial action were done at the reactor site to remove radioactive contamination.

The first was decontaminating the floor surfaces having removable contamination where the biological shield was removed. The floor surfaces were vacuumed with a high-efficiency filter or cleaned with a wet cloth.

The second was decontaminating floor surfaces having fixed contamination by scabbling and jackhammering the areas of contamination. In some places, the concrete was saw-cut along joints or cracks to remove all residual contamination.

The third type of remedial involved removing contaminated soil with a shovel at various locations, including the reactor pit; sand trap; utility tunnel, which was also contaminated with lead residual; and various locations throughout the biological shield area.

The wastes from all these remedial action activities were placed in 55-gal. steel drums for disposal or proper storage. All the water generated from the activities was placed in an approved 250-gal. tank and transported to the liquid waste treatment plant for treatment.

During remedial action operations, measures were taken to prevent the spread of contamination and to control exposure rates of the workers. Measures were taken to monitor airborne radioactivity resulting primarily from the dust and to limit personnel exposure from carbon monoxide exhaust gases from various pieces of engine-driven equipment.

The following contamination control measures were implemented during remedial action at the Water Boiler Reactor.

- Water kept the dust down in all scabbling and jackhammering activities. Plastic on the walls and ceiling protected the room from the dust created during concrete removal. A portable high-efficiency filter system was used to exhaust the room.
- All personnel wore respiratory protection when working around an operation that could produce contaminated dust or harmful exhaust gases.
- The room was isolated from the rest of the building by a partition constructed of sheets of plastic and wood.
- A controlled area was established outside the east entrance to Room 122. This controlled area was the access and egress area from the contaminated zone, where all personnel and equipment leaving the area were checked for contamination.

Air was sampled in the room to ensure the success of these measures to control contamination.

Lessons Learned

The TA-2 WBRDP management team experienced valuable lessons in decommissioning a highly contaminated and activated nuclear-fueled reactor.

Overall, the decontamination efforts at Los Alamos have demonstrated that nuclear cleanup and waste management can be done efficiently, safely, and cost effectively (Fig. 12). The TA-2 Water Boiler Reactor was decommissioned with maximum attention to the safety of workers and the public and to protecting the environment. The skills employed, technology used, and lessons learned will assist others in planning and performing similar projects.

Summary of Lessons Learned

A brief synopsis of lessons learned during the WBRDP is as follows.

Implementation of radiological controls - The decontamination work was planned and executed with safety, waste minimization, and productivity priorities. To perform this work safely, each task required the following:

- characterizing areas and equipment for radiological hazards;
- detailed planning, including radiological controls, to preclude spreading contamination and to minimize radiation exposure;
- preparation of contingency and emergency responses;
- thorough training, supervision, and radiological monitoring; and
- proper selection and use of protective clothing.

Special tooling - A variety of commercially available tools and equipment was used. Some of the tools, including the following, were modified to meet project objectives:

- remote drilling and cutting;
- standard cutting tools such as drills and saws with abrasive and metal blades;
- special concrete cutting tools such as scabblers and concrete saws; and
- special ventilation and dust-removal techniques.

Surface fixatives - Before contaminated items (mainly concrete) were cut or broken, surface fixatives were used to contain loose contamination.

Radiological exposure - An aggressive ALARA campaign is employed at Los Alamos National Laboratory. Personnel exposures are routinely kept at less than 1 R/y. Detailed procedures, through training and extensive use of mock-ups, were aspects of the success of this program and the ultimate contributors to the success of this project.

CONCLUSION

Through proactive efforts in safe decontamination and decommissioning and through a continuing commitment to protecting the public and the environment, the Waste Management Group at Los Alamos ensures that facilities are safely decommissioned and that the wastes from such operations will pose no harm to the public or to the environment.

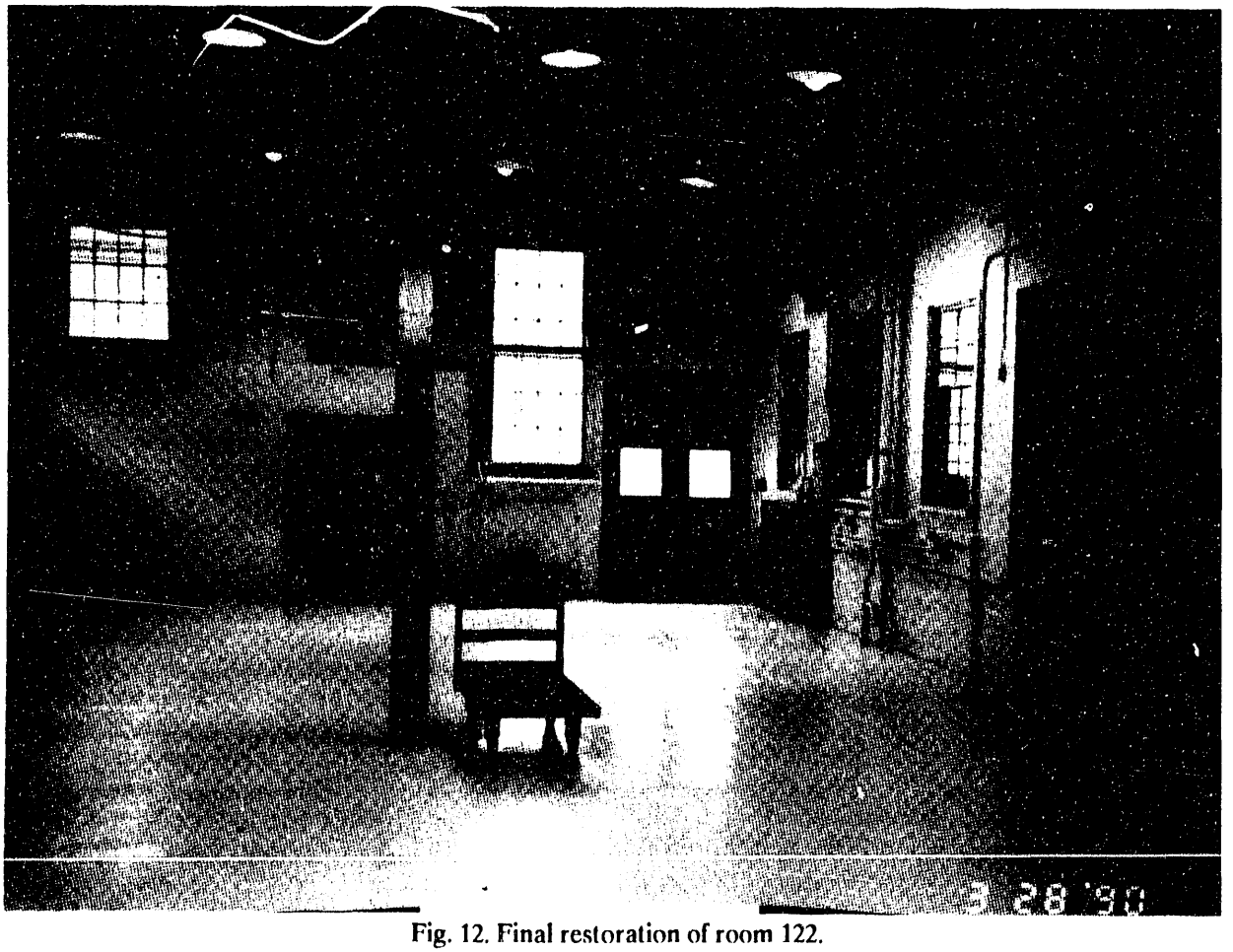


Fig. 12. Final restoration of room 122.

REMEDIAL ACTION FOR THE BAKER AND WILLIAMS WAREHOUSES SITE NEW YORK, NEW YORK

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ABSTRACT

The Baker and Williams Warehouses site in the Borough of Manhattan on the west side of New York City was remediated as part of the Formerly Utilized Sites Remedial Action Program (FUSRAP), a Department of Energy (DOE) effort to identify and clean up or otherwise control sites where residual radioactive contamination exceeding current guidelines remains from the early years of the Nation's atomic energy program. The site, formerly owned by Baker and Williams Company, was used during the 1940s by the Manhattan Engineer District (MED), predecessor to DOE, for short-term storage of uranium concentrates. A 1989 radiological survey conducted for DOE by Oak Ridge Associated Universities (ORAU) indicated the presence of residual contamination in the east bay basement and the west bay of the first floor of one of the three buildings at the site.

This paper describes the rationale for implementation of the selected alternatives to remediate contaminated surfaces in these areas. The selected remedial alternatives included mechanical decontamination by scarification and chemical decontamination using Nutech-755, a nonhazardous, nontoxic product that breaks down the concrete and releases entrapped contaminants by a process similar to etching. A verification survey of the remediated areas in April 1991 confirmed that all areas designated as exceeding guidelines had been successfully remediated to meet criteria.

BACKGROUND

The Baker and Williams Warehouses include three adjacent buildings located at 513-519, 521-527, and 529-535 West 20th Street in the Borough of Manhattan on the west side of New York City (Fig. 1). During the 1940s, the site was used by MED, predecessor to the Atomic Energy Commission (AEC) and DOE, for short-term storage of uranium concentrates produced in Port Hope, Canada, from African ores. Approximately 138,430 kg (305,186 lb) of orange and yellow sodium uranate was delivered to the warehouses during 1942, and approximately 10,000 kg (22,000 lb) of sodium uranyl carbonate and 9,080 kg (20,000 lb) of black uranium oxide were received in 1943. Records indicate that ore shipments were received at Building 529-535. Because Buildings 521-527 and 529-535 are joined by common doorways, the possibility existed that radioactive concentrates had been stored at both buildings. Building 513-519, which did not adjoin or share access with the other buildings, is not thought to have received any radioactive material.

Uranium ore concentrates were stored at the site for relatively short periods before shipment to other MED facilities. An initial review of the limited records available indicated a low potential for the presence of radioactive material at the site as a result of storage activities. However, information was not sufficient to verify site conditions at the termination of MED/AEC activities. A preliminary radiological survey was scheduled to determine whether additional investigations under FUSRAP were warranted.

DOE obtained consent from the present owner of the warehouses, and a preliminary radiological survey was conducted in August 1989 by Oak Ridge Associated Universities (ORAU). The radiological survey consisted of surface scans on the floors and lower walls to identify areas with elevated gamma or beta-gamma direct radiation. Direct measurements for total and removable alpha and beta-gamma activity were performed at randomly selected locations. The results of the radiological survey indicated that residual contamination existed in the east bay basement and in the west bay of the first floor of Building 521-527 (1).

Total alpha activity levels ranged from 27 to 400 dpm/100 cm^2, and total beta-gamma levels ranged from 350 to 100,000 dpm/100 cm^2. Building 513-519 was not surveyed during the initial radiological survey because it was not accessible. Surface contamination guidelines established for the Baker and Williams site were 5,000 dpm/100 cm^2, average; 15,000 dpm/100 cm^2, maximum; and 1,000 dpm/100 cm^2, removable. These guidelines were based on the primary contaminants at the site (uranium-238 and uranium-235). The guidelines (2) are acceptable levels for natural uranium, uranium-238, uranium-235, and associated decay products as specified in DOE Order 5400.5.

REMEDIAL ACTION

After contamination was confirmed, it was necessary to determine the authority for remedial action. An examination of site history in accordance with FUSRAP protocols determined that DOE was responsible for remediation of the site under FUSRAP (3). Because of the limited scope of work necessary for remedial action, the Baker and Williams site was a candidate for an Expedited Response Action (4). Expedited procedures were developed to expedite effective remediation of small sites in a manner that is consistent with the National Environmental Policy Act (NEPA), the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) and the National Contingency Plan (NCP). The Expedited Response Action is limited to those sites having relatively low levels of contamination, particularly those having only indoor contamination.

On the first floor of Building 521-527, contamination was limited to the floor area (Fig. 2); the floor was a 15.2-cm (6-in.) concrete slab topped with 2.5 to 5.1 cm (1 to 2 in.) of bitumen leveling material. Contamination in the basement included concrete surfaces on floors, ledges, and basement foundation supports (Fig. 3). Analysis of paint and sealant samples confirmed that uranium was the primary contaminant.

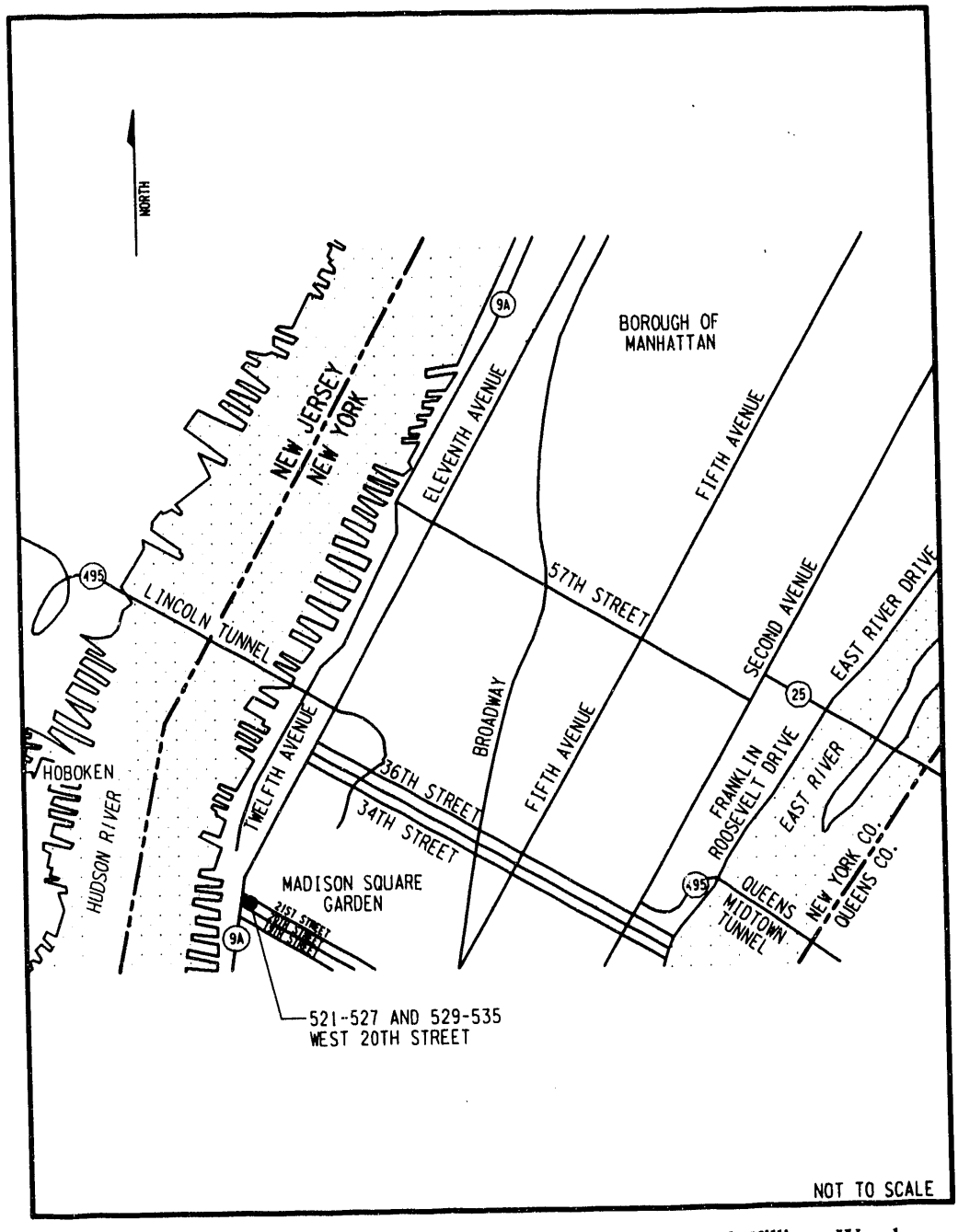


Fig. 1. Map of central New York, New York. Location of the Baker and Williams Warehouses

The areas of contaminated concrete in the east bay basement were chemically removed using a product manufactured by Nutech Corporation. The chemical agent was applied directly to contaminated concrete and allowed to remain for the time required to break down the concrete and remove the concrete solids along with any contaminants to a depth of 1 to 3 mm (0.04 to 0.12 in.). The amount of waste generated was limited.

In the west bay of the first floor, the 5.1-cm (2-in.) layer of contaminated bituminous material was removed. The relative ease of segregating the bitumen material from the concrete slab indicated that efforts to remove the entire depth would be quite effective and minimally time-consuming. However, removal of the entire depth of material would maximize the volume of waste generated. The material would be removed from the floor surface using standard construction equipment such as a skid-steered front-end loader. Void space in the waste containers would be extremely high using this method.

Because the Hanford reservation was identified as the disposal agency, the results of analysis of samples of the bitumen material were compared with Washington State waste regulations. Based on results of the Waste Designation Survey (5), the material was classified as a dangerous waste under Washington state regulations. The economics of disposal mandated that the volume of waste generated during remedial action on the first floor be greatly reduced.

Several remedial alternatives were evaluated; the selected technology employed a floor scarifier that uses a series of rotating mechanical cutting blades designed to mill the bitumen material in 0.16-cm (0.06-in.) lifts. Obtaining and analyzing representative core samples for depth of penetra-

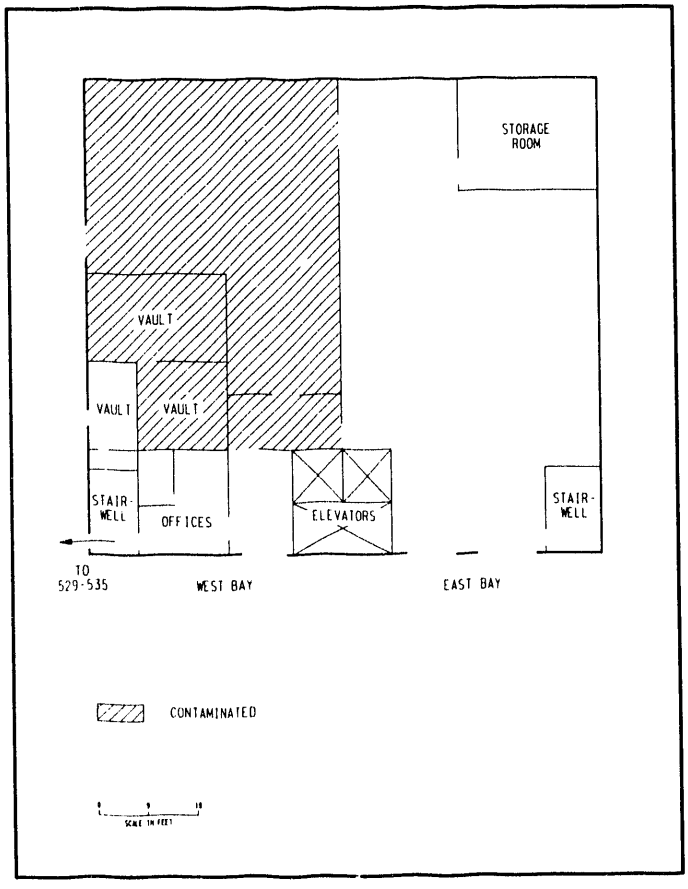


Fig. 2. Contaminated areas on the floor first floor of building 521-527.

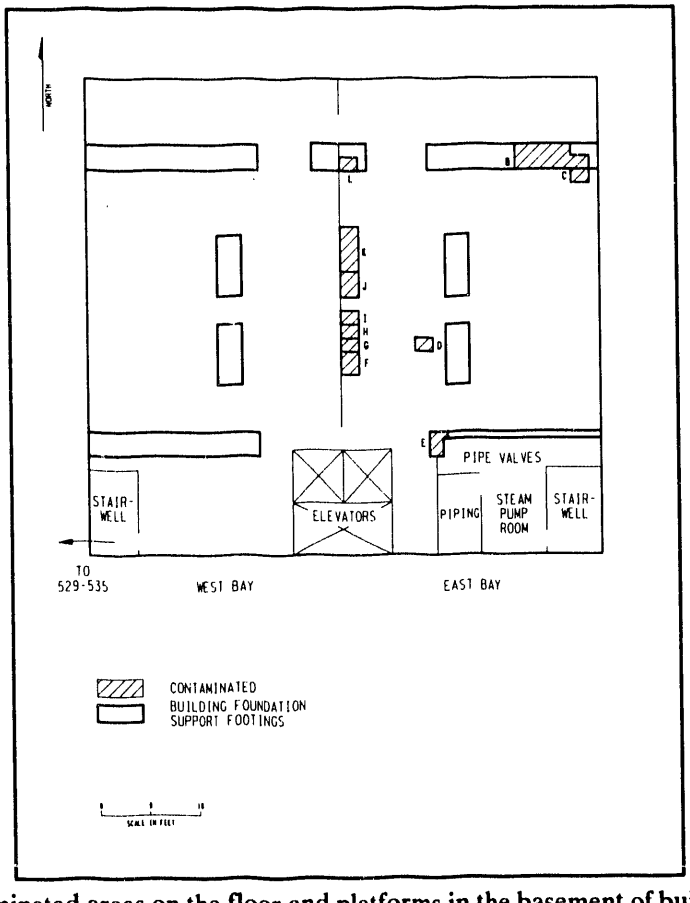


Fig. 3. Contaminated areas on the floor and platforms in the basement of building 521-527.

tion of contaminants was not possible. Because the depth of penetration of the uranium contaminants was unknown, the scarifier was used in a series of iterative passes; the onsite radiological subcontractor verified the effectiveness of each pass. It was anticipated that the use of this method would reduce the volume of waste for the first floor by at least 60%. The trade-off for volume reduction was an increase in the originally proposed schedule time, which was based on using a skid-steered front-end loader to take the entire 5.1-cm (2-in.) lift of the bitumen material.

Another alternative evaluated was removal using standard construction equipment with subsequent processing of the material through a crusher to pulverize the waste. The crusher would be designed to allow direct placement of the processed material in shipping containers. The material would be in a form that reduced the void space in the shipping containers, yet the entire 5.1-cm (2-in.) lift of bitumen material would be removed. This method would reduce the volume by approximately 30%, but the cost of the crusher and the control methods necessary to provide an enclosed space for its operation eliminated this alternative based on economic considerations. Because of the continued operation of the Baker and Williams Warehouses, with clients in and out daily, the limited available space and the noise produced by the crusher were additional factors contributing to the elimination of this alternative.

As a result of changes in the Washington State regulations that occurred during the phase of design and preparation for the work at the Baker and Williams Warehouses, the waste previously classified as dangerous waste was reclassified as low-level radioactive waste (6). The economics of volume reduction were evaluated based on the new designation; the selected alternative remained attractive, despite the increased schedule.

To perform the required remedial action, a contract was let to provide basic labor and equipment services based on time and material rates. Bechtel engineering prepared a remedial action instruction guide that described in detail the actual work operations and was the basis for estimating the required manpower and equipment. The Bechtel Construction Site Superintendent was the lead field authority responsible for implementing the requirements of the remedial action instruction guide. A separate instruction guide was prepared to govern the packaging of the waste in accordance with provisions secured in the Storage/Disposal Approval Record (SDAR) issued by the disposal agency (Hanford).

Negotiations with the property owner were initiated during the winter of 1990. All items of concern, including the right to remediate the designated areas, compensation for replacement of flooring materials, use of utilities, and the leasing of storage and office space during remedial action, were eventually contained in an owner-approved access agreement. It was agreed that restoration would be the responsibility of the owner; no restoration work was performed by DOE or Bechtel. Work was initiated on April 1, 1991, and completed on April 26, 1991.

The initial operations performed in the areas designated for remedial action included constructing negative air pressure enclosures for the first floor area, vacuuming all surfaces within the designated areas with high-efficiency particulate air (HEPA) filtered equipment, and installing HEPA filtered air-handling systems. The enclosures for the first floor were constructed using plastic sheeting over doorways and openings. Continuous air sampling was performed during all remedial action operations to ensure that contamination control measures were successful. Air particulate monitoring included area, background, and personnel monitoring.

After control measures were in place, the Nutech product was applied to contaminated concrete areas in the basement. The constituents of Nutech-755 are nonhazardous and nontoxic; the product is recommended for decontamination of concrete when contaminants have penetrated 1 to 3 mm (0.04 to 0.12 in.) into the concrete surface but is not recommended as a substitute for mechanical decontamination procedures such as scarification when deeper penetration has occurred. Nutech-755 removes contamination by a process similar to etching that destroys the binding, non-aggregate portion of the concrete's structure, releasing entrapped contaminants. The contaminants and disintegrated concrete are then dispersed in the decontamination solution, where they are held in suspension until the mixture is removed.

Most areas in the basement were decontaminated with one to two applications of the decontamination agent. The product was applied as a gel, allowed to set for 7 hours, and removed with a water spray and vacuum cleaning system. The water used to remove the expended product was recycled through a muslin cloth filter and reused, thereby limiting the volume of wastewater generated to less than 114 L (25 gal). The wastewater was placed in a 250-L (55-gal) drum heater and allowed to evaporate at a controlled rate. Diatomaceous earth was applied to the resulting residue to remove any remaining liquids. For areas that could not be decontaminated chemically, a chipping hammer was used to penetrate to the appropriate depth. In most cases, use of the chipping hammer was confined to the first 2.5 cm (1 in.). The volume of waste generated during decontamination of the basement was less than one 250-L (55-gal) drum.

Contaminated areas on the first floor were remediated using a series of iterative passes with a self-propelled, propane-fueled scarifier. The onsite radiological monitoring contractor recorded levels of radiation at each pass using a Geiger-Muller counter for direct-contact beta-gamma measurements and an alpha scintillation detector for direct-contact alpha measurements. The areas were scarified until the levels of radiation met guidelines.

The first-floor areas were isolated using the negative-pressure enclosures described above. The first floor was a controlled area; personnel entering were required to wear hooded Tyvek clothing, booties and gloves with taped interfaces, and full-face respirators. Generation of dust during operation of the scarifier eliminated the possibility of downgrading the personal protective clothing for the duration of activities. Air particulates in controlled areas were monitored continuously. At one point, carbon monoxide levels within the controlled area approached action levels. To reduce both carbon monoxide and particulates, the exhaust from the scarifier was redirected out of the controlled area, and additional air-handling units were installed.

The majority of first-floor areas were remediated with a single pass of the scarifier which removed approximately 0.16 cm (0.06-in.). First-floor areas such as floor/wall interfaces that were inaccessible to the scarifier were remediated using a hydraulic pavement breaker. In these areas, it was necessary to remediate the entire depth of the bitumen material.

The width of the cutting tool path used by the scarifier was 30.5 cm (12 in.). The machine could be set up for fine, medium, or coarse cuts depending on the arrangement of a series of blades and spacers. The setup for the first-floor areas

was for a medium cut and consisted of 76 circular cutters with 172 spacers (2 spacers between each cutter). The blades were positioned 19 across on a series of four circular racks. The material removed during the cutting operation was retained in a hopper having a capacity of 90.8 kg (200 lb); the hopper was removed from the machine and emptied into an appropriate waste container.

The first-floor remediation generated 11 250-L (55-gal) drums of waste. The originally estimated volume of waste generated from the first floor using the "Bobcat" method to remove the entire lift of bitumen material was 130 250-L (55-gal) drums. The method used to remediate the first floor provided a volume reduction equal to 92% of the original estimate, resulting in an estimated cost savings approaching $60,000.

A post-construction survey of the remediated areas by an Independent Verification Contractor (IVC) is required under FUSRAP; a survey similar to the original designation survey is performed to verify that remediation of all areas has been completed (7). A verification survey of the remediated areas at the Baker and Williams Warehouses performed in April 1991 indicated that all areas that had been designated as exceeding guidelines were successfully remediated to meet criteria (8). The total volume of low-level radioactive waste generated during remedial action at the Baker and Williams Warehouses site was 12 250-L (55-gal) drums. The waste was packaged according to provisions outlined in the SDAR and Instruction Guide for Receiving, Filling, Storing, Packaging, Preparing, and Transporting Waste that had been prepared for the Baker and Williams Warehouses site. The waste was containerized in lined 17C drums and is stored in an area leased from the current owner of the facilities while awaiting shipment to the Hanford reservation.

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A CASE STUDY: UNDERPINNING OF STRUCTURES AS AN ALTERNATIVE TO DEMOLITION/RECONSTRUCTION FOR REMOVAL OF UNDERLYING CONTAMINATED SOILS AT THE ST. LOUIS DOWNTOWN SITE (SLDS)

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ABSTRACT

From 1942 to 1958, a chemical works plant in downtown St. Louis, Missouri, chemically treated natural uranium feed materials to produce pure uranium trioxide and other uranium and thorium compounds for the Manhattan Engineer District/Atomic Energy Commission. Characterization activities to determine the vertical and areal extent of radioactive contamination of the soil have been conducted under the jurisdiction of the Department of Energy's (DOE) Formerly Utilized Sites Remedial Action Program (FUSRAP).

This paper is concerned with locations where radioactivity exceeds DOE guidelines for soil, under or around existing buildings. As an alternative to demolition and reconstruction of buildings where depth of soil contamination extends below foundation levels, a preliminary study has been made to evaluate the feasibility and advisability of underpinning, which transfers the loads to strata below the depth of contamination. The affected soil can then be excavated and replaced with satisfactory clean backfill, avoiding demolition. The study involved 22 buildings where soil contamination extends under their footprint or is present in their immediate vicinity. The preliminary study concludes that only Buildings 101 and K-1 are candidates for successful underpinning.

The process of analysis leading to a preliminary underpinning recommendation is described using these two buildings as examples. Building 101 will require strengthening of the roof structure (periphery) prior to demolition of the closure wall and underpinning. Transfer of column loads to driven underpinning piles will use "needle beams," adapted with a unique "claw" to reduce deflections and bending moments. At Building K-1, a similar arrangement will be used for underpinning of column B-8, and jacked piles will be used to support a lateral bearing wall. The method of "pretesting" jacked piles is discussed, as is the need for lateral support of the underpinning structure.

INTRODUCTION

Radiological, chemical, and hydrogeological characterization has been conducted at the St. Louis Downtown Site (SLDS) in St. Louis, Missouri. This work is part of the United States Department of Energy's (DOE) Formerly Utilized Sites Remedial Action Program (FUSRAP). Characterization was required at this site because it had been used for refinement of uranium between 1942 and 1958 under contract to the Manhattan Engineer District/Atomic Energy Commission. SLDS is currently operated as a specialty chemical production plant.

A detailed characterization report (1) indicates that the soil under or around 22 of the buildings in the plant is contaminated to various depths and must be removed and replaced by satisfactory clean backfill as part of the remedial action program. When the depth of contamination is greater than foundation depth, temporary or permanent alternate support must be given to load-bearing members before excavations can proceed below the original bottom of footing (BOF) elevation.

The first step in evaluating an underpinning alternative is to perform a detailed inspection of each of the affected buildings. Available drawings generally show as-built conditions, but not present conditions because modifications to the structures are not necessarily always recorded in subsequent revisions. The quality of workmanship or materials used in the construction, as well as the processing activities carried out within the building, may cause its premature deterioration, particularly when the foundation material is a heterogeneous, nonengineered rubble fill.

A new structure has a surprisingly high capacity to absorb total or differential settlements. However, once its initial structural integrity is exceeded, the building becomes particularly vulnerable to any further disturbance of its support; this could be the case in underpinning, no matter how carefully the operation is conducted. Criteria that eliminated 20 of the 22 buildings from the list of candidates for an underpinning alternative were established by the site inspection of these buildings, their size and present use, the lack of sufficient data on depth of contamination, the anticipated degree of complexity of underpinning, and probable cost. The two remaining buildings, 101 and K-1, are the only ones for which underpinning is considered a viable and reasonable alternative (to demolition and reconstruction) and further analysis is warranted.

This paper describes the development of preliminary underpinning solutions for Buildings 101 and K-1. However, in order to develop final designs, considerable additional field and laboratory work will be required to obtain accurate data on the subsoil and groundwater conditions at each of these buildings.

BUILDING 101

This 1-story warehouse was built in 1971 and is now used as a bulk shipping center for the Plant (Fig. 1). It is an axisymmetrical structure measuring 240 ft (73.2 m) on each side with 40-ft (12.2-m) spans. The reinforced concrete footings were designed to impose a maximum contact pressure of 1000 lb/ft^2 (5.0 tons/m^2) to the soil; maximum column loads are about 100 tons. Steel trusses support a composite industrial roof, and the enclosing wall is made of hollow concrete block. This wall serves two additional purposes: (1) to support

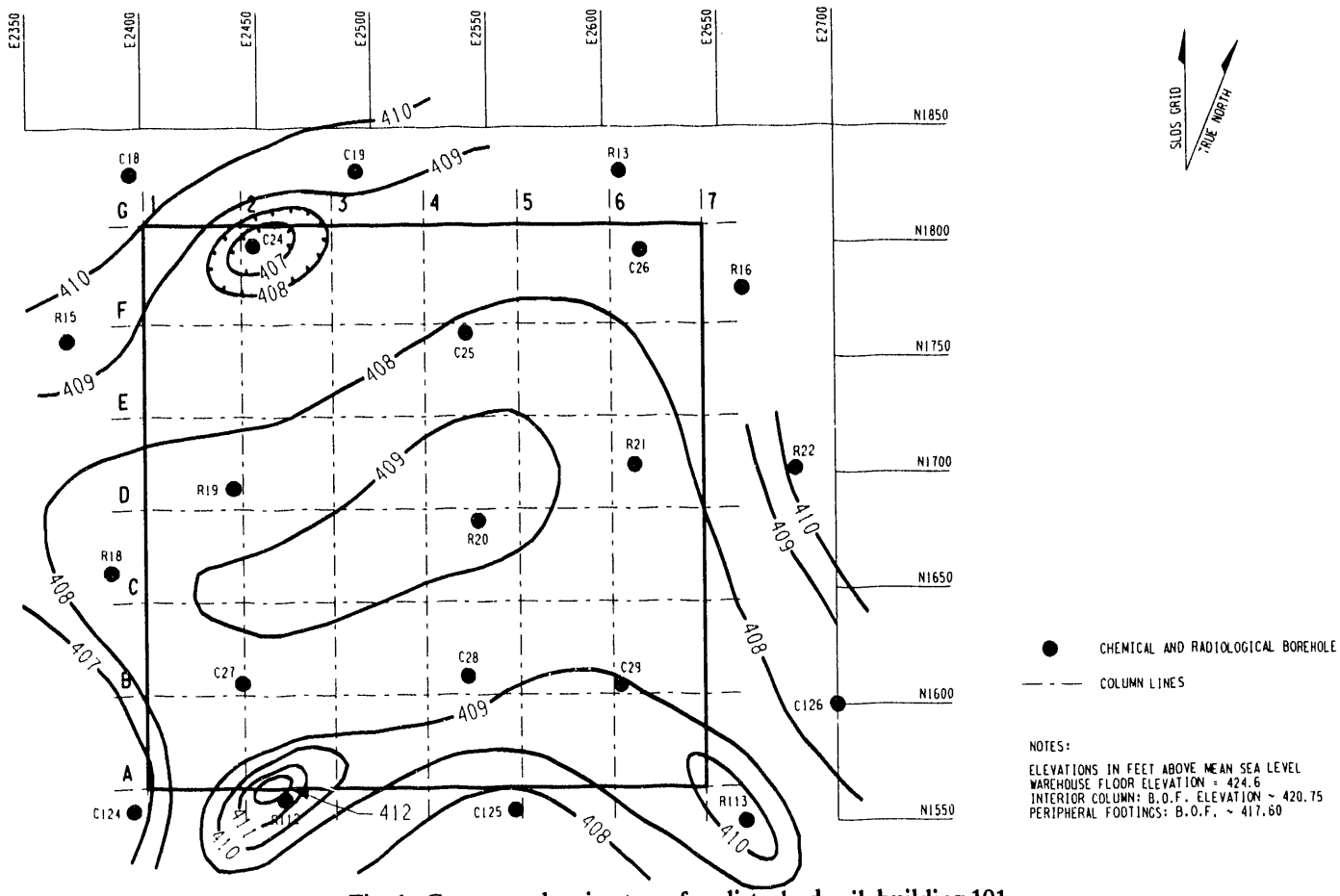


Fig. 1. Contours showing top of undisturbed soil, building 101.

the outer-bay secondary roof trusses of two opposing sides of the building and (2) to provide lateral support for all the peripheral columns. These two functions are normally served by a line of roof trusses that ties together the outside columns, independent of the closure wall. Thus, partial demolition of the wall can be accomplished without impairing the stability of the roof, in case extensions are anticipated to be added to the building in the future.

Soil and Foundation Conditions

Figure 1 also shows the location of the 21 chemical and radiological boreholes under and around this building and a contour plot of the surface of undisturbed soil beneath the rubble and fill extending to the surface. Almost everywhere under the building, the contamination extends throughout the thickness of the fill layer. This corresponds to a depth of up to 12.75 ft (3.89 m) below BOF. Footings are at elevation 420.75 ft (128.33 m) above mean sea level, and warehouse floor elevation is at 424.6 ft (129.55 m) above mean sea level. The dimensions of the main footings, based on column load and design contact pressure, are 15 by 15 ft (4.6 by 4.6 m).

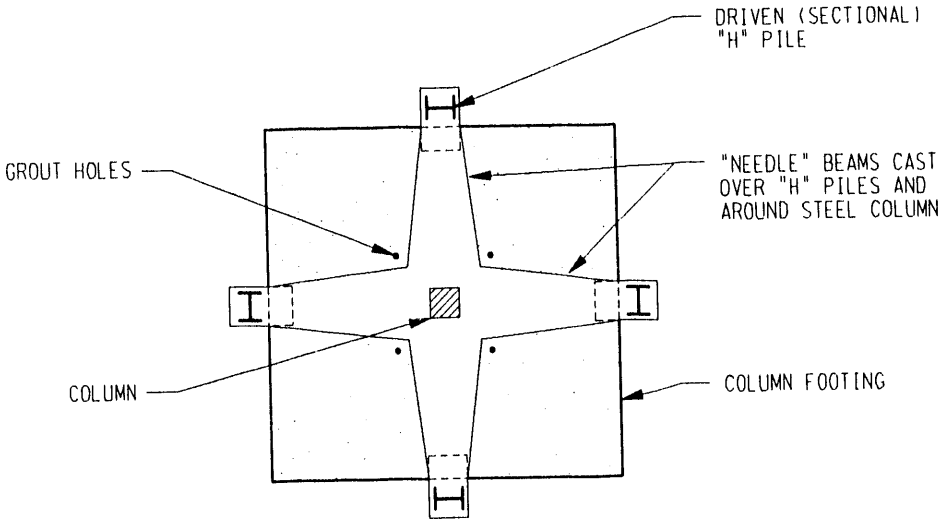
For the purposes of the preliminary underpinning feasibility study, the available soils information was considered sufficient, but for a final design an additional soils investigation will be required to define the engineering properties of the underlying strata to which the loads will be transferred. The undisturbed soil profile in the immediate vicinity of Building 101 consists of a series of alternating layers of clayey sand, silty sand, sand, and silt of medium consistency or density. The weathered limestone base is reached at depths of 60 to 70 ft (18.3 to 21.4 m).

Four of the borings indicate the existence of a localized perched water table at depths of 7.3 to 15.8 ft (2.2 to 4.8 m). The characterization report (1, see Fig. 6-47) shows that the elevation of the groundwater aquifer ranges from 395.0 to 400.0 ft (120.5 to 122.0 m) above mean sea level at this location. Consequently, in the preliminary evaluation, it was assumed that removal of contaminated soil will take place above aquifer groundwater level and that small volumes of perched groundwater will be disposed of by sump pumps lowered into the excavations.

Basic Underpinning Scheme

Before removing the contaminated material below BOF elevation, the underpinning of the affected columns must be completed. This will be accomplished by transferring the column loads to undisturbed strata below the estimated excavation depth by means of driven "H" piles tangent to each footing. Load transfer from the columns to the driven "H" piles is accomplished by use of "needle" beams (Fig. 2).

More often than not, a certain amount of reinforcement of the structure is necessary prior to underpinning, either to facilitate its execution or to prevent damage to the existing structure because of the underpinning work. In this case, it is recommended to construct the missing peripheral roof truss to replace the added-on functions of the closure wall. The closure wall and its footing are then demolished, and both inside and outside column footings are underpinned. The closure wall and its footing will be reconstructed after removal of contaminated soil and placement of compacted clean backfill have been completed.



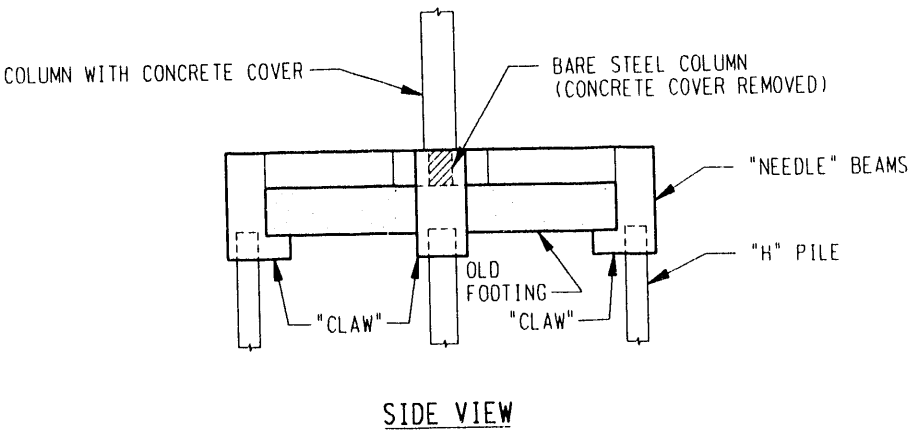


Fig. 2. Basic underpinning scheme, building 101.

The following sequence of events will be necessary to carry out the underpinning work prior to removal of all contaminated soil under and around the building:

- Reinforce the roof structure by construction of the peripheral roof trusses to support roof elements now resting on the closure wall and to provide alternate lateral support to outside columns.
- Demolish the closure concrete block wall and its foundation.
- Demolish the warehouse floor and excavate soil to BOF elevation.
- Install driven "H" piles on sides of each footing (Fig. 2). Because of headroom limitations, the piles will be driven to the required depth in two (or more) field-spliced segments. Piles will penetrate sufficiently into the undisturbed soil to provide the required load-carrying capacity of 25 tons each.
- Construct "needle" beams (Fig. 2) embracing the columns and capping the piles. This completes the underpinning work.
- Excavate the balance of contaminated soil to the approximate elevations shown in Fig. 1.
- After all contaminated material has been removed, backfill the excavation with clean compacted soil. Construct the new peripheral footing and wall and the floor slab. This will complete the remedial action for this building. Grouting through holes drilled on each footing to fill cavities that may exist between backfill and the underside of the footing will add the bearing area of the footing to the load-bearing capacity of the piles.

"Needle" Beams

The columns supporting the roof structure are steel sections encased in concrete. This concrete cover, between the top of the footings and the top of floor slab elevation, must be chipped out, exposing the steel column. Angles welded to the column and embedded into the concrete "needle" beams (or other similar means) are normally quite sufficient to transfer the load.

In order to diminish the bending moment of the cantilever "needle" beam, to limit deflections, and to hold the footing up,

a "claw" will be added to the end of each beam by excavating niches [1 ft (0.3 m) in depth] underneath the footings (Fig. 2).

BUILDING K-1 (PLANT 1)

This is a 2-story structure, built in 1941, to which some non-structural modifications were made in 1943. It has been used as a laboratory, and deep soil contamination exists particularly in the vicinity of its southeast corner. The building measures 125 ft (38.1 m) east-west and 62.5 ft (19.1 m) north-south. It has two longitudinal rows of columns with spans of 15.6 ft (4.8 m) east-west and 21 ft (6.4 m) north-south. Maximum column load is estimated to be 60 tons. The heavy masonry peripheral walls are load-bearing, transmitting about 10 tons per linear meter to the foundation. Figure 3 shows the column distribution and the logged soil data points in this vicinity. A design soil-bearing capacity of 2000 lb/ft^2 (10 tons/m^2) has been assumed. The resulting column footing is about 8 ft (2.4 m) square, and the bearing wall would rest on a strip footing about 3 ft (0.9 m) wide. BOF elevation is 4 ft (1.2 m) below floor slab, or 416.3 ft (127.0 m) above mean sea level.

Soil and Foundation Conditions

Only two of the seven borings (C-02 and R-03) show contamination of the soil below the elevation of the footings, limiting the extent of required underpinning to the southeast corner of the building (Fig. 3). Groundwater elevation closely coincides with BOF, and the contaminated soil extends approximately 10 ft (3.1 m) below the footings. Consequently, prior to soil removal, groundwater level will be lowered at this corner of the building by means of well points. Treatment of the effluent will be carried out as required, depending on the degree or type of contamination.

Basic Underpinning Scheme

The contamination depth established in boreholes C-02 and R-03 determines that the following load-bearing members will require excavations below BOF and, consequently, will also require prior underpinning (see Fig. 3):

- Column B-8
- Length of bearing wall [about 80 ft (24.4 m)] shown darkened in Figure 3

In underpinning work, precautions should be taken to prevent both vertical movement of the structure (settlement) and lateral displacement. Adequate horizontal bracing of the underpinning is vital. For column B-8, a solution similar to the scheme used in Building 101 is acceptable, that is, driven "H" piles on each side of the footing capped with cast-in-place "needle" beams.

Underpinning of the section of bearing wall will be accomplished by means of jacked piles [staked about 9 ft (2.8 m) apart] located underneath the wall's footing. However, this row of piles is vulnerable to lateral displacement after removal of the contaminated soil and before backfilling. Consequently, to prevent horizontal movement of the base of the wall, the underpinning structure must be braced to the neighboring columns. As shown in Fig. 4, transversal reinforced concrete beams tie the wall underpinning to columns B-6, B-7, and B-8. In the case of column B-8, the tie-beams connect directly to the "needle" beams on top of footing B-8.

The piles that transmit the wall loads (about 10 tons per linear meter of wall) to deeper firm strata cannot be driven

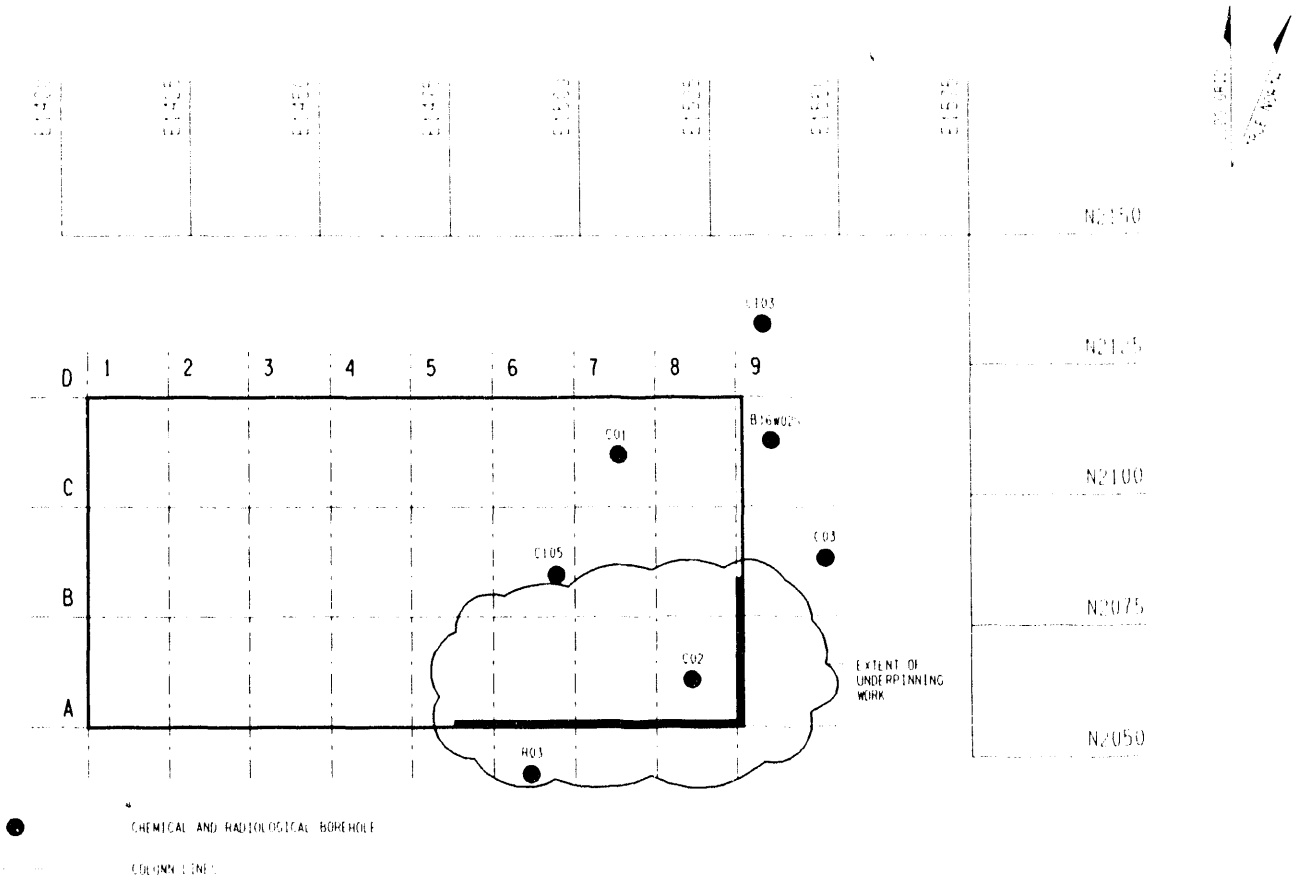


Fig. 3. Borehole locations, building K-1.

(as for Building 101 and column B-8) because they are underneath the strip footing itself. These piles are jacked down using the weight of the wall as a reaction. A design consideration is to determine whether the wall's strip footing has the longitudinal structural capacity to transmit the vertical loads to the jacked piles spaced 9 ft (2.8 m) apart. After excavation of the contaminated fill, the strip footing will act as a structural element spanning between the previously jacked piles. If the longitudinal structural capacity of the strip footing is adequate, the following steps are carried out after installation of the jacked piles.

- Excavate and construct a reinforced concrete longitudinal beam underneath the existing strip footing to tie the jacked piles together.
- Connect the transversal tie-beams to this new structural member, thereby providing adequate lateral bracing between the wall's underpinning and columns B-6, B-7, and B-8.

If, on the other hand, the existing wall strip footing has deteriorated or is structurally insufficient to bridge the wall load between piles, the following work will be necessary before the underpinning piles are jacked (Fig. 4).

- Construct a reinforced concrete beam in sections underneath the existing footing to provide the necessary longitudinal structural capacity. The length of the sections is a function of the structural (longitudinal) strength of the strip footing. This is a meticulous, slow, and delicate procedure, which must continue until the whole beam is constructed under the footing. It provides temporary support to the wall via its bearing area.

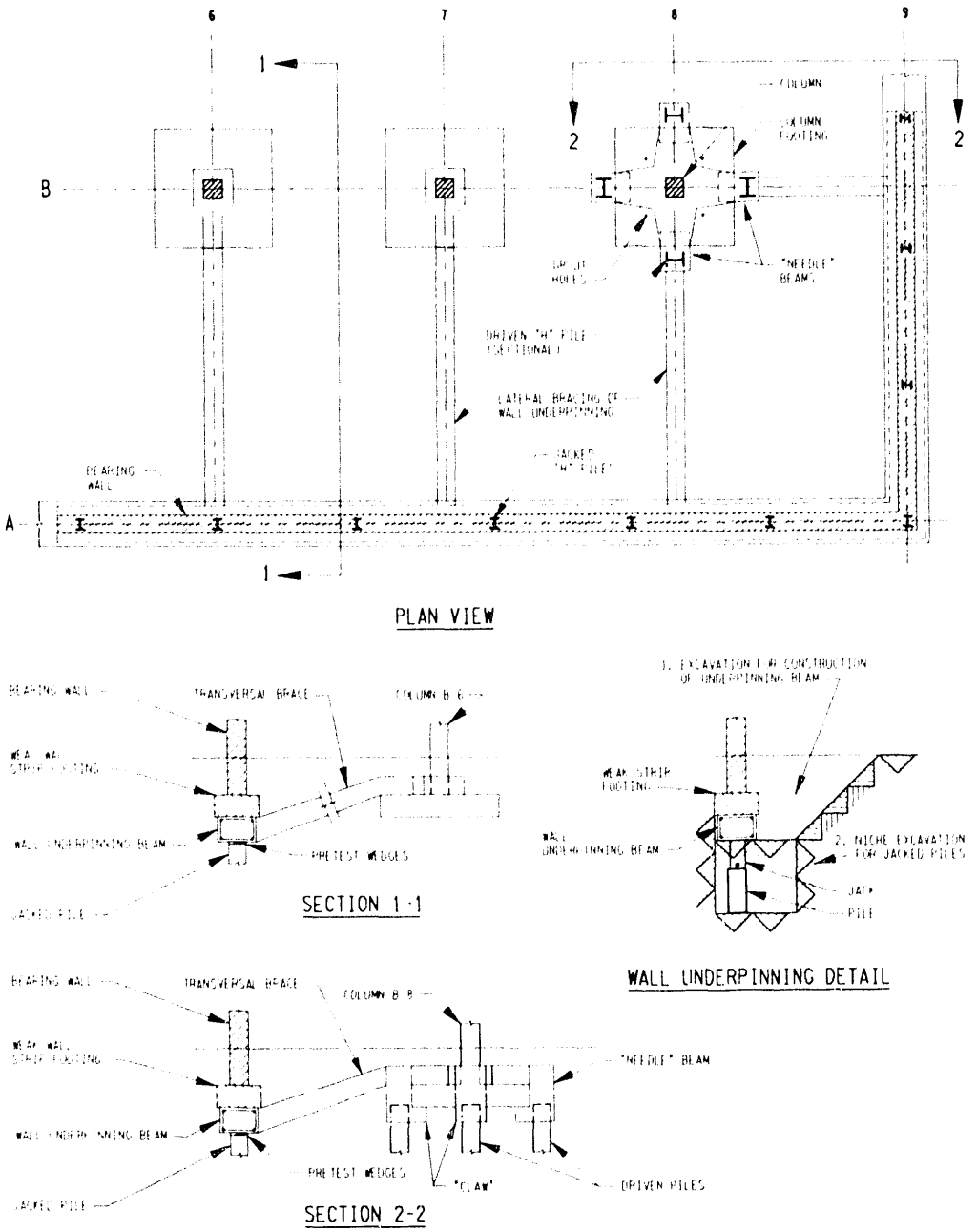


Fig. 4. Underpinning to support weak wall strip footing building K-1.

- Construct the transversal tie-beams between columns B-6, B-7, and B-8 and the underpinning beam to provide horizontal bracing, and proceed to jack the piles under the wall using its weight as a reaction.

Jacked Piles

The jacked piles consist of sections of field-welded "H" steel beam, each about 3 ft (0.9 m) long. The hydraulic jacks used to push the sections down are usually about 2 ft (0.6 m) long; a manometer is used to determine the reaction provided by the pile at a particular moment. It is customary to jack the piles until they reach a reaction of 1.5 times the future working load of the pile, in this case 30 tons. Control of the operation should be such that "ghost" reactions are not mistaken for final reaction in firm bearing material.

If the jack is removed when adequate reaction is reached, the pile will rebound a short distance. If a supplementary section of pile is then added (to fill the space where the jack was removed) and is wedged against the substructure, it will settle an amount equal to the described rebound, possibly affecting the structure when the actual working load is applied to the pile. To prevent damage from this type of settlement, the pile must be wedged against the substructure while the jack is applying full load to the pile. This is accomplished by placing a short cross beam over the pile and replacing the original jack by two jacks, one at each end of the cross beam. Full load is then reapplied to the pile. Because there is now a space between the jacks, centered with the pile, a short supplementary section of pile can then be inserted vertically over the cross beam and wedged against the foundation beam, with the pile under full load. The two jacks can then be removed, and no rebound occurs in the pile. This technique, called "pretesting," is an essential procedure in satisfactory underpinning practice. Underpinning with jacked piles is a delicate operation requiring specialized manpower and equipment.

CONCLUSIONS

A preliminary evaluation of the application of underpinning methods as an alternative to demolition and reconstruction of 22 buildings at SLDS indicates that, based on present subsoil knowledge, only two buildings (101 and K-1) would qualify as candidates for successful underpinning. To proceed with advanced designs, additional soils and groundwater information is necessary. As part of this field work, test pits must be made to determine actual footing sizes, depth, and condition. An exhaustive search of available design and as-built data is also necessary to establish structural strength and safety margins of key elements. Only then can final designs be developed.

This paper describes the process of analysis for an underpinning solution and provides additional elements of judgment to guide the decision in selecting demolition or underpinning. For Building 101, some structural reinforcement of the roof is necessary before underpinning the peripheral columns. The closure wall is impractical to underpin and should therefore be demolished and reconstructed. For Building K-1, the underpinning scheme can be either simple or complicated, depending on the actual structural integrity or strength of the outside wall footing. In either case, horizontal bracing of the jacked piles is necessary. Temporary groundwater depletion and disposition are required at the location of Building K-1, and perhaps also at Building 101. Comparative economic analysis based on the underpinning solutions described in this paper indicates a decisive advantage of underpinning over demolition and reconstruction. However, many additional factors, beyond the scope of this paper, must be considered before reaching a final decision.

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HEALTH-BASED CLEANUP GOALS AT HAZARDOUS WASTE SITES: IMPLICATIONS FOR RISK MANAGEMENT

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ABSTRACT

The challenge of setting realistic and well-defined remediation goals at hazardous waste sites is not being met. The majority of remedial alternatives are being selected without adequate evidence of their effectiveness and permanence. Remediation goals are being set that are not technically achievable. To correct this situation, DOE should focus on the fundamental areas of setting priorities in the remediation process and developing and selecting effective and permanent remedial alternatives.

INTRODUCTION

The Superfund Amendments and Reauthorization Act of 1986 (SARA) established more stringent requirements for remediating inactive hazardous waste sites in the United States. The central requirements are that remedial alternatives be "protective of public health and the environment" and "significantly and permanently" reduce the toxicity, mobility, or volume of contaminants. As a result, hundreds of decisions have been made to clean up hazardous waste sites to health-based levels using treatment technologies. These remedial action decisions reflect both the mandate's preference for permanently addressing contamination and the increased availability of quantitative toxicological data. A number of questions have arisen, however, regarding the definition, application, and feasibility of health-based cleanup goals at hazardous waste sites.

In an attempt to obtain an overview of the hazardous waste remedial action decision process, we performed an in-depth analysis of 50 of the 74 Records of Decision (RODs) at Superfund sites during fiscal year 1987. (1,2) The objectives of the study were to characterize the role of risk assessment in the decision-making process and to determine whether SARA is being implemented in an effective and environmentally protective manner. We found a large gap between expressed expectations for the Superfund program and reality. The program appears to suffer from a basic inconsistency between what society wants and what technology can provide.

The issues raised by our analysis of RODs and subsequent remedial actions center on the two fundamental elements of the decision-making process: setting priorities for deciding which sites to remediate and selecting cost-effective remedial alternatives that provide for effective and permanent cleanup. Remediation to health-based standards is being selected for almost all NPL sites without a systematic framework for using risk assessment as a priority-setting tool. At the same time, the majority of remedial alternatives are being selected without adequate evidence of their effectiveness and permanence, even at sites which pose an urgent threat to human health.

Not only are inadequate rationales for selection provided in the RODs, but many treatment remedies currently being implemented do not appear to be providing cost-effective solutions to the hazardous waste problem. Retrospective evaluations of the pump and treat remedy for contaminated groundwater indicate that aquifer restoration to health-based standards is not achievable within a reasonable time frame given the current state of technology. Moreover, few source treatment technologies other than incineration have been successfully implemented at Superfund sites thus far.

IS RISK ASSESSMENT BEING USED IN THE SUPERFUND DECISION PROCESS?

Although the Superfund remedial action decision process is a complex process that involves a variety of technical, political, and economic considerations, the primary goal of site remediation is the protection of public health. Therefore, assessment of the presence and magnitude of public health risks under baseline (no-action) conditions is a key element of the decision-making process. Travis and Doty found that risk assessment is indeed a central element of the Superfund decision process.[1] A quantitative baseline risk assessment had been conducted for at least one medium for 72 percent of sites where a remediation decision had been made. Thus, the central question is not *whether* risk assessment is being used at Superfund sites, but *how* it is being used.

Although many uncertainties inherent in risk assessment methodology may affect the precision of risk calculations, the key issue in terms of prioritization is not whether contamination exists and at what level, but which pathways of exposure are currently complete and which pathways are likely to become complete in the future. The answers to these questions do not come easily and require extensive information that has not been available to the risk assessor in the past. Since a risk assessment reflects risks at a site only to the degree that the assumptions used in the risk calculations reflect actual current or future site conditions, deficiencies in demographic data and other information regarding the likelihood of future exposure can be just as significant as can the lack of quantitative toxicological data. Approximately three-fourths of the sites on the NPL fall in the gray area of being potential public health concerns because of the lack of data needed to determine that the site is not a concern.

* Managed by Martin Marietta Energy Systems, Inc. under Contract No. DE-AC05-840R21400 with the U. S. Department of Energy.

IS EXPOSURE TO CONTAMINATION OCCURRING AT HAZARDOUS WASTE SITES?

There is a general belief that large numbers of people are being exposed to elevated health risks at hazardous waste sites. The facts do not appear to support this viewpoint. The Agency for Toxic Substances and Disease Registry reviewed 951 NPL sites and found only 11.5 percent with actual or potential current human exposure.(3)

IS THERE A CORRELATION BETWEEN RISK LEVELS AND DECISIONS TO REMEDIATE?

Risk assessment, the cornerstone of EPA's current decision-making process, plays a limited role in defining cleanup priorities. Eighty-eight percent of all sites reviewed were remediated, with little correlation between risk levels and decisions to remediate. All sites with contaminated soils remaining on-site were remediated, regardless of risk levels or the likelihood of migration to groundwater. Risk ranges for contaminated groundwater were essentially identical for sites that were remediated and those that were not. Remediation decisions appear to be driven more by cost, EPA policy, compliance with state and federal environmental regulations, and professional judgment than by current or future risk levels.

WILL REMEDIATION BE EFFECTIVE?

The selection of effective remedial alternatives is essential to the remediation process. However, remedial action decisions are currently made under a cloud of uncertainty regarding effectiveness. Sixty-eight percent of the remedies selected in Superfund decisions reviewed by Doty and Travis (1990) required additional studies to confirm the extent of contamination, the effectiveness of the technology, or its applicability under the site conditions.(2) Thus, despite the exorbitant costs of remediating sites currently on the NPL, remediation is not guaranteed at the majority of sites.

At some sites, the need for immediate action outweighs the necessity of resolving all uncertainties associated with a remedial alternative prior to selection. However, the majority of sites do not warrant such a degree of urgency. A fundamental need for Superfund is an expanded program to establish the effectiveness of remediation technologies and identify site-specific factors that influence effectiveness.

WILL REMEDIATION BE PERMANENT?

Another key factor in the attainment of remedial action goals is the selection of permanent remedies. Although SARA emphasizes the selection of permanent remedial alternatives, only 19 percent of the source remedies reviewed by Doty and Travis (1990) afford permanence to the maximum extent practicable.(2) Thirty-five percent of the remedies selected provide only a moderate (questionable) degree of permanence because the effectiveness of one or more components of the remedy has not been determined. Forty-five percent of the remedies provide minimal permanence because they provide for containment only, provide only partial treatment, or utilize a technology of questionable effectiveness and permanence. Thus, accomplishing any remediation goal is unlikely unless more attention is directed toward the development and selection of effective and permanent remedial alternatives.

CAN CONTAMINATED AQUIFERS AT HAZARDOUS WASTE SITES BE REMEDIATED?

The prevailing view among environmentalists and Superfund managers is that aquifers at hazardous waste sites can be restored through groundwater pumping. In fact, approximately 68 percent of Superfund RODs select groundwater pumping and treating as the final remedy to achieve aquifer restoration.(2) In the past, Superfund managers have displayed so much certainty regarding the effectiveness of pumping that most RODs simply state that pumping will continue until drinking water standards are reached, without presenting any analysis demonstrating that these standards are indeed achievable.

The simple fact is this: contaminated aquifers cannot be restored through pumping and treating. Two lines of evidence support this assertion. First, it is supported by extensive experience predicting the effectiveness of groundwater pumping using groundwater transport models. Leading groundwater scientists have predicted that continuous pumping for as long as 100 to 200 years may be needed in order to lower concentrations by a factor of 100, assuming the ideal conditions of a totally dissolved contamination in a homogeneous aquifer.(4-6) Aquifer restoration is less reliable at sites involving non-aqueous phase liquids (NAPLs) that either float on top of the water table or sink to the bottom of the aquifer. At best, even if eventual restoration is conceivable, it is impossible to predict how long pumping and treating will take to restore an aquifer.(4) In spite of this observation, aquifer restoration is the remedial objective at approximately 93 percent of the sites which are known to involve NAPLs.(7) The director of EPA's groundwater research laboratory in Ada, Oklahoma, has pointed out that restoration could take thousands of years for water-insoluble constituents such as jet fuel.(4) When large pools of dense NAPLs are present at the bottom of an aquifer, meeting drinking water standards is unachievable at any cost.(8)

Further proof of the ineffectiveness of pumping and treating for aquifer restoration comes from direct experience in pumping contaminated aquifers over the past 10 years. A recent EPA study involving 19 sites where pumping and treating had been ongoing for up to 10 years concluded that although significant mass removal of contaminants had been achieved, there had been little success in reducing concentrations to the target levels.(7) The typical experience is an initial drop in concentrations by a factor of two to ten, followed by a leveling out with no further decline. To exacerbate the problem, once pumps are turned off, concentrations rise again.

Take, for example, the IBM Dayton hazardous waste site in New Jersey.(7) Groundwater at the site was contaminated with approximately 400 gallons of VOCs, primarily 1,1,1-trichloroethane (TCA) and tetrachloroethylene (PCE), with maximum groundwater concentrations ranging from 9,590 ppb for TCA to 6,132 ppb for PCE. Pumping with an average onsite extraction rate of 330 gpm between 1978 and 1984 lowered VOC concentrations to below 100 ppb. However, subsequent to shutdown of the operation in 1984, PCE concentrations rose to 12,558 ppb in 1988. Pumping was resumed in 1989, but the remedial objective was changed from restoration to containment. Thus, despite extensive groundwater pumping, this site is no closer to remediation than it was twelve years ago.

DISCUSSION

Thus far, the challenge of defining terms and setting realistic and well-defined goals for hazardous waste sites has not been met, and money is being spent with no guarantee that the program is providing adequate protection of public health and the environment. Inadequacies in the decisions we reviewed consist of both the lack of clear priorities in deciding which sites to remediate and to what degree a site should be remediated, and the lack of selection of remedial alternatives which afford effectiveness and permanence. As a result, the majority of resources are being directed toward the remediation of many low-risk sites using remedial alternatives of questionable effectiveness.

The present decision-making process reflects an ambiguous approach to addressing risk. Many sites are being cleaned up where no actual human exposure exists and potential public health risk is unlikely. Thus, minimization of the extent of environmental contamination per se seems to play a larger role in the selection of remedial alternatives than does protection of human health. The degree of risk reduction associated with the remedial alternatives considered is rarely evaluated quantitatively, and thus, cost-effectiveness discussions are undermined. Because the remedial alternatives selected often lack effectiveness and permanence, protectiveness of public health and the environment cannot be expected, even in cases where current human exposure to contamination does exist.

RECOMMENDATIONS

To meet the challenge of effectively remediating hazardous waste sites, we recommend a "worst sites first" policy, balancing a clear definition of worst sites with attainable expectations for addressing these sites. Therefore, DOE should focus on the fundamental areas of setting priorities in the remediation process and developing and selecting effective and permanent remedial alternatives.

Priorities in the Decision-Making Process

Goals and priorities need to be more clearly defined in the decision-making process. More emphasis needs to be placed on: (1) immediately identifying and remediating sites which pose a clear and present risk to human health; (2) prioritizing remediation sites on the bases of risk and achievable risk reduction; (3) making the extensiveness and effectiveness of remediation correspond with the degree of current and/or future risk; and (4) establishing realistic goals given the state of technology, acknowledging that aquifer restoration is currently not technically feasible, and recognizing that attempting to restore the environment to a pristine state is not always necessary.

Effectiveness and Permanence of Remedies

More attention needs to be directed toward determining the effectiveness of remedial alternatives selected. First, quantitative assessments of the degree of risk reduction associated with remedial alternatives should be conducted. Second, there is an urgent need for DOE to accelerate efforts in the areas of both field research and theoretical studies to demonstrate the effectiveness of classes of treatment alternatives under various field conditions. Environmental variables (i.e., soil type, pH, microbial content) should be identified that can be used to predict the effectiveness of a remedial alternative under a given set of environmental conditions. Without such information, DOE will select alternatives for which effectiveness is uncertain.

Discontinue use of Applicable or Relevant and Appropriate Requirements (ARARs) as Cleanup Goals for Aquifer Restoration

Current policy at Superfund sites is to select the most stringent ARAR as the cleanup goal for the site. This policy is unrealistic and misleading. Not only is restoration of contaminated aquifers to levels compatible with ARARs simply infeasible, but the continued pursuit of this objective creates false expectations on the part of Congress and the public. Reliance on ARARs simply postpones the necessary realization that the best that can be accomplished at contaminated sites today is plume containment and contaminant mass reduction.

Make Plume Containment and Contaminant Mass Reduction Primary Remediation Goals

Although pumping is ineffective for aquifer restoration, it has great value for plume containment and contaminant mass reduction. The record shows that a significant fraction (up to 50%) of the mass of contaminants can be recovered from contaminated groundwater either through pumping or in conjunction with vapor extraction. Action should be taken early to contain the containment plume (before the Remedial Investigation/Feasibility Study process is complete) because even small delays can exacerbate the problem. Plume containment should be the stated objective in the ROD, and remedial designs should reflect this objective.

Recognize That Restoring Aquifers To a Pristine Condition Is Not Always Necessary

Not all aquifers are created equal, either in terms of original water quality or in their potential future uses. Therefore, a more flexible approach to remediation is needed. For contaminated aquifers that are near current sources of drinking water, every effort must be made to contain the plume indefinitely. However, for aquifers that are unlikely to be drinking-water sources, total restoration may not be necessary, and pumping for mass reduction for 3-5 years followed by natural attenuation (dilution) may be sufficient. Because natural attenuation is rarely considered as a remedial alternative for Superfund sites, guidelines for the selection of this alternative need to be developed.

Enhance Efforts To Protect Groundwater

Once groundwater is contaminated, restoring it to a condition compatible with health-based standards is difficult, if not impossible. Remedial efforts should, therefore, focus on developing and implementing permanent, cost-effective source control remedies. Efforts should be made to prevent future contamination and to assign a high priority to waste minimization efforts. Recycling should be encouraged by the federal government, and a realistic national policy on recycling needs to be developed. Prevention is the most critical element of a sound groundwater management strategy, and current policy at Superfund sites shifts attention and resources away from this strategic priority.

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MEETING HEALTH-BASED STANDARDS AT HAZARDOUS AND MIXED WASTE SITES: ARE WE DELUDING OURSELVES?

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ABSTRACT

Achieving health-based standards is clearly a desirable goal in hazardous and mixed waste remediation. However, the application of such standards is only appropriate if they can be applied with reasonable accuracy and the criteria met using available technology. This paper contends that for a substantial number of sites, health-based goals cannot be applied with the necessary accuracy. Furthermore, it is problematic as to whether current technologies can achieve those standards. The paper outlines the uncertainties and complexities that undermine the current risk assessment and site remediation processes. The paper concludes with a discussion of how uncertainty can be managed during remediation using techniques derived from geotechnical engineering -- the observational method.

INTRODUCTION

Risk assessments seek to combine the best available information about the exposure and toxicity of chemicals to make qualitative or quantitative statements about the existing or potential impacts of exposures. The U. S. Environmental Protection Agency (EPA) uses a risk assessment process as a determinant for action at hazardous and mixed waste sites. The EPA's risk assessment guidelines prescribed under the recent revisions to the Superfund National Contingency Plan seek to produce estimates of the "baseline" risk posed by a site if no remediation efforts are made. The key parameters of health risk are estimated and used to calculate a target remedial goal for contaminant concentrations at the site.

In practice, however, the EPA's risk assessment process is not proving effective. Critics contend that it has been "virtually a total failure in successfully achieving community acceptance and speed or permanency of cleanup....the risk assessment model is regarded with extreme suspicion because it is so difficult to understand and because it is based on flawed and inadequate scientific evidence about health effects. Most regard it as a bureaucratic fast shuffle designed to rationalize the convenient at any given site....the risk assessment model has resulted in a further downturn in the Superfund program's credibility with waste site communities" (1).

Providing another view, Doty and Travis (2) have examined 50 post-SARA records of decisions (RODs), and have concluded that the estimated site risks had little role in determining whether and how the sites were remediated. The site decisions appear to have been based more on the presence of contamination rather than on a consideration of risk. Their recommendations include increasing the role of risk assessment in site decisions by urging that "quantitative assessment of the degree of risk reduction associated with remedial alternatives is needed."

This paper examines the risk assessment process, and the large uncertainties attendant to each of the steps of a risk assessment for site remediation. This paper contends that the current application of risk assessment as a decisionmaking tool in the site remediation process is incorrect. For complex sites the huge uncertainties inherent in the risk estimates make it impossible to discriminate reliably among remedial alternatives. Furthermore, the current process cannot resolve the inevitable arguments among the stakeholders over tradeoffs between risk and remedial cost. The paper concludes with a discussion of a different approach for managing uncertainty.

EPA'S CURRENT RISK ASSESSMENT PROCESS

In 1983 the National Academy of Sciences defined risk assessment as "the characterization of the probability of potential adverse effects from human exposures to environmental hazards" and denoted its four basic components: hazard identification, dose-response assessment, exposure assessment, and risk characterization. EPA's version of the risk assessment process, including its application to hazardous waste sites, is similar and includes these four basic steps:

1. The identification of contaminants and their locations on the site.
2. A toxicity assessment, identifying the toxicological properties of the contaminants and the types of hazards or health effects associated with exposure to them.
3. An exposure assessment, identifying how people, animals, or sensitive environments may be exposed to contaminants from the site, including identification of the mechanisms for release and transport and of pathways by which exposures can occur; characterization of the potentially exposed populations and environments; and identification of exposure points, exposure routes (e.g., breathing or drinking), and the expected frequency and duration of the exposures.
4. The risk characterization, which integrates the information developed during the toxicity and exposure assessments in order to estimate the potential risk to public health and the environment from exposure to site contaminants. The risk characterization can be quantitative or qualitative depending on the type of information available.

Given the enormity of the remediation problems and the limited funds available, this process appears to be compatible with EPA's goals of solving the most important problems first and making the best use of Superfund dollars. The process seeks to conserve limited funds by remediating to "acceptable" levels. That is, following remediation, the hazardous materials that remain on site should pose a very low level of residual risk as determined by the risk assessment. One of the primary assumptions is that the technologies are available to accomplish the tasks of assessing the risk, determining acceptable risk, and successfully implementing the remediation (see Fig. 1).

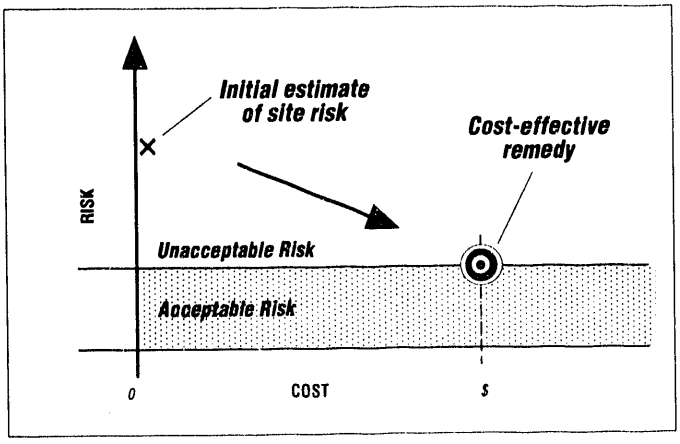


Fig. 1. Risk assessment and remedy selection, as assumed by the EPA process.

Many people believe that it is possible, and necessary, to develop quantitative and accurate risk assessments that will simplify risk management decisions and speed up the remediation of hazardous waste sites. Recently, EPA has sought to clarify its guidelines by narrowing the range of risk levels that determine when a decision can be made to undertake protective measures. EPA previously chose a conservative range of levels, specifying that action was acceptable if the excess lifetime cancer risk posed by contaminants at a site was assessed within the range of $1x10^{-6}$ to $1x10^{-4}$, or between one additional cancer case per million and one per ten thousand exposed population. An April 1991 directive from the Office of Solid Waste and Emergency Response raised the recommended decision criterion for taking action to a cancer risk level of $1x10^{-4}$ or more (3).

The belief continues, however, that risk assessments can be quantified with a significant and reliable degree of accuracy. EPA is far from alone in this belief. A recent example was a June 1991 proposal to the Bush administration from the Institute for Regulatory Policy (IRP), calling for an executive order on health and environmental risk assessment that would "provide uniform centralized guidance designed to make risk assessments as scientifically objective as possible" (4).

IRP's proposal was presented with the goal of removing political considerations from the guidelines governing risk assessment techniques and decisions, thus making the process an objective, purely scientific one that would resolve many of the issues currently disputed in the courts. However, the underlying assumption, again, is that practitioners can link with reasonable accuracy the health-based target risk levels with measurable concentrations of contaminants in the field. This is one of a number of false assumptions that have governed environmental protection and waste remediation efforts for too long, which are:

- We can estimate with reasonable accuracy the risk posed by a hazardous or mixed waste site, using current technology.
- We can determine what "acceptable" risk means to the stakeholders, defensibly and consistently.
- We can reduce this risk to "acceptable" levels by applying remedial technology.
- We can show convincingly at any given site that acceptable risk has been achieved.

Except for simple hazardous and mixed waste problems, these assumptions are incorrect. This is because of the nature of the waste contamination problem and the low state of development of the technologies to cope with it. As Paulson observes (5), "in dealing with the policy aspects and the public's perception regarding soil and ground water contamination, both public demands and policy imperatives have sought far more certainty than current technical capabilities can deliver in a reliable, effective, and timely manner." Hall adds, "At our present state of knowledge, the health risks associated with exposure to a chemical cannot be accurately characterized by a single number or even a range of numbers.... The most serious potential danger associated with the use of health risk assessment is the failure to recognize its limitations and uncertainties." (6)

The desirability of universal and scientific health-based standards to govern risk assessments is clear, but we are deluding ourselves if we think we can comprehensively develop and implement such standards. The problem lies in the difficulty of achieving concrete standards for risk assessment and risk management in the face of substantial uncertainty associated with the components of the risk assessment.

UNCERTAINTIES AFFECTING RISK ASSESSMENT AND SITE REMEDIATION

Engineers and scientists are beginning to understand that there are some basic flaws in the currently accepted waste remediation process. They derive from a misapplication of technology to the problems faced. Simply stated, there is a widespread lack of understanding of three primary elements in risk assessment and site remediation:

- the inherent complexities of the waste problems,
- the uncertainties that result from these complexities,
- and the inability of our current technology to reduce these complexities to manageable levels.

As McCarty puts it (7), "The scientific knowledge of the many complex questions involved and the technology for restoring contaminated subsurface environments still are quite primitive, largely because of the short time frame over which subsurface contamination problems have been addressed seriously." Uncertainties affect each component of the risk assessment process, as described below.

Identification of Contaminants and Their Locations

"Envision an extremely complex, three-dimensional maze in which are lost a variety of chemicals--some concentrated and localized, and some dilute and spread out. Imagine further that the chemicals are all moving at different rates and directions as a result of gravity and/or the flow of air and water through the maze. Then imagine that the internal walls of the maze are porous, like a hedge, and that the chemicals, air, or water can move into and even through them at rates that vary throughout the maze. Lastly, imagine that you must find and remove all of the chemicals but cannot enter the maze to do so. This, in essence, is the problem confronting those trying to clean up contamination of the subsurface" (8).

Mackay's metaphor effectively depicts a subsurface environment that is fraught with uncertainty. With site remediation, it has been assumed that the complexities in the subsurface would eventually yield to improved sampling techniques, better fate and transport models, or more data. It is now clear, however, that the subsurface is a highly variable media in which small aberrations or changes (e.g., cracks in

rock) can have substantial impacts on water and chemical movement, and lead to large differences between model predictions and observed results. Hazardous contaminants may also be found in widely varying concentrations and potency throughout a heterogeneous subsurface environment. Spaces between sampling points hide these elements of the subsurface, and the conventional sampling methods cannot identify all the significant geologic conditions that could impact the movement of contaminants, such as sand lenses, fractures in rock, or impervious layers. They are also incapable of extensive detailed assessments of soil properties that could affect the movement of contaminants. The questions to which the technologist needs answers are beyond the abilities of the available subsurface characterization techniques.

In a complex and heterogeneous subsurface, as McCarty notes (9), "layering of permeable (sands and gravels) and less permeable (silts, clays, and rock) strata are common and may contain discontinuities that could result from [illegible] or large-scale stratigraphic features. Conductivity of water and contaminants through rocks and other barriers may result from joints and fractures that are difficult to locate and to describe. The mixture of gravel, sand, silt, clay, and organic matter of which the subsurface environment consists can vary widely from location to location, as can the grain-size distribution and mineral composition within each broad class of subsurface strata. In addition, past construction of wells that are perhaps now abandoned and forgotten often can provide passage ways between separated aquifers. Such complex systems are all too common, and when contaminated they provide some of the most challenging and difficult situations for restoration."

The direct methods of subsurface drilling and groundwater sampling are still the technologies primarily used to locate and identify quantities of waste. These methods permit a general stratigraphic characterization of a site, the extrapolation of general soil composition and physical properties from single-point measurements, and identification of groundwater quantity and quality at well locations leading to extrapolation of the quantity and quality of water available from an aquifer. However, even if the site investigation team "honeycombs" the site with soil borings and monitoring wells (at enormous expense), it will never be able to say with confidence that all significant contamination has been identified, or that sufficient site characterization has been achieved.

As Mackay notes (10), "the common analyses of aquifer tests (pump tests) and core samples miss slight but important stratification within the permeable media and generally do not address the characteristics that control the relative mobility of contaminants (i.e., sorption capacity of the solids for contaminants)....Monitoring wells must be carefully located and installed to yield representative samples or head determinations from precise known intervals in the subsurface. Unfortunately, it appears that this is not always the case. Anecdotal reports indicate that the screened intervals of monitoring wells often are uncertain, especially for older wells. Furthermore, the screened intervals generally are rather long (10 feet or more), which may in some cases dilute understanding of contaminant distribution, particularly where there is significant geological variability and where contaminants are likely to be present or moving in narrow strata."

At Love Canal, extensive investigations provided over 2,600 borings on 40 acres, yet the soil volume analyzed was still only 0.01 percent of the site. The cost of retrieving this kind of data is prohibitively expensive, yet even intensive sampling cannot obtain a truly accurate portrait of fine details such as cracks and sand lenses in the substrata. Groundwater monitoring wells and soil borings can detect or define areas of contamination only if the contamination is spread over the site in a volume large enough to allow detection. The chances of locating small quantities of highly potent contaminants are very low. Thus, significant quantities of contamination can elude the best site sampling efforts.

Newer techniques such as ground-penetrating radar, vapor detection, and resistivity can also provide general stratigraphic assessments and locate medium to large areas of contamination as well as objects like drums. But with their low resolution and ranges limited to shallow depths, these techniques are not accurate enough to pinpoint small deposits and are therefore incapable of locating all significant quantities of contamination. Waste quantities as small as 100 liters can contaminate an aquifer: 100 liters of trichloroethene released into an aquifer containing 3×10^{10} liters of water can contaminate to levels above the 5 microgram per liter criterion.

Toxicity Assessment

Toxicologic and epidemiologic studies can provide estimates of the toxicological effects of single chemicals and permit the establishment of emission standards for regional exposures and workplace exposures applied to general populations for single chemicals. In general, however, the science of toxicology is still at an early stage of development. Substantial scientific work is needed yet on the characterization of potential effects of toxic substances, dose-response functions, potential synergistic or antagonistic effects, and the translation of animal data to humans. Most current models are highly inaccurate at low dose levels. It is also very difficult to accurately determine how compounds will behave if released into environmental media, such as air, soils, or water; the compound may break into individual components, degrade, or metabolize into new constituents. Furthermore, substantive toxicological information is available on only a fraction of the chemicals in commercial use.

Kunreuther and Gowda (11) have pointed out that "chemicals compose a significant portion of [hazardous] wastes, but of the 65,000 commercial chemicals identified as being currently marketed, there is little or no data on their potential to cause cancer, birth defects, or chronic diseases. A recent National Academy of Sciences report concluded that sufficient information to complete a health hazard assessment is available for less than 2% of commercial chemicals. Exposure data are quite poor, and most testing for toxic effects has focused on cancer rather than reproductive and neurological disorders or on other chronic problems. Almost nothing is known about the synergistic effects of exposure to combinations of chemicals."

Also, as noted by McCarty (12), "Transformations of many of the most common ground water contaminants of concern do occur, often producing other chemicals that are sometimes more hazardous than the original. Unfortunately, knowledge of what environmental parameters to measure and how to interpret them properly in order to predict the transforming potential in a given subsurface system currently is quite primitive....we do not yet have adequate techniques for determining how the biological population at a given site will respond to a given contamination insult, the changes in the chemical environment that will occur if they do respond, and what chemical changes in mixtures of chemicals actually will occur. Today we have a better understanding of what

transformations can occur and why, but we still lack an ability to make adequate predictions of rates from observed surface chemical and biological characteristics."

Exposure Assessment

The methods used to estimate how contaminants may reach receptors, through transport studies and models applied to such areas as groundwater movement, can accurately assess saturated groundwater flow in porous media, and therefore solve with reasonable dependability problems in groundwater resources and water supplies. General exposure assessment studies can provide estimates of the exposure mechanisms of single chemicals for large populations. Comprehensive waste remediation, however, requires accurate estimates of the fate and transport of significant quantities of contamination in both saturated and unsaturated zones. Again, the contamination could consist of very small volumes of highly potent chemicals, ranging from insoluble to highly soluble; they may have widely varying affinity to soils, may react with each other or with surrounding soils in varying ways and time periods, and may be characterized by multi-phase flow in widely heterogenous media. Accurate risk assessment and effective remediation require accurate data on these subsurface activities and must provide good estimates on how specific populations would likely be exposed to significant quantities of a wide variety of chemical contaminants; but our current technologies and methods are not up to the task.

Groundwater remediation efforts, for example, have "relied on the removal of ground water contaminants in the dissolved form (i.e., through so-called pump-and-treat programs)....In many cases, organic contaminants have been released to the subsurface as nonaqueous-phase liquids (NAPLs), which are immiscible with water (e.g., chlorinated solvents--trichloroethene (TCE), tetrachloroethene (PCE), etc.--and petroleum hydrocarbons--gasoline, aviation fuel, oil, etc.)....the migration of significant volumes of NAPL within the subsurface may follow complex paths, resulting in the distribution of NAPL in large and small pools and also in zones of residual saturation (containing myriad droplets and/or ganglia of NAPL). This distribution of NAPL may be widespread relative to the areal size of the source, owing to heterogeneities of the subsurface. A review of information from relatively well-documented sites of known NAPL contamination indicates that the mass of contaminants present in the NAPL form, even years after the contamination originated, may be much greater than that dissolved in the resulting ground water plume.

Cleanup programs for such sites clearly should be designed on the basis of information on the distribution and behavior of the NAPL masses. Unfortunately, neither type of information generally is available or adequate. Although NAPLs less dense than water can often be located in pools floating on the water table, there is little known about their behavior during remediation (i.e., dissolution by ground water flowing beneath the pool, effects of smearing of the NAPL mass within the aquifer as the water table rises and falls from pumping or natural events, and so on). For NAPLs more dense than water, which in some cases may migrate downwards below the water table, the situation is worse: there are no reliable methods for location of the NAPL mass within the saturated zone and little understanding of the rates at which NAPL in various distributions (droplets, pools, ganglia, etc.) will be dissolved by flowing groundwater" (13).

Not surprisingly, the current fate and transport models are subject to substantial differences between model predictions and observed results. Also, "models can take on a certain rigidity that makes them resistant to change even when fairly compelling evidence has accumulated pointing to the deficiency of the model....Perhaps the clearest current example is the quite legitimate concern about dense, nonaqueous pollutant layers that are a common feature of sites involving significant quantities of chlorinated solvents. This phenomenon casts a whole new light, a rather depressing one indeed, on the use of most ground water models that have been used to predict transport of these classes of contaminants in aquifers" (14).

The toxic dose that might be received by a receptor is another element of the exposure characterization that is subject to great uncertainty. The dose will depend on the activities of the receptor (e.g., residential, industrial, or recreational activities), as well as the conditions of the exposure media (soil, air, water, or biota) and the exposure route (ingestion, inhalation, or dermal contact). Uncertainties here range from inadequate knowledge about receptor activities to lack of models for some exposure routes and unknown chemical-specific parameter values. The huge number of variables renders us for the most part incapable of making exposure predictions with the precision and accuracy necessary to discriminate among alternatives.

In summary "...the risk assessment process is deliberately over-predictive. There is no scientific proof concerning whether or not very low concentrations of chemicals cause adverse health effects, and proof is unlikely to exist in the near future....There are at least 50 health-protective policy assumptions used in the quantitative risk assessment process because of a lack of scientific certainty (e.g., that the dose-response curve is linear at low doses). A quantitative risk, therefore, is not a realistic prediction of the effect of exposure" (15).

Effectiveness of Remedial Technologies

The current scheme for hazardous waste site remediation relies on the proposition that we have the necessary technologies to effectively manage and eliminate hazardous waste. Treatment technologies such as incineration, neutralization, carbon adsorption, and air stripping are able to treat or destroy a limited number of known substances and waste streams under carefully controlled conditions. But these technologies must be able to treat and destroy all substances, both known and unknown, mixed in soils and water in multi-phase flow and in widely varying concentrations. The technologies must be able to perform under a wide range of field conditions with highly variable input streams....All this while alleviating public concern over the emissions from remedial processes like incineration.

For the most part, the technologies used for hazardous waste site remediation have not been proven to be effective, and remain in a low state of development. Many of them have been adapted from chemical process technologies on process streams of known composition. Many have reached the laboratory or pilot stages, but performance under laboratory conditions does not guarantee performance under field conditions. Worse, as Downey notes (16), "laboratory results too quickly have been translated into a "technology success"....Laboratory panaceas often have led the public to expect far more than field engineers can deliver....Rigorous laboratory methods can be costly and time-consuming, but shortcuts in the laboratory inevitably will yield embarrassment

and waste in the field." Even when technologies have been shown to successfully destroy particular waste streams, effectiveness for one waste stream does not mean effectiveness for another. Canter (17) notes "the frequent selection and use of technologies previously used for other sites without considering the uniqueness of the cleanup needs at the particular site in terms of hydrogeology, contaminant characteristics and combinations, contaminant treatability, and limitations of the technologies themselves." In general, the remedial technologies have not demonstrated sufficiently reliable performance to enable engineers to confidently select them for more than a few remediation efforts.

Canter also notes (18) that "many cleanup programs are focused on only one aspect of the site problem. Thus, these programs are not completely addressing all of the needs at a given point in time. Examples of this piecemeal approach include (1) contaminant source remediation without cleanup activities for the unsaturated and saturated zones, (2) ground water remediation without source control and unsaturated zone cleanup, and (3) soil and ground water remediation without source control."

SITE (the EPA's Superfund Innovative Technology Evaluation program) seeks to foster new and effective cleanup technologies. Numerous new technologies have so far been accepted into the program and overall this is a move in the right direction. But the Office of Technology Assessment's evaluation of cleanup efforts at 10 Superfund sites found that unproven SITE technologies had already been used prematurely at Superfund sites. The OTA found much else to criticize, including "There is no clear line between sufficient and insufficient technical and economic data for selecting among cleanup technologies....The information used to compare treatment technologies is often inaccurate and incomplete....The chemical character and complexity of site contaminants and how they affect the use of some technologies do not get enough attention." (19)

Risk Characterization

In light of all these uncertainties, it is hardly surprising that our current interpretation of risk assessment is subject to fundamental and fatal flaws. Accurate and defensible risk assessments require the ability to handle problems in non-discrete, highly heterogeneous chemical, physical, and biological systems. Again, we are unable to make predictions with the precision and accuracy necessary to discriminate among alternatives. Many of the critical parameters in these heterogeneous systems are not quantifiable. The current risk assessment application is governed by too many simplifying assumptions about the nature of a site and the location, quantity, movement, fate, and dose-response of a multitude of contaminants of concern. We delude ourselves that we can provide accurate risk assessments when too often we cannot, with dire consequences if something goes wrong in this high-stakes field.

The objective of a risk assessment is to assemble the best available information about the risks associated with some activity. It cannot provide more than a systematic organization of what is known and what is unknown. Our delusion occurs when we forget how much we do not know, and have simplified the problem to make it tractable. Freeze et al. (20) have recognized this uncertainty, and have developed a decision analysis method for the explicit inclusion of uncertainty in engineering design in which the hydrogeological environment plays a significant role.

Paulson summarizes: "Risk assessment is a relatively new tool and, as such, is still relatively crude. While advances have been made, there is still the need to use a substantial amount of judgment, rendering the tool potentially less useful than policymakers would like; generally, this also leaves an affected community skeptical....the assessment process as a policy tool all too often founders on the shoals of inadequate amounts of more fundamental information, ranging from the movement of contaminants in soils and ground water and the specific routes and levels of exposure to the pharmacokinetics of individual contaminants in mammalian systems" (21). Doty and Travis (22) include recommendations that "Superfund policy-making should focus on the fundamental areas of determining: (1) when health-based cleanup goals are necessary, and (2) when attaining such goals is feasible."

DISCUSSION

Many thorny problems have resulted from the misguided faith in risk assessments. The fundamental flaws in our understanding of hazardous waste remediation, coupled with an implicit sense of urgency to remediate, have compounded the problems and delayed progress. Regulators have been put under great pressure to assess potential risks and perform remedial activities at waste sites, regardless of whether the technology is available to achieve effective remediation. R&D efforts have been displaced in favor of a "let's go do it" approach that has delayed development of the necessary assessment and remedial technologies. Engineers and scientists have been sent out into the field without a proper understanding of the problems they face and without the necessary scientific backup, or the tools necessary to solve the problems.

Among waste site communities, public expectations of the rapid remediation of waste sites were artificially raised. With the results less than expected, there has been considerable public outcry and loss of faith in those charged with implementation. The huge uncertainties associated with the assessment of risks have also enabled opposing parties to produce valid counterclaims against the assessments and decisions of others. It is relatively easy for any stakeholder to craft an alternative set of equally credible assumptions to dispute the assertions of another (23). The inability of the current system to discriminate among alternatives is depicted in Fig. 2. Because of the "high stakes" nature of the problem ($tens of millions per site, risk to public health and the environment), the remedial decisions are highly contentious. Regulators and potentially responsible parties are spending considerable time and resources on technical studies disputing the contentions of others, or trying to prove the unprovable. But current technology cannot provide defensible answers to questions like "How clean is clean enough?" or "Who is at fault?" All of this further damages public confidence in the risk assessment and site remediation programs, and prolongs the remediation process.

In summary, the process for selecting and remediating hazardous wastes sites is based on the presumption that by using current scientific and engineering techniques, it is possible to determine the location of significant quantities of contaminants, accurately determine the risks associated with these contaminants and what constitutes "acceptable" risk, and devise a remedy that will reduce the risk to "acceptable" levels. This is simply not the case. The technologies available today cannot locate all significant quantities of contaminants in the subsurface of a site, nor can they provide reliable assessments of how those contaminants will behave. They have

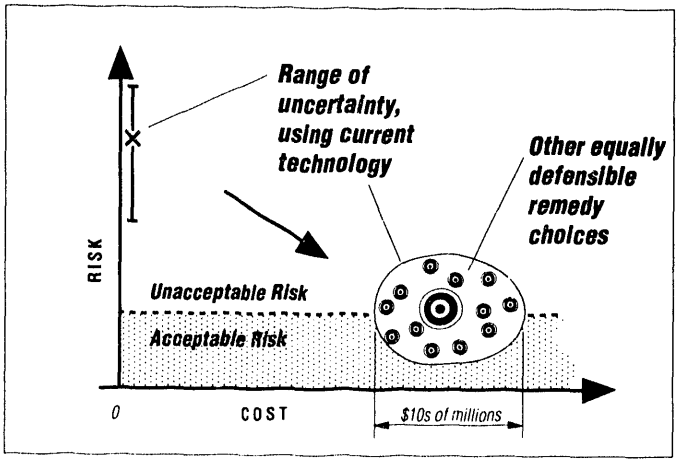


Fig. 2. Risk assessment and remedy selection: technical reality.

few accurate answers about the effects of exposure to these contaminants, especially at low exposure levels. Despite the legislated preference for "permanent" remedies, the technologies available for such remedies are for the most part unproven. The results has been painfully slow remediation.

Currently, the best that risk assessment technology can do is to provide a general estimate of the risk posed by a site, and make relative comparisons of residual risk that might be achieved among several remedial technologies. Except for very simple sites, current technology cannot provide a sufficiently accurate answer to the perennial question, "How clean is clean enough?" The burden of answering this question properly resides with the regulators.

Because of the huge uncertainties that remain, the answer cannot be delivered as values for residual chemical concentrations. The answer should be posed as a series of engineering performance specifications based on (1) the general assessment of residual risk and (2) what can be achieved by the chosen remedial technology. Furthermore, the recommended remedial action should be crafted as a combination of treatment systems to treat or destroy the contaminants which can be identified, and a series of engineering controls designed to detect and manage contaminants missed or subsurface conditions never recognized in the earlier study phases. In other words, the risk decision should be based on a recognition of the many possible discrepancies in our understanding of the site and its risks.

This approach for managing uncertainty has been used in other fields of engineering. In the high-risk arena of dam design, geotechnical engineers have been handling the order-of-magnitude physical uncertainties in the geologic structures. Here it is recognized that small discontinuities in the site geology can be the nucleation point for failure of the dam structure, and that no reasonable amount of study can locate these discontinuities. Designing to the worse-case condition is wasteful. However, a design using an assumed average condition is dangerous.

A third approach known as the "experimental" or "observational" method was formulated decades ago, and was seen as a better option (24). While recognizing that full geological characterization is not possible, the method seeks to derive the most probable model of the site and identify other possible site conditions that could reasonably exist. Responses to these reasonable deviations to the most probable model are incorporated into the design as preplanned actions to be taken if such deviations are detected during construction.

The key elements of the observational method, a fundamental method in the geotechnical engineering field, are: recognize uncertainty explicitly throughout project planning and execution; assess the probable site conditions and the implications of uncertainty about those conditions; identify in advance additional remedial actions if conditions are found to differ from the probable conditions; monitor during remediation to determine the actual conditions; and modify the remedial design to suit the actual conditions.

We believe this method has good application in hazardous waste site remediation. Using this method, the scientist or engineer does not solve the uncertainty problem but enters the design and implementation phases better prepared. Remedial decisions are made with an awareness of potential deviations, and plans are set to cope with them. The observational method, or "engineering under uncertainty," offers a more rational approach than either assuming that average properties exist throughout a site, or assuming that worst-case conditions prevail throughout a site. Instead, the technologist assumes that some things cannot be known until the project is underway, and makes allowances for what cannot be known ahead of time. It is far safer to accept uncertainty and plan for it than to assume that "state-of-the-art" technology will make highly accurate predictions and provide all the necessary answers. We are now beginning to use this method for site remediation and have had good success.

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CONTAMINANT SORPTION/DESORPTION RATES: IMPLICATIONS FOR GROUNDWATER RESTORATION

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ABSTRACT

It is widely recognized that contaminants sorb appreciably to solids during groundwater treatment. Most early attempts to model the transport of sorbin solutes were restricted by assuming that local equilibrium prevailed with respect to sorption and desorption. More recent evidence from both field and laboratory experiments demonstrates that both sorption and desorption are rate-limited, and that the local equilibrium assumption is untenable as a basis for exact simulation of groundwater transport (1). The rate limitation can be explained in terms of physical diffusion processes (2,3,4); diffusional mass transfer resistances are believed to exert substantial effects a range of scales: microporous solids, aggregates, and layers (5,6). This paper will present data that quantify the magnitude of such diffusional resistances in terms of effective times to achieve equilibrium, and will demonstrate how slow equilibrium influences the performance of aquifer restoration.

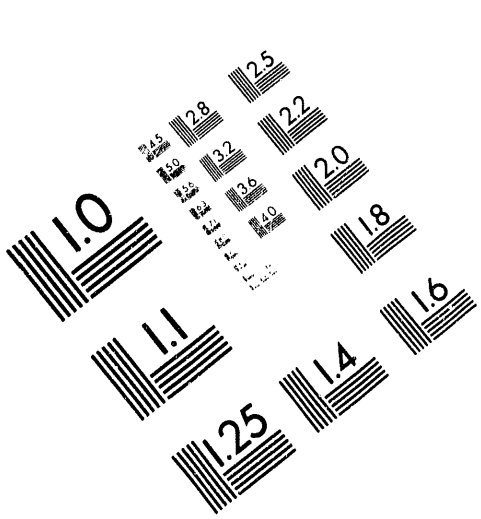
Roberts et al (1) presented field evidence indicating that sorption equilibrium was not attained during the course of a two year transport experiment conducted at the Borden Ontario field site at a scale of tens of meters. Ball and Roberts (7) showed that the sorption capacity of aquifer material is saturated very slowly, requiring equilibration times on the order of tens days for a moderately strong sorbing compound such as tetrachloroethylene (PCE) and hundreds of days for a more strongly sorbing compounds, tetrachlorobenzene (TeCB). Special care is required to conduct sorption measurements over such long time periods; as an expedient, the aquifer can be finely ground to expedite the sorption equilibrium measurements. A pore diffusion model applied to the rate data succeeded in interpreting the data consistently. To explain the slow sorption observed at the grain scale, strong diffusion hindrance in micropores was invoked as a hypothesis (8). However, the rate limitation at the grain scale is insufficient to account for the time lag observed in approaching a constant retardation factor at the field scale. Other diffusional resistances arising from aquifer heterogeneities can be expected to exert a significant effect in field studies (6).

The diffusional resistance concept was applied to transport data gathered in a field study of aquifer remediation conducted at Moffett Field, California (9). Laboratory measurements of sorption equilibrium and rate indicated that organic solute transport under conditions of the field experiment would be substantially influenced by the rate limitation, as was borne out by the field observations (10). The rate limitation applies to desorption as well as to sorption, and the diffusion model is successful in simulating both processes with a single consistent set of parameters. Rate-limited sorption causes a gradual increase in the apparent retardation factor, as well as in the distribution ratio between the solid and mobile phase; rate-limited desorption is of special significance for aquifer restoration, because it tends to constrain the release of contaminant into the moble porewater where the contaminant is available for displacement or degradation (11). Increased spreading of concentration fronts, with the appearance of extended tailing, is a consequence of rate limitation during both saturation and elution. Further, diffusional rate limitation must be taken into account in planning experiments to measure sorption equilibrium: in some cases it is advantageous to pulverize the solids to expedite the attainment of equilibrium, in order to assure that the sorption capacity has been fully quantified (7,8).

Diffusional rate limitations must be taken into account in modeling the performance of aquifer restoration operations, whether the approach is based on a pump-and-treat or an in-situ treatment strategy. In-situ approaches offer the advantage of maximizing the concentration gradient that drives desorption, but the diffusional rate limitation nonetheless slows in-situ treatment, and may govern the overall rate of treatment in many instances.

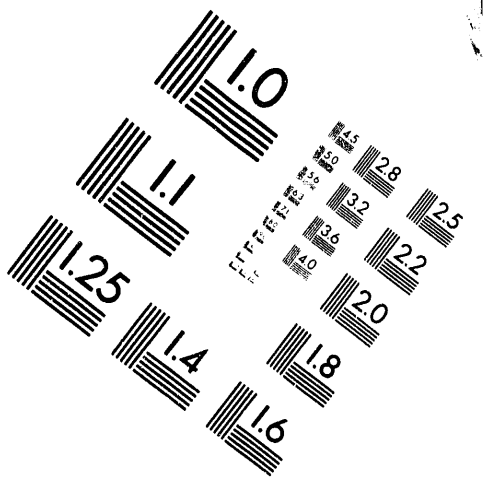
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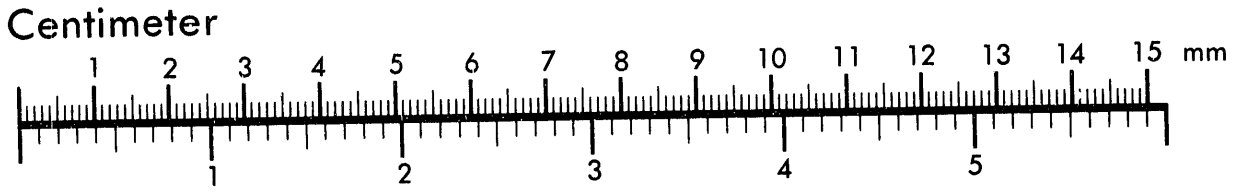
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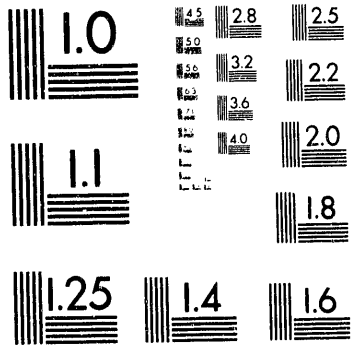


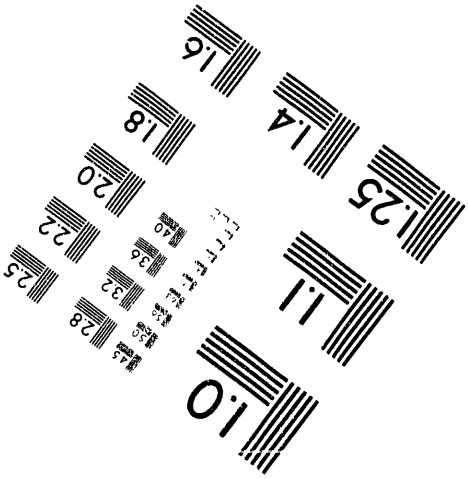


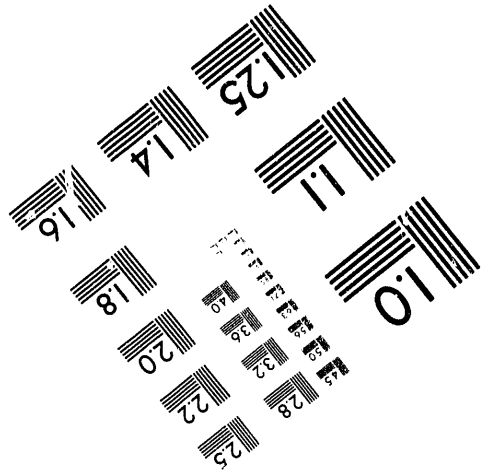
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THE EFFECTIVENESS OF THE PUMP AND TREAT METHOD FOR AQUIFER RESTORATION

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ABSTRACT

Recent theoretical studies and field experience have indicated that aquifer restoration using the pump and treat approach is not as feasible as was originally predicted. The present paper further characterizes the effectiveness of this remedial approach. Results of the analysis suggest that groundwater pumping is ineffective for permanently reducing levels of aquifer contamination to meet health-based goals for groundwater. The primary contributors to the ineffectiveness of pumping are factors associated with the physical and chemical processes that affect the behavior of contaminants in the subsurface environment. The limitations of this approach need to be recognized before progress can be made toward developing more feasible alternatives.

INTRODUCTION

With the passing of the Superfund Amendments and Reauthorization Act of 1986 (SARA), the philosophy of the Superfund program shifted toward long-term solutions to addressing contamination. The new program required that remedial alternatives be "protective of public health and the environment" and "significantly and permanently" reduce the toxicity, mobility, or volume of contaminants. Since that time, many decisions have been made to restore aquifers to drinking water standards. However, until recently, little data have been available with which to evaluate the effectiveness of this remedial approach. During the past few years, the Environmental Protection Agency (EPA) has been studying this cleanup method and has modified its approach to groundwater cleanup, acknowledging that complete restoration is not feasible at all sites (1-3). EPA has maintained, however, that restoration is possible at some sites and that more study is needed to further evaluate the effectiveness of pumping. The purpose of the present paper is to report the results of a study of the effectiveness of groundwater pumping which updates and expands upon EPA's performance record data base (4).

APPROACH

The effectiveness of groundwater pumping and treating as a remedial alternative for aquifer restoration was evaluated by reviewing: (1) performance records for 16 sites where pumping and treating has been implemented for more than one year with the objective of aquifer restoration, and (2) recent theoretical and laboratory studies. Sites were selected for evaluation based on availability of data. The sites do, however, represent a wide range of site sizes, site conditions, and regulatory programs. Sixty percent of the sites studies are NPL sites. All but one of the sites involve VOCs as the primary contaminants, with concentrations ranging from 5 ppb to 250,000 ppb. Pump and treat systems consist of 2 to 20 recovery wells, with pumping rates ranging from 10 gpm to 2,000 gpm. The extent of evaluation of groundwater extraction remedies was limited by the following factors: (1) the period of time during which most pump and treat operations have been conducted; (2) the extent of the site investigation on which the remedial design is based; and (3) the protocol used to measure and report the effectiveness of the remedy. Many of the pump and treat operations reviewed have not operated more than two or three years. However, more than half the sites reviewed have performance records ranging from 4 to 12 years, and patterns are evident at these sites that provide a basis for evaluating sites with shorter performance records.

INDICATORS OF PUMP AND TREAT EFFECTIVENESS

Permanent reduction of aquifer concentrations over time and reduction of the contaminant mass in the aquifer are the primary indicators of the effectiveness of a pump and treat system in restoring an aquifer to a specified cleanup level. The ideal scenario would be a steady decrease in contaminant concentrations until the target level is attained. Performance records suggest, however, that although concentrations may drop initially, this decline is followed by a leveling of concentrations with little or no further decrease in concentrations (3,4). At sites where the plume appears to be well-contained, concentrations have leveled after average VOC concentration reductions of approximately 60% to 90% in onsite wells, with large masses of contamination (approximately 50%) remaining in the aquifer (4). At all sites where contaminant concentrations have leveled, the concentrations remain well above the target levels, even at sites where cleanup goals were established above drinking water standards (Tables I and II). When pumps are turned off, the concentrations rise again, often to levels greater than the initial concentrations.

FACTORS INFLUENCING EFFECTIVENESS

Groundwater pumping is ineffective at the sites reviewed because continued sources of groundwater contamination exist. These sources consist of contaminated soils (the primary source) and immobilized contaminants in the vadose zone and subsurface (secondary sources). Although completion of soil remediation is likely to increase the efficiency of the pump and treat systems, all sites involve contaminants sorbed to aquifer material, trapped in low permeability zones, or pooled in the

* Research conducted at Oak Ridge National Laboratory's Risk Analysis Section and sponsored by the U. S. Department of Energy under Contract No. DE-AC05-84OR21400 with Martin Marietta Energy Systems, Inc.

TABLE I

Status of Sites With Cleanup Goals Above Drinking Water Standards

Site	Goal	Results
United Chrome, WA	10 ppm chromium	leveled at 600 ppm
Savannah River, SC	Extract 99% mass	leveled after < 25% red.
Sylvester, NH	1,500 ppb TCE	3,000 ppb
IBM Dayton, NJ	100 ppb VOCs	leveled at 100 ppb rose to 13,000 ppb after pumps shut off
Twin Cities, MN	27 ppb TCE	Conc. unchanged at 1,000 ppb
General Mills, MN	270 ppb TCE	leveled above 500 ppb
Harris Corporation, FL	500 ppb VOCs	leveled at 1,000 ppb

TABLE II

Status of Sites With Drinking Water Standards As Cleanup Goals

Site	Goal	Results
Verona Wellfield, MI	MCLs VOCs	leveled at 2,500 ppb
Sharpe Depot, CA	5 ppb TCE	leveled at 100 ppb
Ponders Corner, WA	5 ppb PCE	leveled at 50 ppb
Des Moines TCE, IA	5 ppb TCE	leveled at 500 to 1,000 ppb
Amphenol Corp., NY	5 ppb TCE	leveled at 50 ppb
Nichols Eng., NJ	5 ppb carbon tetrachloride	leveled at 150 ppb
IBM San Jose, CA	50 ppb TCA	leveled at 50 ppb in B aquifer; A aquifer still contaminated

non-aqueous phase that serve as a continued secondary source of contamination (4). Evidence to date suggests that eliminating secondary sources of contamination within a reasonable time frame is technically infeasible, and this factor will continue to be the primary contributor to the ineffectiveness of pump and treat systems, even after soil remediation is complete.

Contaminant Sorption and Desorption

Contaminants in groundwater partition between the water and organic matter in soils. Organic contaminants tend to preferentially sorb to the aquifer material, causing a reduction of the mobility of the contaminants relative to the flow of the groundwater. As groundwater is pumped, the chemicals are held back (retarded) by their adherence to the soil particles. The mass of contaminant sorbed to the aquifer material is generally significantly greater than the mass in solution. Thus, the aquifer materials act as a continuing source of contamination to groundwater.

Estimates of contaminant retardation are essential to predicting the length of time required to clean up an aquifer. Retardation is typically expressed in terms of a retardation factor, derived by dividing the average velocity of the groundwater by the average velocity of the contaminant (5). At best, for a plume containing only dissolved and sorbed contaminants in a uniform homogeneous aquifer, the volume that has to be removed will equal the contaminated volume times the retardation factor, not considering hydrodynamic dispersion. Retardation factors, however, vary for different chemicals and vary from site to site for the same chemicals. For example, TCE has been shown to have retardation factors ranging from 1 to 40, depending on the composition of the aquifer material (6). Moreover, recent evidence suggests that retardation factors actually increase over time.

A considerable number of desorption studies suggest that the long-held assumptions of dynamic equilibrium and complete reversibility in organic chemical desorption models are inaccurate (7-12). Although the sorbed contaminants react initially in a rapidly reversible way, a significant portion of the contaminants exhibit slowly reversible (nonequilibrium) behavior. The contaminants have a higher affinity for soils (up to 200 times greater K_d) in the desorptive direction than in the sorptive direction. In some cases, the contaminants appear to be irreversibly sorbed (8,11). The degree of reversibility appears to be related to the contaminant's residence time in the soil, suggesting that soil long-contaminated with hydrophobic chemicals is resistant to desorption (7,8). Although the mechanism behind this phenomenon is not yet fully understood, the preponderance of evidence to date supports the contention that the tailing of organic solutes in groundwater is controlled by molecular diffusion from remote areas in the soil matrix (9-12).

Decreased contaminant desorption rates over time result in concentration leveling and decreased contaminant extraction rates over time. Although groundwater concentrations drop initially, large masses of contaminants may remain in the aquifer materials, and many pore volumes of water must be brought into contact with the soil particles in order to extract the contaminants. This process results in the recovery of very large volumes of mildly contaminated water. Contaminant extraction is particularly inefficient at lower concentrations (Table III). At the IBM San Jose site, pumping at 2,000 gpm over a four-year period resulted in the extraction of more than

5 billion gallons of water and less than 800 lbs. of contaminants (3).

Non-aqueous Phase Liquids

Many of the organic chemicals found at hazardous waste sites are immiscible in water and are likely to be present in a non-aqueous phase. They are, however, slightly soluble in water, and partitioning of components from the non-aqueous phase may result in the development of a dissolved plume in addition to the immiscible phase that acts as a continuous source of contamination. Contaminants such as chlorinated solvents, creosotes, and PCB oils are denser than water and sink to the bottom of the aquifer, leaving behind ganglia of residual contamination and becoming trapped in pore spaces by capillary action. Contaminants such as benzene, xylene, and toluene are lighter than water and float on top of the water table. The mass of contamination in the non-aqueous phase may be considerably greater than in the dissolved phase (13).

Aquifer restoration within a reasonable time frame is infeasible at sites involving NAPLs. At best, even if eventual restoration were conceivable, predicting how long pumping and treating will take to restore an aquifer is not possible (13). Removing trapped NAPLs from the subsurface is infeasible because NAPLs cannot be mobilized under typical aquifer conditions. NAPL mobilization is controlled by mass transfer limitations in liquid phase dissolution (14). Although some success has been achieved in removing a portion of floating NAPL layers, little success has been achieved in locating dense NAPLs (DNAPLs), much less extracting them.

Forty-four percent of sites with ongoing pump and treat operations are known to involve NAPLs (4). However, because of the constituents involved, the mass of contaminants, and the fact that contaminants have migrated into the deeper aquifers at the sites, the likelihood of pooled DNAPLs is great at virtually all NPL sites involving chlorinated solvents as the primary contaminants.

Hydrogeologic Factors

More than half the sites where pumping and treating for aquifer restoration is ongoing involve significant portions of the contaminant mass in either areas of low permeability or trapped in fractured bedrock (4). The rate at which contaminants can be extracted using pump and treat is affected by advection, the process by which moving groundwater transports dissolved solutes. When contaminants are trapped in low permeability zones or in fractured rock, the rate at which these contaminants come into contact with moving groundwater is greatly reduced. In heterogeneous systems where layers of varying permeabilities exist, pumping causes preferential flow in areas of high permeability. Thus, the contaminants that remain in low permeability zones are removed very slowly by molecular diffusion. Even highly soluble contaminants may become trapped in the finer pore structure (15). At sites with fractured bedrock, dissolved contaminants may enter the rock matrix by diffusion and be stored there by adsorption, greatly decreasing the likelihood that the contaminants can be removed (13). When NAPLs enter fractured rock aquifers, they flow deep into the fractures, and little or no water can penetrate and flush these areas, further complicating the mobilization of NAPLs.

REMEDIAL TIME FRAMES

Modeling had been conducted at two-thirds of the sites reviewed. However, 25% of these sites have already exceeded the predicted time frame by as much as a factor of two. Although some of the sites gave unrealistically short time frames, the overall time frames for the remaining sites are underestimated by at least a factor of three. Recent modeling studies suggest that remedial time frames of 100 years to 1,000 years will be needed for restoration of VOC-contaminated sites (6,15). The primary factor contributing to the failure of models to predict remedial time frames is the inability of the models to consider such phenomena as NAPLs and the time-dependent decrease in contaminant desorption rates.

EFFECTS OF PUMPING

Several phenomena associated with pumping and treating can further complicate the cleanup effort or cause ecological damage. A large volume of uncontaminated water, many times the volume of contaminated water, must be used to flush the aquifer. If this water is not reinjected into the aquifer, dewatering can occur, resulting in serious land subsidence and other ecological damage. Even when dewatering does not occur, changes in the flow and distribution of groundwater that can cause ecological damage such as the loss of habitats for some local species. Pumping at the IBM San Jose site, a California site with widespread low-level contamination, has resulted in the dewatering of the shallow aquifer. A groundwater balance estimate for the Santa Teresa Basin showed that 6,900 to 29,900 acre-feet of overdraft occurred in 1985 (3).

Groundwater pumping can result in the mobilization of DNAPLs to deeper aquifers. When perched NAPLs exist, drilling can puncture the bed causing the pool to drain to a lower aquifer. If the water table is lowered from a position above perched NAPLs, the NAPLs can become remobilized and drain to a deeper aquifer (13). This mobilization of contaminants can hasten the contamination of deep aquifers used as drinking water sources.

TABLE III

Mass Extraction Rates and Initial Concentrations At Selected Sites (4)

Site	Vol. of Groundwater Extracted (gal)	Mass Extracted (lbs)	Max. Initial Concentration	Extraction (lbs/mil gal)
United Chrome, OR	1,664,000	13,376 ($Cr6^+$)	7,000 ppm	8,136
Savannah River, SC	782,000,000	168,000 (VOCs)	300,000 ppb	214.83
Twin Cities, MN	1,062,622,000	19,510 (VOCs)	20,000 ppb	18.36
IBM San Jose, CA	12,147,000,000	7,700 (VOCs)	100 ppb	.63
		84 (1,1-DCE)	5 ppb	.003
GenRad Corporation, MA	12,000,000	2.6 (VOCs)	1,000 ppb	.15

CONCLUSION

The evidence to date does not support the contention that aquifer restoration using the pump and treat approach is technically feasible. At sites with performance records of more than two years, concentrations have leveled after an initial decline. For some sites, leveling has taken place at relatively low concentrations; however, concentrations remain significantly above cleanup goals, and approximately 50% of the contaminant mass may still be present in the aquifer. Typically, once the pumps are turned off, concentrations rise again, often to levels higher than initial concentrations.

The primary contributors to the ineffectiveness of pumping for aquifer restoration are phenomena resulting from physical and chemical processes, such as contaminant sorption and the existence of non-aqueous phase liquids and zones of low permeability. Although soil remediation and system modifications can optimize efficiency, the complications resulting from fundamental chemical and physical processes cannot be overcome by simply conducting more site characterization, completing source remedial actions, and modifying pump and treat system designs.

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GROUNDWATER CLEAN-UP: THE SAVANNAH RIVER SITE EXPERIENCE (U)

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ABSTRACT

A full scale pump and treat groundwater remediation program which addresses a large plume of volatile organics has been ongoing at the Savannah River Site since 1985. The system has recovered over 100,000 kilograms of solvent and is containing the center of the plume. While overall protection is being achieved, reducing the concentration of contaminants to very low levels is problematic.

INTRODUCTION

Protection of the Earth's valuable resources is of great concern to the public in relation to safety and health. One of the resources receiving extensive attention is groundwater. Past waste disposal practices have impacted groundwater quality in many locations throughout the nation. In response, the Federal Government has passed legislation to protect and restore the environment. In many cases, application of this legislation has lead to strict clean-up standards. Savannah River Site (SRS) experiences suggest that meeting clean-up standards is a challenge in light of technical realities.

The purpose of this paper is to describe the corrective action program that is addressing a plume of volatile organics beneath the A/M Area of the SRS. The history and status of the program, costs, measures of performance, lessons learned, and challenges faced are presented.

HISTORY

SRS, which has been in operation since 1953, is a 780 square kilometer reservation that produces special isotopes for the national defense program (Fig. 1). As a result of past waste disposal practices, groundwater at several locations within the Site has become contaminated with solvents, metals and radionuclides. In 1981, the groundwater located beneath the Site's fuel and target fabrication facility (M-Area, Fig. 2) was found to be contaminated with volatile organic degreasing solvents, primarily trichloroethylene (TCE) and tetrachloroethylene (PCE). The sources of contamination were a settling basin and sewer line (now closed) (1), a solvent storage area, and other release points located near the fabrication facility. In response, SRS voluntarily initiated a groundwater corrective action program, including an extensive groundwater monitoring system. Groundwater remediation in the A/M Area began in 1982 with the startup of an experimental air stripper. To date over three hundred monitoring wells have been installed to characterize the plume.

Full scale groundwater recovery with treatment by air stripping has been ongoing in the A/M Area since 1985. The remedial system comprises eleven recovery wells and an air stripper. Since the beginning of remediation, over 114,000 kilograms of degreaser solvents have been removed from over 4,920,000,000 liters of groundwater. The system is effectively reducing the mass in the central plume region, and is serving to contain the contamination present there. SRS has realized through continuing evaluations that the current system will require augmentation to address other areas as discussed below.

Ongoing investigations have determined that a significant amount of solvent remains in the vadose zone. More recently, a separate phase of solvents was detected in a monitoring well located near the closed settling basin. Both occurrences continue to influence the amount of solvent in the aqueous phase. SRS has completed a program to more fully characterize the vadose zone beneath source areas. Contamination in the vadose zone has been and will be addressed by vacuum extraction. The presence of dense non-aqueous phase liquids (DNAPLs) is the focus of a current characterization effort. DNAPLs represent an even greater challenge in terms of characterization and remediation because they can be more difficult to locate.

SRS has completed some enhancements and plans to expand the corrective action program. The recovery rate of the current system was recently increased. In 1989, packing in the full scale air stripper was replaced, the system was tested (2) and the flow from the recovery wells to the air stripper was increased from 1,500 to 1,900 liters per minute, a 25% increase. Additional recovery capacity has been installed; SRS has installed a recovery well and relocated a prototype air stripper to a source area near the northern Site boundary, outside the influence of the original recovery system.

In addition to relocating the prototype air stripper, SRS also plans to install additional groundwater recovery capacity near the northern Site boundary, and in a dilute plume region in the south of the A/M Area, and downgradient from the major sources of contamination. SRS has also initiated projects that will address contamination remaining in the vadose zone. A 1987 pilot system recovered over 450 kilograms from the vadose zone in a three week period. More recently experimental horizontal well systems, tested by the Savannah River Laboratory under the auspices of the Office of Technology Development, have recovered over 7200 kilograms from the subsurface through the use of vacuum extraction and in situ air stripping of the aquifer near a source area (the closed sewer line). Based on the success of these efforts, SRS plans to pursue the installation of additional systems that will address source sites.

The remediation program at SRS is providing knowledge and experience regarding how well clean-up programs work. SRS is conducting extensive risk assessments associated with contaminated sites. A better understanding of the limits of remediation, combined with the amount of risk posed by the impact, should eventually lead to improved decisions regarding clean-up goals.

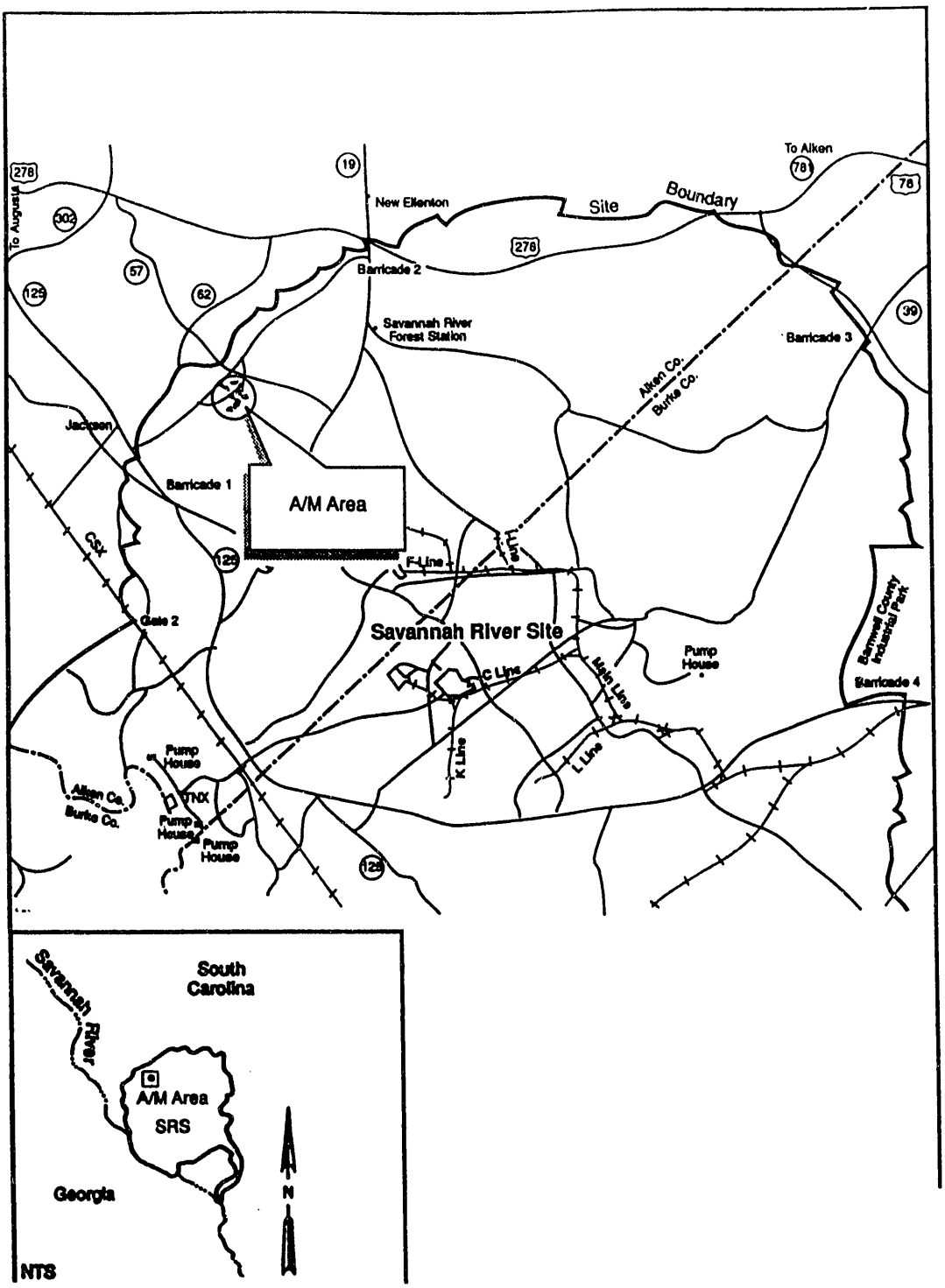


Fig. 1. Savannah River Site location map.

PROGRAM COSTS

The original 11 recovery well and air stripping system cost $4,800,000 to design and construct. The system costs approximately $100,000 per year to operate and maintain. The system has performed very well with an operating utility of greater than 95%. The major maintenance concern is lightning strikes.

Other costs associated with the corrective action program are the expenses of groundwater monitoring, data interpretation and management, modelling, reporting, and continuing investigations and project development.

REMEDIATION REQUIREMENTS, GOALS

The A/M-Area Groundwater Corrective Action Program is permitted under the post closure requirements of the Resource Conservation and Recovery Act (RCRA). The facility became fully permitted in September 1987.

Exact conditions for the program are stated in the Site's hazardous waste permit (3), and in the associated permit application (4). Goals and standards are summarized below.

The initial goal of the program was to remediate the most contaminated groundwater by maximizing mass removal from

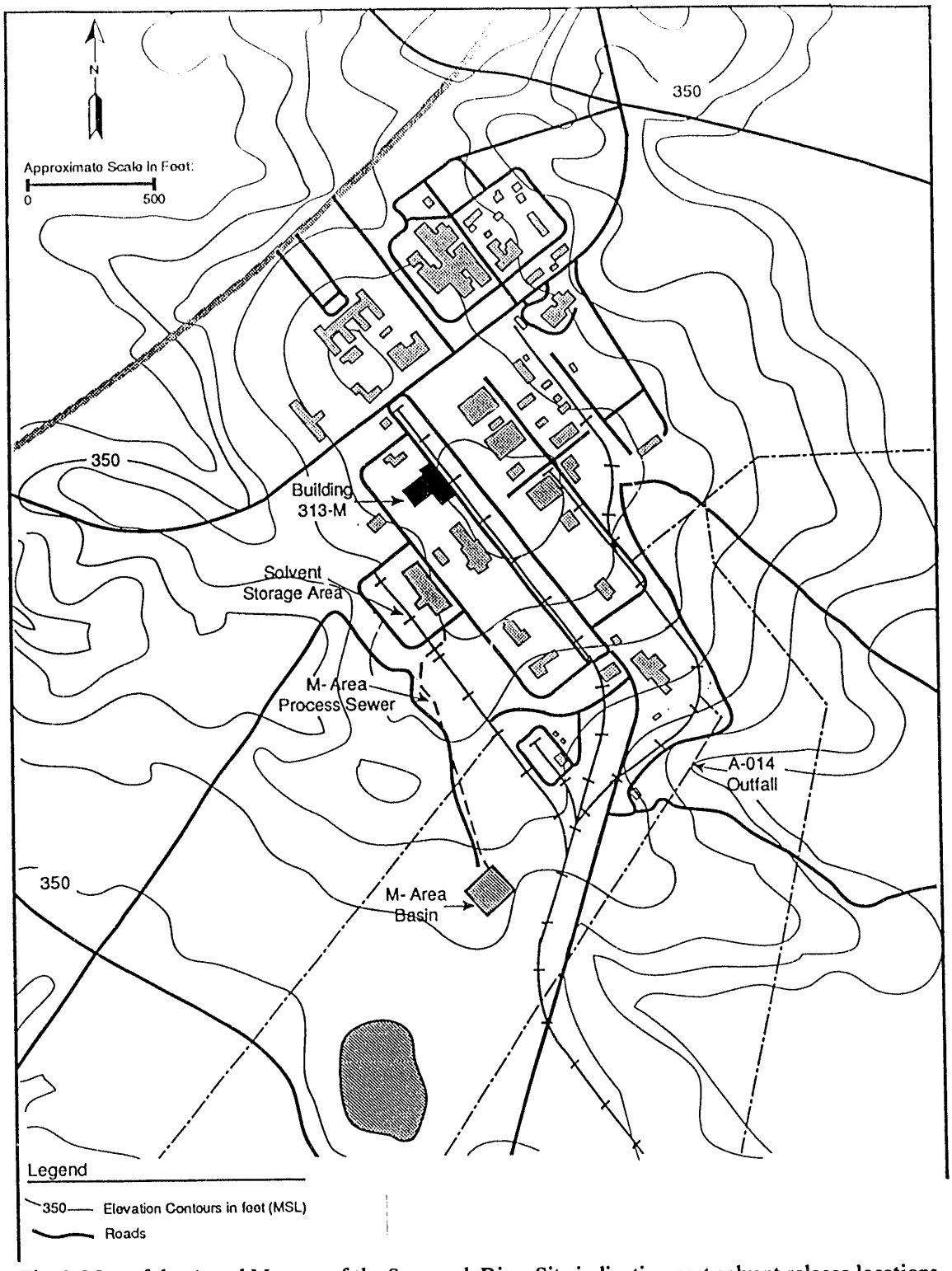


Fig. 2. Map of the A and M areas of the Savannah River Site indicating past solvent release locations.

the center of the plume. It has been the SRS position that the remediation would take place in stages. The corrective action program (4) calls for groundwater remediation to be continued until "...the groundwater concentration...no longer poses a threat to human health and the environment..." However, concentration limits listed in the permit and permit application for the primary constituents of concern are very near analytical detection limits. Although concentrations of a few other constituents are above the limits described in the permit and associated application they do not exceed these limits in the influent stream to the air stripper. These other constituents are of limited extent, and are detected in only a few monitoring wells near the closed settling basin.

Although the program is largely driven by RCRA, SRS is also in the process of integrating the requirements of the Comprehensive Environmental Response, Compensation and Liability At (CERCLA). It is expected that the eventual integration of CERCLA requirements into the groundwater program will encourage the use of risk and cost benefit

analyses to determine the degree and need of future enhancements to the program.

MEASURES OF PERFORMANCE

RCRA requires that the effectiveness of the permitted corrective actions be reported. SRS supplies quarterly groundwater reports to South Carolina and the EPA. SRS and South Carolina have agreed upon methods to be used to demonstrate the effectiveness of the A/M Area Groundwater Corrective Action Program. Three methods used are: Zone of Capture Analysis, Mass Removal and Changes in Inventory.

Zone of Capture

Zone of Capture is defined as the volume element of groundwater which will enter a pumping well during a given time period. A 30-year Zone of Capture Analysis for the original recovery well system showed that the most concentrated portion (about one-third of the total plume area) as currently outlined by a 5 part per billion isoconcentration contour will be recovered in 30 years (Fig. 3). The most

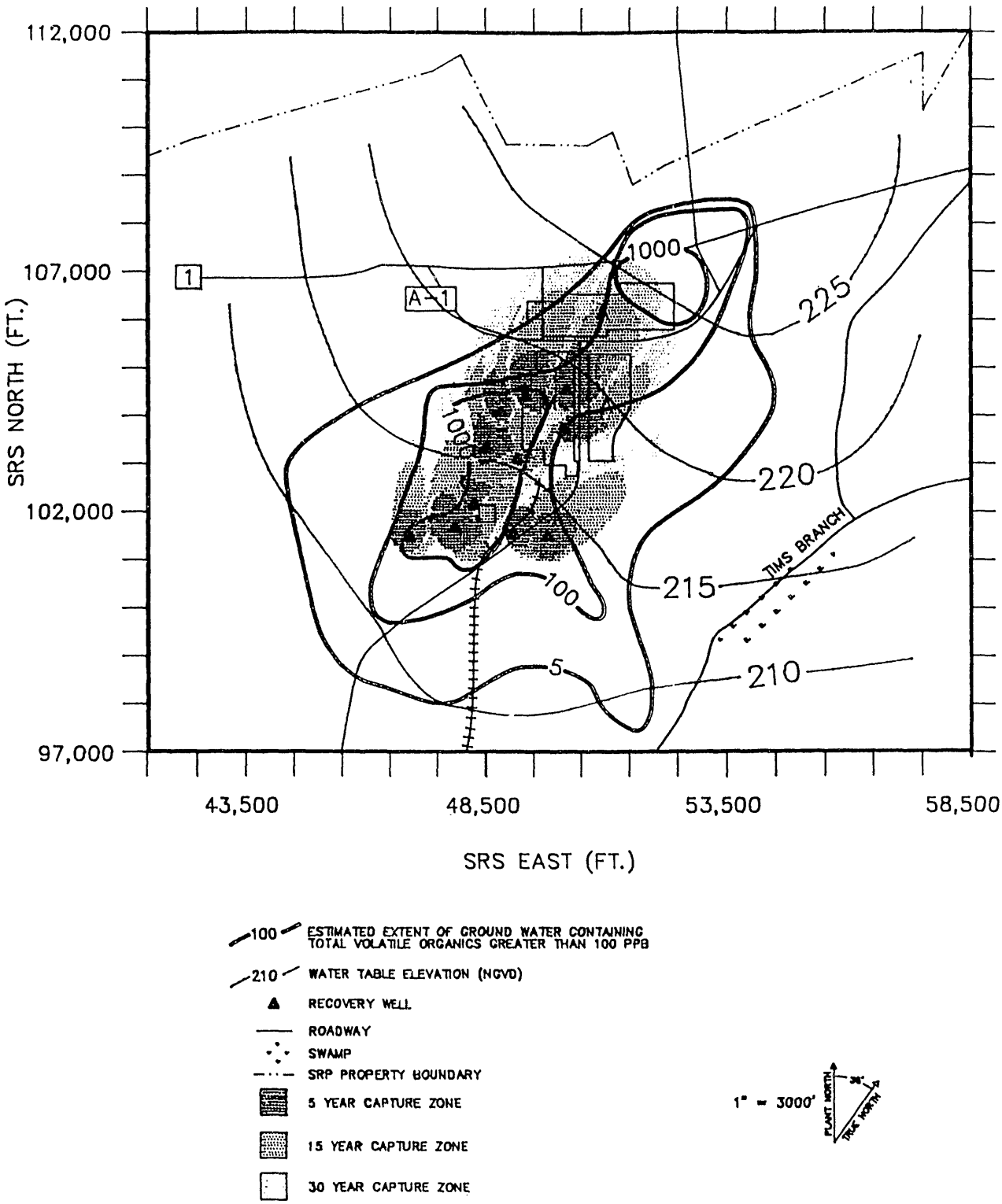


Fig. 3. 30 year Zone of Capture Map (shaded) superimposed on isoconcentration contours (ppb) for one of three flow units.

concentrated portion of the plume includes concentrations greater than 1,000 ppb. In addition, unaffected groundwater from upgradient of the northern plume boundary will enter the recovery wells within the 30 year period. The Zone of Capture Analysis indicated good vertical containment at the center of the plume as well.

The Zone of Capture Analysis also shows that more dilute regions of the plume are outside the influence of the recovery system. The original system was not designed to address these areas. However, SRS has initiated modifications to the corrective action program which will enhance the effectiveness of the program relative to lesser impacts. As stated previously a second remediation system has been installed. Other enhancements are forthcoming as described above.

Mass Removal

One measure of effectiveness is the amount of contamination removed by the corrective action system. A primary goal of the program has been to maximize contaminant recovery. The amount of mass removed is calculated by performing a mass balance across the air stripper. As stated above, over 114,000 kilograms of solvent have been removed since startup of the system. This value compares favorably with the original estimate of 225,000 kilograms of solvent in the groundwater. The original mass of contamination in the groundwater was calculated from isoconcentration contour maps. A method for calculating the inventory in the groundwater is described below.

Changes in Inventory

Inventory changes calculated from monitoring wells is yet another way to determine the effectiveness of the remediation system. In this method a concentration value from a monitoring well is applied to a discrete area. A mass of contamination within that area is calculated and added to values associated with other wells (and areas) from the same sampling period. Current values for the amount of mass can then be compared to those calculated from prior periods. Although the method is somewhat arbitrary, if applied in a consistent manner does provide useful results. As provided above, the amount of solvent removed by the recovery system between 1985 and 1990 was greater than 100,000 kilograms, however, the net difference as shown by the inventory method for the same period was only about 42,000 kilograms.

An evaluation of the data suggested that the difference between the mass balance approach and the inventory approach could be explained by the influence of residual contamination in the vadose zone and the DNAPL beneath the closed basin. Both occurrences continue to act as sources of contamination to the groundwater. The difference between the two methods was part of the basis for the initiation of a vadose remediation program at SRS. As discussed above, a vadose zone characterization program has been completed at source areas and remediation systems for the vadose zone are being designed. In addition, a program to more fully assess the occurrence of DNAPLs is underway.

Other Tools

As a guide by which to compare performance, SRS constructed a theoretical mass removal curve for a thirty year period (Fig. 4). The curve is a simple exponential decay which assumed an original starting mass of about 225,000 kilograms and assumes that 99% of the mass will be removed in thirty years. (The theoretical curve is meant to be a guide and does not represent a clean-up goal.) The solvent mass remaining in the vadose zone, and the mass associated with the DNAPL is not accounted for in the original mass estimate. Also shown in Fig. 4 is a plot of the actual amount of mass removed. Although the deviation is small, it can be seen that the two curves are separating. The inflection in the plotted data is related to the 25% increase in the recovery rate which took place in 1990. While there has been incremental benefit from increasing the flow, the actual mass removal curve will become asymptotic above the theoretical curve.

A simple plot of concentrations versus time is shown in Fig. 5. A smooth curve through the data points has been extrapolated to thirty years. The concentration values plotted represent the concentration of the influent to the air stripper at a given point in time. The initial concentration of contaminants in the influent was about 50,000 ppb. The concentration in the influent has decreased to about 10,000 - 15,000 ppb over the six years of operation.

Figures 4 and 5 illustrate that the easy part of the clean-up is the early part. The data presented indicates the natural

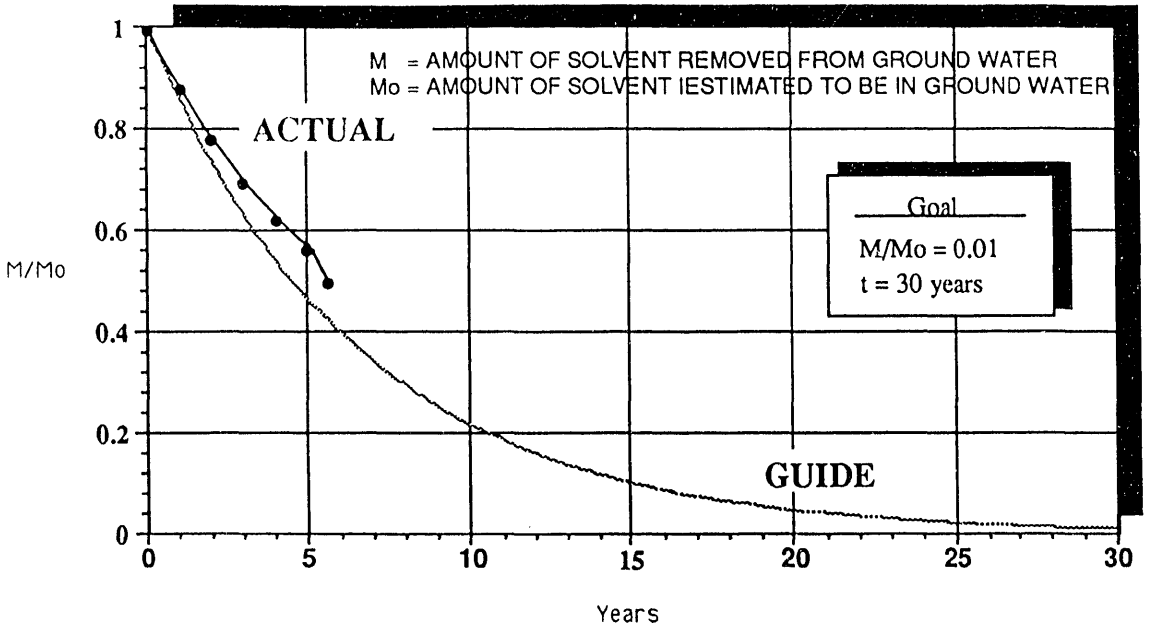


Fig. 4. Actual rate of solvent recovery (plotted data) compared to Theoretical 99% Mass Removal Guide.

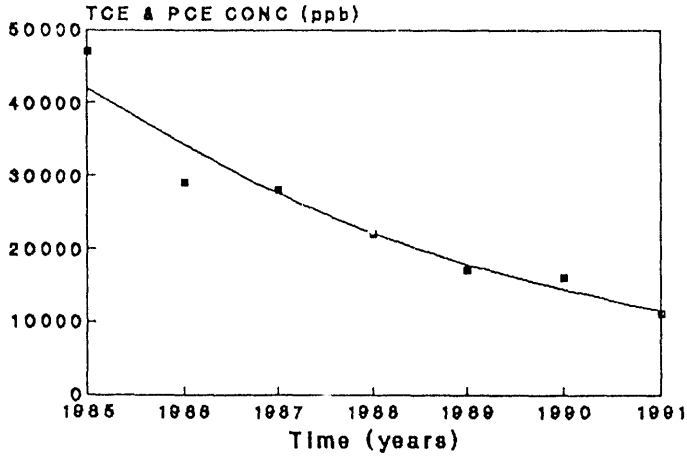


Fig. 5. Concentration trend showing decreasing concentration of solvents in the air stripper influent.

limits of the current recovery system. However, neither curve should be used as an indictment of the pump and treat method.

CONCLUSIONS

SRS has developed a groundwater program intended to detect, characterize and remediate groundwater impacts. When evaluated against original goals the pump and treat system has been successful; a large amount of mass has been removed, and significant progress has been made regarding plume contaminant. However, low concentrations are probably not achievable through a standard approach. Although new technologies offer hope, they must still overcome the difficulties presented by a complex hydrogeologic system. In addition, other issues such as vadose zone contamination and uncertainties associated with DNAPLs need to be addressed. It is imperative that the source of contamination be addressed to prevent further degradation of the groundwater resource. However, the limits of any type of remediation must be faced such that reasonable clean-up targets are chosen.

DOE and WSRC are committed to restoration while assessing risk and continuing to search for less expensive methods. Risk based approaches to clean-up may lead to more logically deduced clean-up goals and standards. It is essential that the benefit of such efforts be assessed such that resources are applied wisely.

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INNOVATIVE INVESTIGATION METHODOLOGIES AND TECHNIQUES FOR SITE CHARACTERIZATION

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ABSTRACT

During the past 5 years, emphasis and accompanying dialogue have increased regarding the cost of performing hazardous waste investigations, the length of time necessary to perform these investigations, and the validity of the data once the work in the field has been completed. For example, it is fairly well known that, on an average, 50% or more of the cost of performing these investigations is related to chemical analysis of the various types of media. The average length of a remedial investigation usually exceeds 3 years based on those sites listed on the National Priorities List. Once a field program has been planned and identified, the regulators usually require that all data collected be of the highest quality, which necessitates that all data be collected and analyzed using Contract Laboratory Protocols and Level IV data validation procedures. The level of data quality often significantly increases the cost of field investigation, increases the number of samples required, and increases the length of the field program. More than 4 years ago, the Hazardous Waste Remedial Actions Program (HAZWRAP) began to develop a plan to address these issues. This planning resulted in the development of a program that incorporated new field methods, new technologies, and new approaches, which in turn addressed all of the aforementioned areas of concern. This paper addresses certain components of this program and how they were implemented.

CORE OF THE HAZWRAP APPROACH

The heart of the approach is to divide the field investigation into two components – a screening phase and a confirmation phase. Although the components are called phases in this text, the two parts of the field program are actually one continuous field activity that is not separated by a demobilization and a remobilization. A second significant aspect of this approach is defining the data quality objectives (i.e., to identify for each sample collected the end use of the data, the purpose for the sample, the manner in which the sample is to be collected, and the analytical data quality required to meet the aforementioned requirements).

The purpose of the screening phase is to qualify the problem, identify the source (if it is not known), and obtain some level of relative quantification regarding the magnitude of the problem. This task is not designed to provide absolute information [obtain Level IV Contract Laboratory Program (CLP) data] but to enable individuals to discern the bounds of the problem, especially regarding source area identification. To accomplish this objective, several approaches, techniques, and methodologies are used. All data that are collected in the field are analyzed in the field using Level I or Level II data quality analytical procedures. The field techniques that are selected for this phase are those that allow a large number of samples to be collected in a short amount of time and at a much lower cost per unit. A mobile laboratory with portable analytical equipment, such as a portable gas chromatograph with an electron capture device or flame ionization detector, or both, are usually used. This laboratory allows all of the data to be analyzed, reviewed, and evaluated in the field. The field hydrogeologist can then decide whether the operating conceptual model is still valid or if a change is required. Making these decisions in the field allows for maximum flexibility, maximum use of hours and equipment, and optimum data collection.

Once some boundaries have been placed on the extent and magnitude of the problem, the field program shifts into the next phase, which is confirmation. Note that this shift in field emphasis is not separated by different mobilizations but occurs as one continuous process. During the confirmation phase, collecting all the necessary data that must be of much higher data quality to support such requirements as risk assessment is desired. The data collected from the screening phase is used to optimize the data collection during the confirmation phase. This optimization is extremely important because the field data acquisition methods tend to be more costly and time-consuming during this phase. The screening process allows the field personnel to optimize the selection of confirmation data collection, thereby lowering the overall cost of the project in fewer samples, less time, and lower CLP analytical costs.

The remainder of this paper addresses those field activities, techniques, and methods that have been successfully used by HAZWRAP during the screening phase of hazardous waste field investigations to allow optimization of effort and cost.

SCREENING METHODOLOGIES AND TECHNIQUES

HAZWRAP believes that, more than any other area, the investigation of groundwater impacts overall cost, sampling and analysis cost, and overall schedule. Unlike source area investigations that can be completed within one mobilization (although the mobilization may be composed of many sequenced segments), groundwater investigations tend to be more elusive. To reduce the cost and time required to obtain the necessary data to support groundwater remediation under traditional methods, HAZWRAP was interested in developing a groundwater program that would more efficiently address groundwater problems in less time and at a lower cost while at the same time maintaining the level of data quality required.

To accomplish this goal, HAZWRAP has successfully used a few new technologies and methodologies to reduce the effect of high cost and multiple phases. Two of these methods are the HydroPunch® and the screened auger. Both of these devices allow groundwater samples to be collected during the drilling process without the installation of wells for sample

collection. Groundwater samples are collected from a single borehole and can be collected at any predetermined interval or horizon. By using either device, a vertical profile of the chemical distribution within groundwater can be determined if the samples collected are analyzed on-site or in a fixed-base laboratory with a quick turnaround. This type of activity allows several things to occur. The horizontal location of a well may be determined in the field based on the outcome of these measurements. The number of wells to be installed can be optimized because the screening of groundwater yields the general geometry of the contamination. Vertical profiles of contamination can be created to ensure that a well is installed at the precise vertical location in the subsurface that would provide the required information. Because all the samples collected in the field would be analyzed by using a screening analytical methodology, which would be accomplished with a portable gas chromatograph, the cost of sending samples to a fixed-based laboratory to be analyzed by a CLP method would be significantly reduced because of fewer wells and fewer samples.

A second methodology or technique that has been employed successfully to address groundwater issues in a more timely and cost-effective manner has been the use of piezometers and open borehole sampling. Many of the HAZWRAP facilities' groundwater flow direction is often not known; in particular, localized groundwater flow directions are not known regarding a specific site. In most cases, whether groundwater contamination exists is also not known. A technique that has been used to address these concerns efficiently and economically involves the use of piezometers and open borehole sampling. The purpose of using this technology is to determine the bounds of a possible problem and to provide some level of quantification to the problem. Open borehole sampling can only occur within subsurface environments that will support an open borehole. This technique has been used successfully at one facility in the west in which, because of the specific nature of the subsurface environment, more conventional methods were unsuccessful. Piezometers, which are used for one purpose or another at more than 40% of HAZWRAP's facilities, have been successful in identifying groundwater flow directions so that the more conventional and more expensive monitoring well location could be determined. Piezometers have been used successfully for determining groundwater contamination with regard to specific sites when the cost of well construction was anticipated to be very high or construction difficult.

A third methodology that has been successful has been the mobile cone penetrometer coupled with groundwater sampling from a HydroPunch®. Although the cone penetrometer technology is not new, the development of the mobile cone penetrometer is a development variation that is relatively new. Its singular most significant advantage is to be able to develop a continuous stratigraphic record of the subsurface environment to a depth of as much as 53 m (175 ft). This device allows the field hydrogeologist to determine the variations and/or layers within the subsurface in the field. The device consists simply of a 2.5-cm-diameter (1-in.-diameter) stainless steel rod that contains electronics in the tip and sides to measure friction that is hydraulically pushed into the subsurface from a 20-ton truck. The information from the sensors is passed on to an on-board computer system that analyzes the data and provides continues readouts. When this information is compared with an existing stratigraphic record from a preexisting well log, the stratigraphy can be identified and divided into its various parts. The mobile cone penetrometer can also be equipped with downhole resistivity equipment for determining contaminant pathways, or with a piezocone, which can measure the hydraulic head within an aquifer; it can also be coupled with the HydroPunch® for groundwater sample collection. This particular combination of equipment has been successfully used in the diverse stratigraphic environments of the Central Valley of California and along the west coast to identify well locations and provide information relative to contaminant transport.

A fourth successful new technology that HAZWRAP has used in subsurface soil or vadose zone sampling is the Terra Probe®. This is a van-mounted subsurface soil sampling device. A van is equipped with a hydraulically operated 1.88-cm (0.75-in.) sampling device that is pushed into the subsurface and collects an approximate 80-mL soil sample. Continuous or discrete samples are achievable. It has been used primarily for vadose screen sampling in and around source areas to delineate the horizontal and vertical extent of contamination. This technology has been extremely successful for source identification in and around underground storage tanks, leaching pits, along leaking pipe lines, etc.

A new drilling technology, the Rotosonic® drilling method, has been used at three of HAZWRAP's facilities and offers great promise. This new drill rig can collect a 3-m-long (10-ft-long) disturbed core of either consolidated or unconsolidated material in < 10 s. Fifteen meters (50 ft) of coring or borehole construction can easily be completed within 30 min, under normal conditions. The rig is capable of coring up to 30-cm-diameter (12-in.-diameter) cores although 10-cm (4-in.) and 15-cm (6-in.) cores offer greater depths and flexibility. Although this method is a little more expensive, the length of time to complete borings or wells is decreased. This technology is an outgrowth of the Deep Sea Coring Project that has taken place during the last many years in the various oceans of the world. The system operates much like the Terra-Probe® on a much larger scale. The drilling head is the heart of the system. Although the core barrel and cutting head do rotate (at 20 rpm), the cutting action is created at the head by a series of cams that set up a harmonic vibration along the core barrel that, in turn, manifests itself at the head as a high-intensity vibration. This intense vibration along with the cutting bit creates the cutting capability. Dual tube cutting is also possible. The largest disadvantages to this technology currently are that the cores are disturbed and liners cannot be used within the drill stem during coring operations. Its largest advantage is its rapid ability to complete wells.

SUMMARY

The technologies presented during this presentation were selected because HAZWRAP has had several years of experience and has been able to evaluate its overall effectiveness. In every case, these devices have reduced cost, reduced schedule, and allowed the confirmatory stage of field investigations to be optimized so that funds could be expended to obtain their maximum benefit. HAZWRAP has used more than five other technologies in their hazardous waste investigations, but their overall contribution and effectiveness has not been determined yet. Other technologies that have been used are the SEAMIST® vadose zone and groundwater sampling system, horizontal well construction for groundwater remediation, field gas chromatograph/mass spectrometer with ion trap for more accurate identification and quantification of contaminants, dual-wall reverse air-rotary drilling techniques, and the colloidal boroscope for the in situ determination of hydrogeologic properties to include groundwater flow direction and hydraulic conductivity.

SITING AND CONSTRUCTING VERY DEEP MONITORING WELLS ON THE U.S. DEPARTMENT OF ENERGY'S NEVADA TEST SITE

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ABSTRACT

Many aspects of the Nevada Test Site's (NTS) hydrogeologic setting restrict the use of traditional methods for the siting and construction of ground-water characterization and monitoring wells. The size of the NTS precludes establishing high-density networks of characterization wells, as are typically used at smaller sites. The geologic complexity and variability of the NTS requires that the wells be critically situated. The hydrogeologic complexity requires that each well provide access to many aquifers. Depths to ground water on the NTS require the construction of wells averaging approximately 1000 meters in depth. Wells meeting these criteria are uncommon in the ground-water industry, therefore techniques used by petroleum engineers are being employed to solve certain siting-, design- and installation-related problems. To date, one focus has been on developing completion strings that facilitate routine and efficient ground-water sampling from multiple intervals in a single well. The method currently advocated employs a new design of sliding side door sleeve that is actuated by an electrically operated hydraulic shifting tool.

Stemming of the wells is being accomplished with standard materials (cement based grouts and sands); however, new stemming methods are being developed, to accommodate the greater depths, to minimize pH-related problems caused by the use of cements, to enhance the integrity of the inter-zone seals, and to improve the representativeness of radionuclide analyses performed on ground-water samples. Bench-scale experiments have been used to investigate the properties of more than a dozen epoxy-aggregate grout mixtures -- materials that are commonly used in underwater sealing applications. Additional experiments are being planned to determine optimal methods for mixing and using the materials in the field. One material appears to have met the stringent set of requirements that were developed for use in deep monitoring wells.

Obtaining ground-water samples from multiple completions in a single well will require the construction of a special geophysical tool that employs packers to isolate the wellbore fluid in the vicinity of the sleeves from the fluid in the remainder of the well, to minimize purging volumes. A pumping system incorporating a custom slim hole pump is being designed to lower the water levels in the wells prior to sleeve actuation, to eliminate cross-contamination of water samples.

INTRODUCTION

Established methods for the siting and construction of ground-water monitoring wells are not always appropriate on the U.S. Department of Energy's (DOE) Nevada Test Site (NTS), because several unique hydrogeologic conditions exist. While some of these conditions occur naturally, others have been created as a result of the underground detonation of nuclear devices. The depth to water on the NTS ranges from 250 meters to as much as 650 meters below ground surface. Such depths require that drilling programs and monitoring wells be engineered with techniques and precisions used in the construction of petroleum production wells. To complicate matters, all drilling, construction, and stemming practices must minimize the introduction of foreign materials into the ground water and must not employ materials that would affect the chemical representativeness of the ground-water samples -- a problem not usually inherent in the design of petroleum exploration and production wells. For these reasons, characterization wells on the NTS exhibit an interesting crossbreeding of ground-water and petroleum exploration technologies.

Geohydrologic Setting

The NTS encompasses in excess of 3500 square kilometers of mountainous, semi-arid steppe. The geology underlying the NTS consists of Precambrian carbonates and clastics, Tertiary rhyolitic volcanics, and alluvial and colluvial sediments deposited in intermountain basins (1,2). Tertiary volcanism has created several caldera complexes near one of the principal testing areas (3) and the entire NTS has been deformed by Mesozoic thrusting and Cenozoic basin-and-range extensional faulting.

The most thorough conceptual model of the NTS's hydrogeology was presented by Winograd and Thordarson (4), whose study was based on virtually all of the available, but admittedly sparse, data. The authors identified ten hydrogeologic units underlying the NTS. Of these, three units -- the lower clastic aquitard, the lower carbonate aquifer, and the tuff aquitard -- were though to control the movement of ground water on a regional basis. Precipitation on the NTS is extremely variable, ranging from 5 cm/yr in the basins to in excess of 50 cm/yr on the mesas. Infiltration is thought to be very low -- perhaps as low as 2 mm/yr in some areas, and potentiometric gradients range from steep (coming off the mesas) to immeasurably flat in the basins. As a result, some of the ground water is thought to be very old. Several regional-scale ground-water flow and transport models have been constructed for the NTS (5,6,7,8), primarily in response to DOE's Yucca Mountain Project. Most of the models are based on data sets that are only slightly expanded over those used by Winograd and Thordarson.

Project Objectives

On the NTS, the principal objective of the Groundwater Characterization Project (GCP) is to refine the knowledge of

the flow and transport systems so that any real risks (if such risks exist) from past and ongoing underground nuclear tests can be understood, quantified, and reduced to an acceptable level. In order to accomplish this objective, approximately 100 wells are to be drilled over a six to seven year period across the NTS. Twenty one existing wells are currently sampled, both by the DOE and by the U.S. Environmental Protection Agency (EPA), for a variety of constituents including radionuclides. However, all of these wells would have to be classified as 'target of opportunity' wells; they were not specifically designed as monitoring wells but, rather, were drilled for purposes of geologic exploration or water production. The wells were not situated properly for use in a ground-water monitoring network. Some were never cased or were screened in multiple aquifers, such that potentiometric levels and ground-water samples exhibit composite values. Even if sampling is continued in these wells, the density of data available at the end of the GCP will be sparse in comparison to most hazardous waste sites. For this reason, it is crucial that the wells be situated and designed so as to provide the maximum amount of useful hydrogeologic data.

Site-Specific Problems

The size of the NTS may make the traditional 'plume chasing' approach, employed at many hazardous waste sites, inappropriate -- especially if each test location is viewed as a potential source area. A better approach might be to cluster the test locations into groups and treat each group as a source. On a larger scale, each of the five major testing areas (Pahute Mesa, Rainier Mesa, Frenchman Flat, Yucca Flat and Shoshone Mountain) could be viewed as an areal source. The number of monitoring wells might be considerably reduced if hydrogeologic studies indicate that regional-scale features have created preferential flow paths. However, making such determinations would require a relatively detailed knowledge of the hydrostratigraphy and subsurface geologic structure.

Among the difficulties of defining the geologic structure on the NTS are, again, its size, the large distances between wells, the expense of constructing deep wells, and the limited areal information that can be determined from borehole geophysical methods. While many geologic characterization holes have been drilled in the areas used for underground nuclear testing, these wells explore less than 20% of the total facility. Thus, the majority of the new hydrogeologic characterization holes will be drilled in previously unexamined areas. Detailed hydrogeologic studies, combined with surface geophysical studies and numerical simulations involving uncertainty analysis and quantitative risk assessment are currently the approaches being advocated to deal with the size-related problem.

Difficulties also exist in attempting to characterize the hydraulic and transport properties of the aquifers underlying the NTS. For example, certain units of hydrogeologic interest either deform plastically or fracture when subjected to small overpressures. These attributes make it especially difficult to quantify in-situ hydraulic parameters, such as transmissivity and storativity, through the use of conventional hydraulic testing techniques. The large depths to water also complicate the designs of equipment used for aquifer testing and sampling. On the mesas, sequences of ash-fall and ash-flow tuffs influence transport rates and directions. These deposits are limited in areal extent and the depositional sequence is not precisely known.

A large number of underground tests have been conducted on the NTS; of these, at least 100 are thought to have directly impacted on the ground-water system. Nuclear testing creates unique features such as cavities, chimney structures, and craters. In addition, nuclear testing has been observed to cause long-term aberrations in the elevations of water tables, especially in Yucca Flat. Potential pathways for radionuclide migration from test cavities have only been partially defined. Initial studies have shown that most radionuclides remain either near the cavities as a result of vitrification and injection or, through thermal convection, remain near the tops of the aquifers; it is not known if other processes carry certain radionuclides downward. The active depth of circulation in the various testing areas has not been determined. All of these specialized hydrogeologic environments influence near- and far-scale patterns of contaminant migration.

WELL DESIGN

A number of alternative well designs were considered for use on the Groundwater Characterization Project (9), the principal criterion being that the selected design had to permit both characterization and monitoring of multiple hydrostratigraphic units over the long term in a cost-effective manner. The designs included (1) drilling several wells at each site to different depths; (2) installing multiple piezometers in a single large-diameter well; (3) using external casing packers on a completion string, to isolate zones of interest; (4) installing a commercial multi-port sampling system, such as the Westbay system; and (5) installing multiple sliding side door sleeves in a single completion string. Each design was weighed against several factors, such as the availability of materials, whether or not the design had a proven history of long-term reliability, the likelihood of being able to install the hardware in a successful manner, the representativeness of groundwater samples that would be obtained with the design, the ability to conduct aquifer tests in the completed intervals, and cost. The method currently advocated employs a modified design of a standard oil-field sliding side-door sleeve. The modifications consists of changes in the designs of the latch-in profile and seals, to improve cycle life.

Wells being constructed on the Groundwater Characterization Project follow a generic design. A 75-cm-diameter surface hole is drilled to a competent casing point, in order to set surface casing. The surface holes generally range from 25 to 35 meters in depth, with preference being given to deeper holes as an aid in establishing hole verticality for subsequent drilling. Once drilled, a 51-cm surface casing is hung in the hole and grouted in place.

Drilling continues through the surface casing with a 45-cm rock bit. Two drilling methods have been employed, depending on the properties of the rocks being penetrated: (1) air hammering (a percussion type of bit, not unlike a jack hammer) using direct circulation (compressed air and foam circulates down through the drill pipe and up through the wellbore annulus), and (2) button bit drilling using dual-wall reverse rotary circulation with any of the following drilling fluids: air, air foam, water, or mud. (In dual-wall reverse rotary circulation, the drill string consists of a pipe within a pipe -- hence 'dual wall.' Drilling fluids circulate down the pipe annulus and return through the inner pipe. The method mini-

mizes the intrusion of drilling fluids into the borehole wall and carries drill cuttings to the surface faster, minimizing the mixing of cuttings from different depths). All drilling fluids are tagged with a 20 ppm tracer of lithium bromide. When the depth of drilling nears the predicted elevation of the water table, drilling is suspended for 30 to 60 minutes to allow hydrostatic pressures to equalize in the borehole. The hole is then blown clear and samples of the drilling fluid are collected and examined with a bromide electrode. Dilution of the bromide tracer by a factor of two is considered diagnostic for confirmation of having encountered water.

Drilling is continued in increments of one field joint (roughly 10 meters) until positive confirmation of the position of the water table has been established. Two additional joints are drilled to provide sufficient depth for a subsequent series of geophysical tests; presently, the tests include fluid density, caliper, spectral gamma ray, dual induction, compensated density, epithermal neutron, magnetometer, and color video camera.

After the geophysical logs have been completed, a fine sand is used to backfill the hole to a point 15 meters above the static water level. A 5-cm tremmie line (a small-diameter line that is used to place stemming materials in the well annulus) and 34-cm carbon steel intermediate casing are hung in the hole approximately 1.5 meters above the sand layer. The purpose of the intermediate string is to maintain hole integrity during subsequent drilling operations; in competent rocks, the intermediate string may be omitted. The purpose of the sand pack is to keep grout from invading the rock in the vicinity of the static water level. Once positioned, the intermediate casing is grouted in place with conventional materials. The lower portion of the casing is grouted from the bottom up with the aid of a stab-in shoe welded to the bottom of the intermediate string. Subsequent lifts are placed with the tremmie line.

After the grout has cured, the hole is re-entered with a 31-cm bit and drilled to total depth. Current plans call for the wells to range in depth from 915 to 1220 meters; however, certain wells may be as deep as 1830 meters. Drilling may be interrupted any number of times for the purpose of obtaining core samples. Once total depth has been reached, the hole is conditioned (cleaned of drilling fluids) and a second suite of geophysical logs is run; the current plan includes fluid density, caliper, spectral gamma, dual laterolog, epithermal neutron, formation microscanner, acoustic, magnetometer, borehole deviation (gyroscopic or multi-shot, run after the completion string has been installed), compensated density, and video (run after completion of the aquifer tests).

After completion of the second geophysical suite, a two-month period has been devoted to hydrogeologic testing and aquifer sampling. Initially, a standard multiple rate (step drawdown type) test is conducted to determine the overall efficiency and specific capacity of the well, as a function of pumping rate; these data are used to select proper pumping rates for subsequent testing. Next, the well is subjected to a standard long term (24-72 hours) radially converging test to determine the gross transmissivity of the aquifer system. A Schlumberger oxygen activation log is run third, to locate specific zones of major transmissivity that might act as pathways for radionuclide migration; this test is similar to an iodine-131 tracejector survey, but it does not introduce radioisotopic solutions into the wellbore. Finally, a series of drill stem tests is used to quantify the transmissivity of the permeable zones identified with the oxygen activation log. The tests are conducted with double packers (primary and guard) above and below the zone of interest, to enhance the chance of obtaining successful packer seals. The physics of the drill stem tests resembles what hydrogeologists might call a variable rate bailer test. Before the test begins, all drilling fluids are removed from the drill stem, so that only air fills the stem. At a specified time, a valve in the drill stem is opened by rotating the drill stem with the drilling rig. This permits the formation water between the packers to flow into the drill stem, in response to its own hydrostatic pressure. The rise in fluid level is measured in the drill stem with a pressure transducer. As the inner diameter of the drill stem is known, both pressure (head) and flow rate can be determined, as functions of time, from the transducer response. Transmissivity is calculated from the temporal changes in the flow rate and pressure. Present plans do not call for the construction of additional wells, that might be used as observation wells, at any of the sites. For this reason, aquifer storativities will not be able to be measured.

At the conclusion of the hydrogeologic tests, a long string (completion string) is installed in the well. The long string is assembled from an engineered 14-cm internal flush stainless steel pipe that has been modified by heat treating to increase its yield strength. Interspersed at field-selected intervals is a set of sliding side-door sleeves that have been modified for use on the GCP. Sliding side door sleeves are commonly employed in the petroleum industry as a means of gaining and restricting access to different producing units; their principal function is to permit production from formations that exhibit different pressures, in multiply completed wells, without crossflow -- i.e., so that one formation cannot abstract fluid (thief) from another. While the sleeves have proven to be extremely rugged, standard designs do not permit more than a few openings and closings. Sleeves used on the GCP will be operated for ground-water sampling on at least an annual basis and perhaps as frequently as four times per year. For this reason, the GCP sleeves have had seal and profile modifications that permit a demonstrated 400 openings and closings, with a 10^7 Pa pressure differential (both overbalanced -- the greater pressure is on the inside of the sleeve -- and underbalanced -- the greater pressure is on the outside of the sleeve), without significant seal or profile wear. A profile is a series of radial grooves that has been machined into the inner diameter of an element in a long string so that the positioning of a tool into the element can be precisely controlled. Profiles are also used as bearing surfaces, for tools that must exert a force against the long string to operate properly. In this case, profiles are used to permit the latching in of a tool that is used to open and close the sleeves. The sleeves are protected from sand intrusion with an external slotted casing. The system offers mechanical simplicity (as compared to designs employing external casing packers) and is simpler to install than are multiple piezometers. The cost of the units is relatively low -- in the $7,000 to $10,000 range. The design also maintains a relatively large wellbore (12 cm at the narrowest point, within the sleeves), permitting the installation of moderately-sized pumps for testing and sampling of the individual hydrostratigraphic units. The only known disadvantage of the design is the unproven long-term integrity of the seals. How-

ever, the large internal diameter of the units would permit the setting of internal packers, should the seals fail.

SLEEVE OPERATION

In the oil field, sliding side door sleeves are opened and closed with a wireline tool called a shifter. The tool is positioned in the hole below the sleeve and is then pulled up until a set of extendable locks or 'dogs' on the tool latch into the sleeve's profile. The tool is jarred upward 20 to 30 times until the sleeve is opened. Once opened, the dogs are forced back into the tool by the sleeve's profile and the tool passes upward through the sleeve. Closing is accomplished in a reverse fashion, with the tool inverted and with a set of sinker bars hung off the tool to provide the jarring force. While such a procedure is adequate for a limited number of openings and closings, profile and seal wear would limit the life of the sleeve to a few cycles.

An alternate means of operating the sleeves has been developed by TAM International (10). Originally conceived as a means of operating sleeves in horizontal wells (where wireline tools cannot be used and where the jarring action of a shifting tool cannot be generated), TAM has developed an electrically operated hydraulic shifting tool. The tool is positioned beneath the sleeve and an electrical signal is sent to the tool to open two pairs of dogs. The tool is then pulled uphole slowly, allowing one pair of dogs to latch into a stationary profile in the sleeve's outer casing. The second pair latches into the moving element of the sleeve. The operator sends a second signal to turn on a hydraulic pump. Hydraulic fluid shifts the second pair of dogs longitudinally, exerting a bearing force against the first set and opening the sleeve. Confirmation of sleeve position is obtained by watching pressure buildups on the pump's discharge side. Once the position of the sleeve has been confirmed, the dogs are retracted, the pump is shut off, and the tool is repositioned for the next operation. A sleeve can be closed without reversing the tool. Sleeve operation is smooth; no jarring actions are required.

GROUTS

The final step in completing the well consists of grouting the long string in place. One problem inherent in the design of any monitoring well with multiple completions involves the mechanical and chemical properties of the stemming materials. It is well known (11) that neat cement raises the pH of well water within which it is in equilibrium to between 11 and 12. This high pH range can affect the chemistry of ground-water samples drawn from the wells. The problem becomes acute with radionuclides, many of which behave chemically in a fashion similar to their non-radioactive metallic counterparts. Awareness of this problem is one reason why hydrogeologists use bentonite to isolate sampling zones.

However, the use of bentonite does not solve the problem entirely. Bentonite can raise the pH of water to between 8 and 10. In wells with a single completion interval, this may be the only problem that bentonite causes and it may be an acceptable trade-off when dealing with cements. In wells with multiple completion intervals -- where layers of bentonite, sand and cement are alternated -- the water in the wellbore can take on a high pH value during the stemming process as a result of contact with the cement. The problem is exacerbated in deep wells where standard stemming practice is to flush out the tremmie line with water after the cement has been pumped into place; this is done to keep the cement from setting up in the tremmie line. The waste cement does not form a plug at the current stemming level. Rather, it is blown throughout the water column in the form of a fine- to coarse-particulate suspension that eventually settles out in the wellbore annulus. The cement crumbs do not develop mechanical strength but, because of their high surface area and buffering capacity, do raise the pH of the well water. When bentonite is subsequently tremmied into position through the high pH water, it deflocculates, forming a fluffy suspension, losing its ability to form a good expanding seal, and losing its compressive strength. If sand or cement is tremmied in on top of the bentonite, it displaces or mixes with the bentonite layer.

An attempt is being made to overcome problems inherent in the use of cement-based grouts by investigating the potential use of geotechnical grouts and epoxies -- materials that are used for sealing cracks in dams, foundations, and underwater structures. To be compatible with the objectives of the wells, we tasked ourselves with finding one or more materials that would meet the following rather stringent set of requirements:

- When placed in contact with water, the grout could not lower the water's pH beyond 6.5 nor raise it above 7.5.
- The concentration of organic chemicals introduced by the grout into the well water must be minimal. Small concentrations of organic chemicals were thought not to be detrimental to project objectives, because the principal species being investigated were radionuclides, not organic solvents.
- The grout had to exhibit a working time of at least 1 hour. Working times as long as 12 hours could be permitted.
- The grout had to be workable at temperatures ranging from 10 to 50 degrees Celsius, to be compatible with ambient and expected down-hole temperatures.
- The grout had to be able to be mixed with conventional mixing equipment.
- It was desirable that the grout not react with quartz pea gravel, so that gravel could be mixed with the grout to decrease the volume of epoxy that was required.
- The grout had to be able to be pumped downhole with conventional pumping and tremming equipment.
- The grout had to develop a mechanical strength similar to that developed by cement-based grouts when placed under water.
- The grout had to exhibit a water permeability, when cured, equal to or less than that exhibited by cement.
- The grout had to maintain a specific gravity in excess of 1.5 during all phases of placement and curing.
- The grout was not permitted to outgas significantly.
- Health hazards posed to workers during emplacement of the grout had to be minimal.
- The grout could not be a source of environmental problems.

A series of bench-scale experiments was performed on samples of cements and epoxy-resin grouts supplied by various vendors. The materials included barite, a weighting agent

used in standard drilling muds; Pyrament, 'regulation set,' Lumnite, and Ci' ment Fondu, a series of grouts recommended by the U.S. Army Corps of Engineers' Waterways Experiment Station (WES); two soil stabilizing hydrophobic polyurethanes called Mountain Grout and Saudi Grout (and mixtures of these with barite) (12); Ceilcote 612 (and mixtures of Ceilcote with cement), GE-329 and GE-332 (13); and Hydromite (14). The results of these experiments will be detailed in a subsequent report, but some initial observations are worth mentioning.

Each material was subjected to a series of increasingly selective tests that included pH, set time (viscosity) as a function of temperature, permeability, and bond strength (a shear-strength test that gives an indication of the bond between the grout and the well casing). The materials were examined visually for qualitative factors such as outgassing, floating, settling through a water column, and miscibility with quartz pea gravel, by pouring the materials through columns of water into 8-cm lucite tubes. The WES cements were eliminated early in the testing program because of the high pH values that they generated. The Mountain Grout products formed hard plugs underwater but were eliminated because of outgassing problems and because of high permeabilities.

The Ceilcote products appear to be the most promising, with a field test of Ceilcote GE-329 (modified) to be performed in the Fall of 1991. The purpose of the field test is to verify that conventional mixing equipment can be used to tremmie the materials into place. In addition, mixing and tremming equipment are being coated with a polyethylene to prevent sticking; the efficacy of this concept needs to be tested. Finally, the quality of the grout plug itself needs to be examined. To accomplish these goals, the grout will be stemmed into a section of well casing that is lowered beneath the static water level in an existing NTS well. After the grout plug has cured, the pipe will be withdrawn, split, and the plug will be examined.

DEVELOPMENT, PURGING AND SAMPLING

Once the well has been completed, each zone of hydrogeologic interest will be developed, purged, and sampled. Development will maximize the ability of the screened interval to produce water by partially removing any of the remaining drilling fluids and cuttings that have invaded the formation, and by flushing and grading the filter pack surrounding the screens. Development of the filter packs will be accomplished either by swabbing or by pumping. The wells will be purged prior to sampling with a high capacity, high lift, slim-hole pump that is being developed. Purging operations will be deemed complete when the discharged water has stabilized with respect to temperature, pH, and electrical conductivity. Ground-water samples will be collected subsequent to purging operations for volatile and semivolatile organics; total petroleum hydrocarbons; standard cations (including metals such as lead); certain other metals of interest including arsenic, mercury and selenium; standard anions; alkalinity; TDS; pH; EC; and a suite of radionuclides including gross alpha, gross beta, gamma scan, ^{3}He, ^{4}He, ^{85}Kr, ^{86}Sr, ^{87}Sr, ^{234}U, ^{238}U, ^{137}Cs, ^{125}Sb, ^{60}Co, ^{90}Sr, ^{14}C, ^{99}Tc, ^{36}Cl, ^{2}H, ^{3}H, ^{16}O, ^{18}O, ^{12}C, ^{13}C and ^{14}C. The large initial suite is being used to establish baseline conditions. Subsequent sampling, for monitoring purposes, will, most likely, be reduced to a smaller suite of radionuclides that act as indicator parameters.

CONCLUSIONS

Established methods for the construction of groundwater monitoring wells are not always appropriate on the U.S. Department of Energy's (DOE) Nevada Test Site (NTS), because several unique hydrogeologic conditions exist that influence the designs of the wells. As a result, the GCP is employing a new design of characterization well, based on a crossbreeding of ground-water and petroleum production technologies. The new design employs a modified form of a sliding side door sleeve, to gain access to formations of hydrogeologic interest. A hydraulic shifting tool is used to operate the sleeves. Packers and sample bottles can be added above the shifter to minimize purge volumes and draw representative samples of ground water. An epoxy-resin grout has been identified that has permeabilities and working characteristics that are slightly better than conventional cement-based grouts. The new grout introduces small amounts of organic materials into the ground water but appears to minimize the pH-related problems caused by the use of cements.

ACKNOWLEDGEMENTS

Thanks are extended to Daryl R. Schwichtenberg and Wallace L. Hammer of Raytheon Services Nevada for performing the engineering work involved in the design of the characterization wells, to Jo Ann H. Rego of Lawrence Livermore National Laboratory for designing and performing the grout tests, to J. Dee Donithan and Ron Hershey of the Desert Research Institute for their contributions in designing the wells and the sampling program, to C.O. 'Doc' Stokley of TAM International for the design of the sliding side door sleeves and shifting tool, and to Joseph Kitchen and Steven Lawrence with DOE/NVO's Environmental Restoration and Waste Management Branch, for initially posing the problems.

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INITIAL SITE CHARACTERIZATION APPROACH AND PRELIMINARY RESULTS; 200 WEST AREA CARBON TETRACHLORIDE EXPEDITED RESPONSE ACTION, HANFORD SITE, WASHINGTON

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ABSTRACT

An Expedited Response Action (ERA) is being proposed to remediate the carbon tetrachloride contamination in the unsaturated soils beneath the 200 West Area of the Hanford Site in Washington. The ERA is based on the preliminary conceptual model that carbon tetrachloride vapors remaining in the unsaturated zone continue to provide a source of carbon tetrachloride contamination to the groundwater. The goal of the initial phase of site characterization was to refine this conceptual model, and to collect data in support of the selection and design of an initial remedial action, while meeting the accelerated schedule of the ERA. Using this approach, site characterization activities were designed to make optimum use of field screening-level data and existing boreholes. Field tasks included analysis of soil gas samples collected from the bottoms of boreholes or detected at the wellhead; a soil gas survey; a pilot test of a vapor extraction system; and groundwater sampling and analysis. Results of this initial phase of site characterization suggest that carbon tetrachloride vapors are still contained within the unsaturated zone in concentrations sufficient to support an effective early removal action.

INTRODUCTION

Carbon tetrachloride, a dense nonaqueous phase liquid (denser than, and immiscible with, water), was disposed to the soil column at three sites in the 200 West Area of the Hanford Site from 1955 to 1973 (Fig. 1). Some of the carbon tetrachloride has since moved downward through the unsaturated zone to contaminate the underlying groundwater. However, the bulk of the carbon tetrachloride is thought to remain in the unsaturated zone, where it may occur as a liquid, a vapor, adsorbed to soil particles, or dissolved in soil moisture.

In 1990, the U.S. Environmental Protection Agency (EPA) and the Washington Department of Ecology (Ecology) requested the U.S. Department of Energy - Richland Field Office (DOE-RL) to proceed with detailed planning, including non-intrusive field work, required to implement an ERA for carbon tetrachloride contamination, located in the unsaturated soils beneath certain disposal sites in the 200 West Area of the Hanford Site. The request was made based on concerns that the carbon tetrachloride residing in the soils is continuing to contaminate the groundwater. The purpose of this ERA is to minimize or stabilize contaminant migration within the unsaturated zone beneath and away from the liquid waste disposal sites in the 200 West Area.

An ERA is a provision included in the Comprehensive Environmental Response, Compensation and Liability Act of 1980 (CERCLA) that allows early remediation to be conducted at waste sites in order to abate potential threats or prevent significantly increased degradation that might occur if action were delayed until completion of the remedial investigation/feasibility study and the record of decision. Thus, implementation of this ERA is not necessarily intended to effect a complete solution to the carbon tetrachloride problem, but to make that solution attainable during the later cleanup of the pertinent operable units.

The detailed plan for conducting the initial phase of the carbon tetrachloride ERA was provided to EPA and Ecology in January 1991 (1). The results of the initial phase of site evaluation summarized here were reported in the ERA Proposal, Appendix B, submitted to EPA and Ecology in June 1991 (2). Based on those results and on an Engineering Evaluation/Cost Analysis of the remedial options, the preferred alternative for removing carbon tetrachloride from the unsaturated zone at Hanford is soil vapor extraction followed by vapor treatment (2,3).

APPROACH

The ERA is being conducted in a phased approach to ensure initiation of a potential remedial action in a timely manner. The initial phase of site evaluation was conducted from January to April 1991 to refine the preliminary conceptual model and to collect data in support of the selection and design of an initial remedial action. The second phase of site evaluation will be conducted to further refine the conceptual model and to collect data in support of optimizing the effectiveness of the soil vapor extraction system and vapor treatment.

In order to meet the accelerated schedule of the ERA, the approach to site characterization included the following:

- Focus primarily on the conceptual model of the unsaturated zone.
- Maximize use of field screening level data.
- Maximize use of existing data.
- Conduct primarily nonintrusive activities to avoid delays and costs related to drilling in and around radioactively contaminated soils. (The carbon tetrachloride disposal sites are also associated with plutonium and americium contamination.)
- Minimize generation of radioactive and hazardous wastes during the investigation; such wastes are difficult and costly to properly manage under the applicable regulations given the ERA timeframe and cost constraints.
- Focus data collection on specific contaminants of concern.
- Conduct a pilot test of a vapor extraction system, the preferred remedial technology, to support the development and evaluation of remedial alternatives (3,4).
- Maximize use of "off-the-shelf" technology.

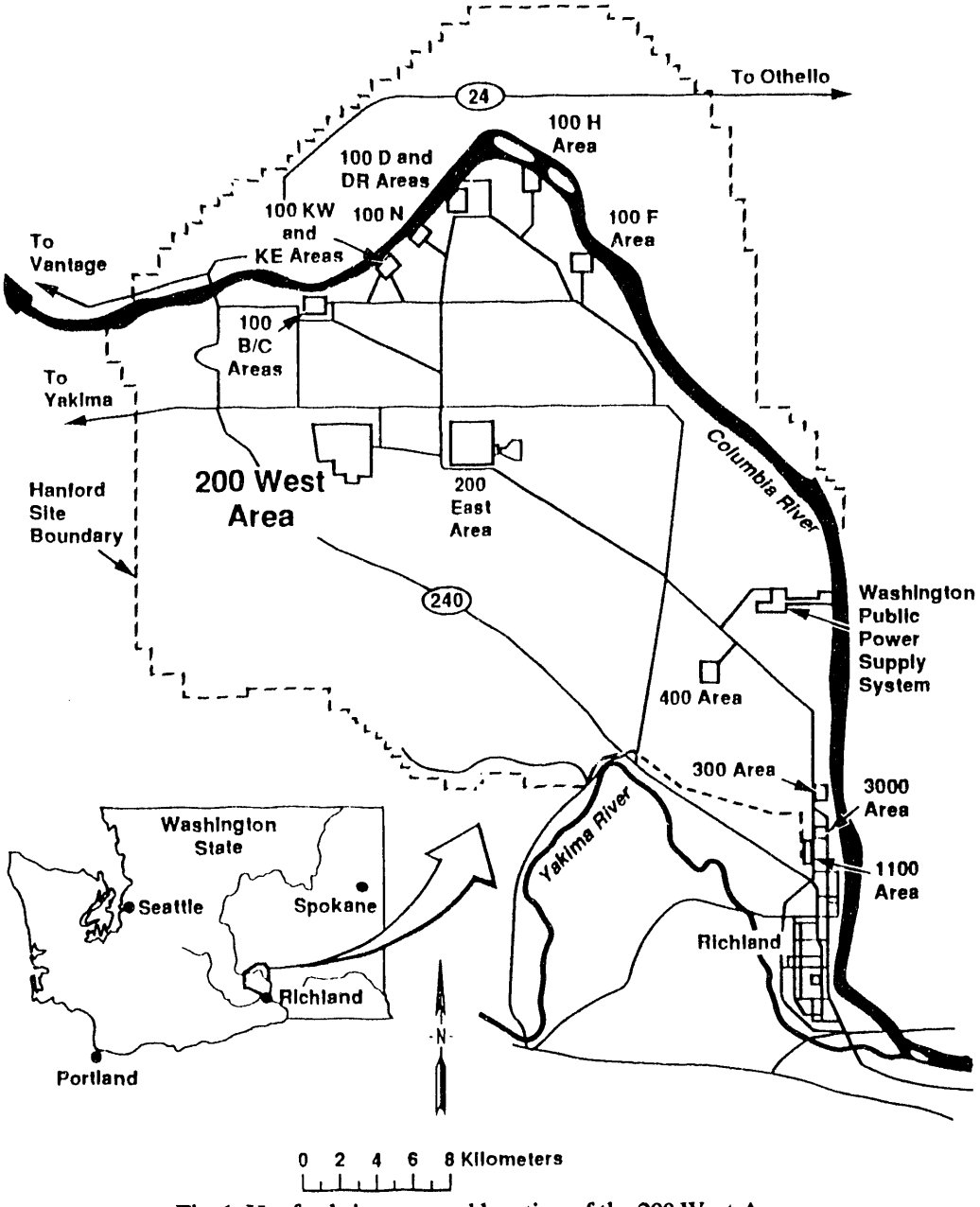


Fig. 1. Hanford site map and location of the 200 West Area.

SUMMARY OF INITIAL PHASE OF SITE EVALUATION

Site Operations

This section describes site carbon tetrachloride usage and disposal at and near the 200 West Area Z Plant (Fig. 2). No other plant in the 200 West Area is known to have used carbon tetrachloride.

Z Plant (currently called the Plutonium Finishing Plant) was designed to process plutonium to a final product form on one of three process lines. Each of these process lines generated side streams which contained recoverable quantities of plutonium. The Recuplex facility and the Plutonium Reclamation Facility (PRF) were established at the plant to recover plutonium from these streams and were the primary contributors of carbon tetrachloride to 200 West Area soils.

The carbon tetrachloride was used, in mixtures with other organics, as a solvent to recover plutonium from aqueous streams. The aqueous waste stream, characterized as a high-salt aqueous waste, was primarily an acidic, concentrated nitrate solution. The chemical processes used to recover plutonium resulted in the production of actinide-bearing aqueous and organic waste liquids. The primary radionuclide components of these liquids were $^{239/240}$plutonium and ^{241}americium.

Both the aqueous and organic phases were discharged to the same liquid waste disposal sites. The organic liquid was periodically discharged batch-wise and was also a minor (less than 1%) component of the aqueous phase.

The carbon tetrachloride disposal sites, located near Z Plant in the 200 West Area, are: the 216-Z-9 Trench; 216-Z-1A Tile Field; and 216-Z-18 Crib (Fig. 2). The 216-Z-9 Trench was used from 1955 to 1962 to receive all organic and aqueous waste from the Recuplex facility. Organic and aqueous waste from the PRF was discharged to the 216-Z-1A Tile Field from 1964 to 1969 and to the 216-Z-18 Crib from 1969 to 1973. Discharge of carbon tetrachloride to the soil column was discontinued in 1973.

Estimates of the volumes and quantities of various liquids and contaminants discharged to the three carbon tetrachloride disposal sites are summarized in Table I. A total of 363,000 to 580,000 L of carbon tetrachloride is estimated to have been discharged to the soil column between 1955 and 1973.

Boreholes have been drilled to characterize and/or monitor the three carbon tetrachloride disposal sites from 1949 to 1978; 46 boreholes are potentially available for additional characterization, monitoring, and remediation.

TABLE I

Contaminant Inventory in Carbon Tetrachloride Liquid Waste Disposal Sites

Contaminant	216-Z-9	216-Z-1A[a]	216-Z-18
Carbon tetrachloride (L)	83,000-300,000	170,000	110,000
Plutonium (kg)	106[b]	57	23
Americium (kg)	2.5	1	~0.4
Total Liquid (L)	4.09×10^6	5.2×10^6	3.86×10^6
Period of Use	1955-1962	1964-1969	1969-1973

[a] From 1949 to 1959 the 216-Z-1A Tile Field received approximately 1 x 106 L of slightly basic, aqueous waste via overflow from associated cribs prior to disposal of PRF waste. From 1964 to 1969, PRF wastes were discharged directly to 216-Z-1A.

[b] 58 kg were later removed.

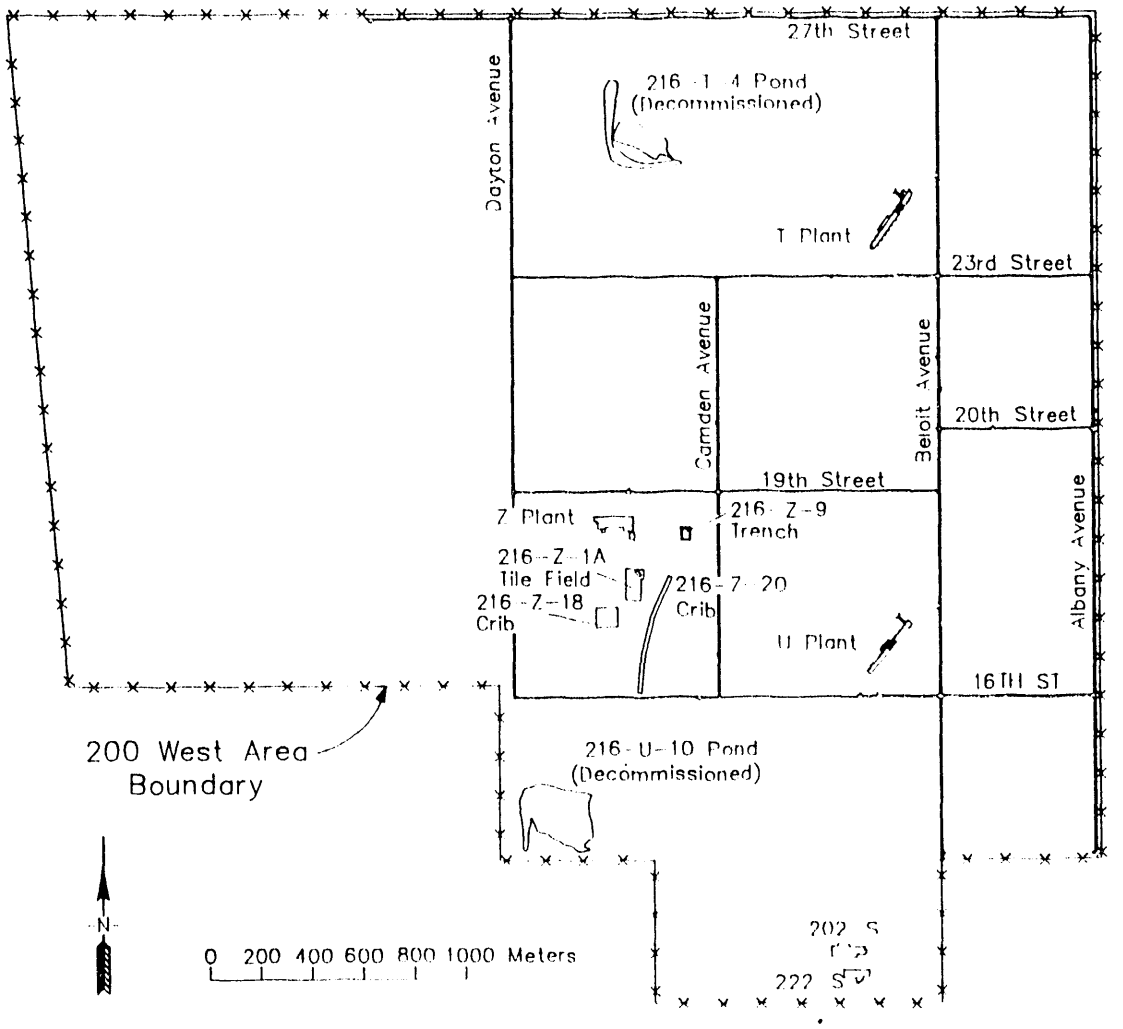


Fig. 2. Site map of the 200 West Area

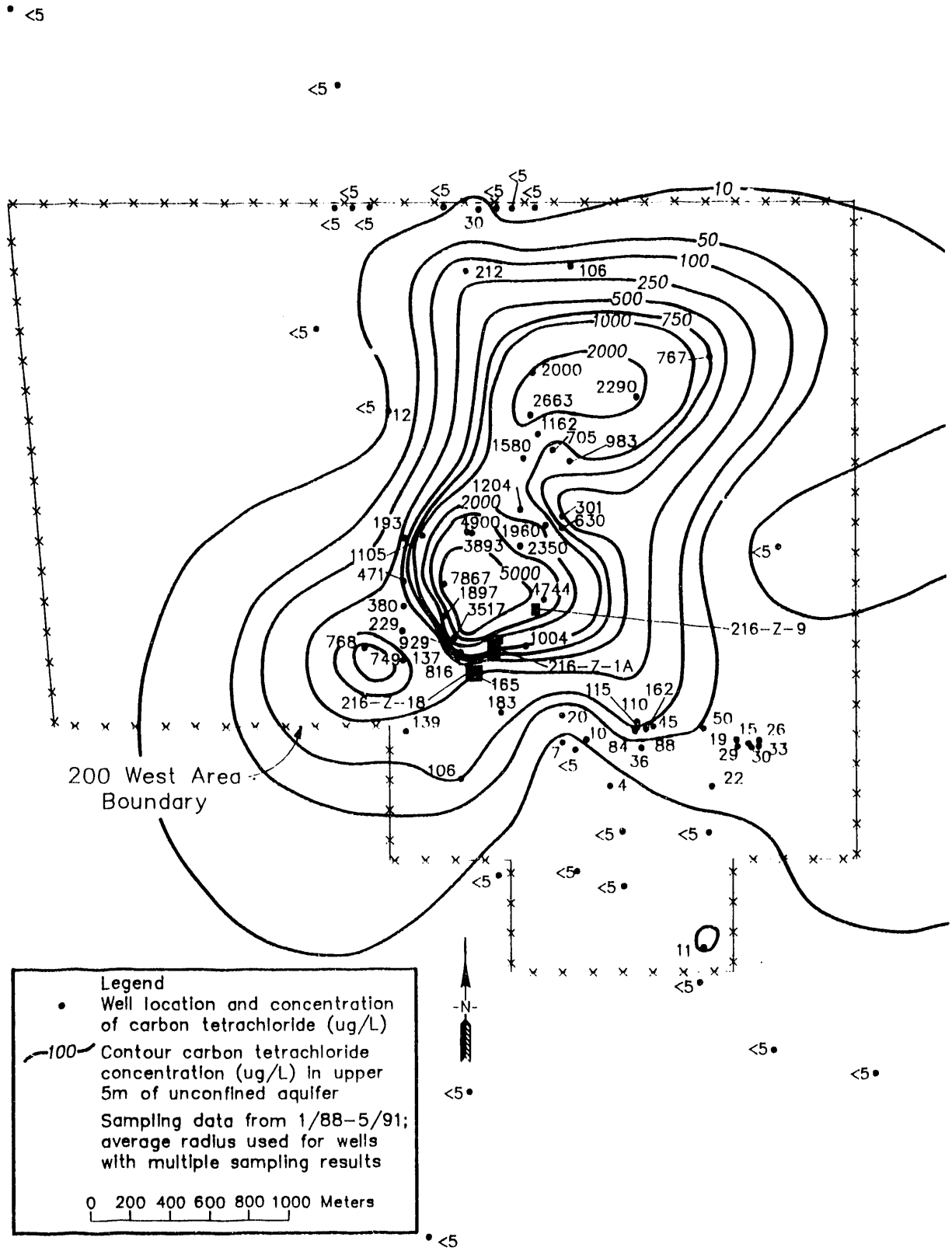


Fig. 3. Carbon Tetrachloride concentration contours in the 200 West Area groundwater, 1988-1991.

Site Hydrogeology

The geology of the 200 West Area consists primarily of fluvial and glaciofluvial sediments underlain by basalts. The sediments are, from oldest to youngest:

- Ringold Formation - a series of alluvial sands and gravels, and overbank and lacustrine deposits, of late Miocene to Pliocene age.
- Plio-Pleistocene unit - basaltic detritus and a carbonate-rich paleosol, often referred to as the caliche layer.
- Early "Palouse" Soil - eolian silt and fine-grained sand.

- Hanford formation - glaciofluvial gravels, sands, and silts deposited by middle to late Pleistocene cataclysmic flood waters.

The uppermost aquifer in the 200 West Area is unconfined and located within the Ringold Formation. The depth to the water table ranges from 58 to 82 m across the 200 West Area and from 60 to 66 m beneath the carbon tetrachloride disposal sites. The saturated thickness of the uppermost aquifer ranges from 67 to 113 m. Locally, groundwater flow directions are generally radial outward from the southwest portion of the 200 West Area primarily because of the continuing influence of the residual groundwater mound underlying the decommissioned 216-U-10 Pond (Fig. 2). Recharge to the aquifer is primarily artificial recharge from waste disposal activities.

The unsaturated zone, which consists of sediments of the Ringold Formation, Plio-Pleistocene unit, early "Palouse" soil, and Hanford formation, ranges in thickness from 58 to 82 m. The Hanford formation is 34 to 40 m thick in the vicinity of the three carbon tetrachloride disposal sites. The low average moisture content of this unit (5.3%) and the common lack of matrix in the gravel facies make it particularly attractive for application of soil vapor extraction technology. Because the Plio-Pleistocene unit is less permeable than the other units, it may temporarily divert or perch liquids and/or dense vapors. The top of this unit occurs approximately 40 m below ground surface.

Nature and Extent of Contamination in Unsaturated Zone

The results of the initial phase of site characterization indicate that carbon tetrachloride vapors are still contained within the unsaturated zone underlying the carbon tetrachloride disposal sites in concentrations sufficient to support an effective early removal action. Other phases of carbon tetrachloride (liquid, adsorbed to soil particles, or dissolved in soil moisture) are also expected in the unsaturated zone but have not been directly observed.

Carbon tetrachloride vapor concentrations in unsaturated zone boreholes, ranging in depth from 24 to 63 m below ground surface, were analyzed using portable photo-ionization detectors in conjunction with a carbon tetrachloride colorimetric tube. Analyses of samples collected from the bottoms of the boreholes or detected at the wellhead at virtually every well associated with the three carbon tetrachloride disposal sites indicated concentrations ranging from approximately 1 p/m vol to 200 p/m vol carbon tetrachloride. However, the observed vapor concentrations may vary with time and appear to be influenced by fluctuations in the barometric pressure.

A permanent soil gas survey network was installed to 1.5 m depth in the vicinity of the 216-Z-18 Crib to determine the feasibility of using soil gas surveys to map carbon tetrachloride vapors in this area and to discover whether the region of highest concentrations coincides with the location of the disposal crib. Carbon tetrachloride concentrations, analyzed first with a portable gas chromatograph and three weeks later with a field screening instrument, reached approximately 15 p/m vol. Again, the observed concentrations appear to depend at least in part on the barometric pressure. Concentrations were highest approximately 45 to 75 m northwest of the crib.

To test the soil vapor extraction system at the 216-Z-1A Tile Field, four borehole casings were perforated in zones chosen to sample vapors at specific geologic intervals (3,4). The samples were analyzed with a gas chromatograph/mass spectrometer. During an 80-h-long extraction test, concentrations of up to 915 p/m vol at a depth of 35 to 42 m below ground surface were observed under a flow rate of 8.5 to 8.8 m^3/min and a well vacuum of 89 to 102 cm water gage. The tests also indicate that carbon tetrachloride vapor has migrated laterally, as seen in the 19 p/m vol concentration observed in a well at least 20 m outside the edge of the tile field.

Vapor samples collected during the vapor extraction system tests were analyzed for other volatile organic compounds. Chloroform was detected, in trace amounts; 2-butanone was also detected, but this may be a reflection of the analytical method.

Plutonium and americium have been detected in the soils beneath the 216-Z-1A Tile Field, and naturally-occurring radon was detected in the vapors extracted from the tile field (4,5). Plutonium and americium have also been analyzed in the soil beneath the 216-Z-9 Trench (6). Although soils from the 216-Z-18 Crib have not been sampled for radionuclides, radioactive contaminants were detected during scintillation probe surveys of existing wells (7).

Carbon tetrachloride or chlorinated hydrocarbons have been detected with field screening instruments during drilling in over half of the 70 wells drilled throughout the 200 West Area since 1987. Most of the reported detections were below the Plio-Pleistocene layer, although wells west of 216-Z-18 Crib had detections both above and below this unit. Analysis of soil samples from some of these wells also indicate the presence of carbon tetrachloride in the unsaturated zone north and west of the disposal sites. Other compounds, including carbon tetrachloride degradation products chloroform and methylene chloride, have also been observed in trace amounts in these soils (2).

Nature and Extent of Contamination in Groundwater

The upper 5 m of the unconfined aquifer in the vicinity of the carbon tetrachloride disposal sites is contaminated with carbon tetrachloride. Average concentrations of up to 7,430 p/b have been observed. In addition to carbon tetrachloride, chloroform and traces of tetrachlorethylene and trichloroethylene were detected near and downgradient from the 216-Z-9 Trench; methyl ethyl ketone was detected in a single bailed sample at the 216-Z-18 Crib.

Throughout the 200 West Area, the carbon tetrachloride groundwater plume (as defined by the 5 p/b contour) is estimated to cover an area of 11 km^2 and to contain only a small percentage of the carbon tetrachloride thought to have been disposed of in the three disposal sites (Fig. 3). The carbon tetrachloride plume appears to be emanating from the area of the disposal sites and extends primarily to the north. Other groundwater contaminant plumes that currently intersect the carbon tetrachloride plume include chloroform, cyanide, fluoride, hexavalent chromium, trichloroethylene, nitrate, ^{90}stronium, tritium, ^{99}technetium, ^{129}iodine, and uranium (8).

Sampling data suggest that there is deeply distributed carbon tetrachloride, at least near the 216-Z-9 Trench, where carbon tetrachloride was detected 52 m below the water table.

CONCEPTUAL MODELS

Based on the initial phase of site characterization, two basic conceptual models have been proposed to describe the

observed contamination in the groundwater and unsaturated zone (2). The two models differ primarily in the nature of the source of contamination to the groundwater.

In both conceptual models, carbon tetrachloride vapor, which is denser than uncontaminated soil vapor, moves downward and laterally away from the disposal sites, providing a continuous source of contamination to the groundwater. In one model a significant amount of the carbon tetrachloride disposed to the ground in the 200 West Area is still present within the unsaturated zone and the vapors are the source of groundwater contamination. In this model, carbon tetrachloride discharged as a dense, nonaqueous phase liquid (DNAPL) has not reached the uppermost aquifer as a separate phase but remains in the unsaturated zone.

The second conceptual model is that some of the carbon tetrachloride discharged as a DNAPL has reached the uppermost aquifer as a separate liquid phase. The DNAPL has settled in the aquifer and provides a continuous source of contamination by dissolution. Residual contamination would also remain in the unsaturated zone.

In both models, aqueous phases containing dissolved carbon tetrachloride migrate to and contaminate the groundwater. The discharges of aqueous phase containing dissolved carbon tetrachloride may have reached and contaminated the groundwater. In addition, carbon tetrachloride vapors in the unsaturated zone, which equilibrate with perched water and/or waste water from other sources, may then be transported to the water table in dissolved form.

Because of differences in crib sizes and quantities of waste received at the three disposal sites, it may be that one conceptual model is appropriate for one or two crib sites and the other conceptual model is appropriate for the other(s).

FUTURE CHARACTERIZATION

The conceptual models were developed by integrating a general understanding of the behavior of carbon tetrachloride in the subsurface with the distribution of carbon tetrachloride observed during the initial phase of site characterization. However, the nature and extent of the carbon tetrachloride contamination in the 200 West Area subsurface remains largely unknown. A better understanding of the contaminant phases and distribution would improve the design of the remediation system and the performance objectives of the system. Thus, the next phase of site evaluation tasks are designed to further refine these models and to test predictions based on these models. Examples of additional field activities being considered include drilling and sampling new boreholes; improving and further evaluating soil gas sampling; and establishing baseline monitoring networks to evaluate remediation performance.

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ACCELERATED CLEANUP OF THE 618-9 BURIAL GROUND

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ABSTRACT

This paper describes the time-critical expedited response action taken at a potentially uranium-contaminated solvent waste disposal trench on the Hanford Site, in southeastern Washington state. An expedited response was initiated to remove solvents, still contained in their original containers, to prevent them from leaching into the groundwater. Actions at the site were initiated in February and completed in May of 1991.

INTRODUCTION

The Hanford Site began operations in 1943, as one of the sites for plutonium production associated with the Manhattan Project. It has been used, in part, for nuclear reactor operation, reprocessing of spent fuel, and management of radioactive waste. Throughout Hanford Site history, prior to legislation regarding disposal of chemical waste products, some chemical waste byproducts were disposed of via burial in trenches. One such trench was the 618-9 Burial Ground. This burial ground was suspected to contain approximately 5,000 gallons of uranium-contaminated organic solvent, disposed of in standard 55-gallon metal drums. The waste was produced from research and development activities related to fuel reprocessing.

On October 18, 1990, an Agreement in Principle between the U.S. Department of Energy (DOE), the U.S. Environmental Protection Agency (EPA) and the State of Washington Department of Ecology (Ecology) was signed which stated that the 618-9 Burial Ground would be among a number of candidate sites to be considered for expedited response actions (ERA). An ERA is a provision included in the *Comprehensive Environmental Response, Compensation, and Liability Act of 1980*, as amended. This provision allows for an ERA to be taken at waste sites where early remediation will abate potential threats or prevent significant or increased degradation if action were delayed until completion of the remedial investigation/feasibility study and the record of decision. In December 1991, following the review of preliminary planning documentation, DOE was instructed by the EPA and Ecology to initiate the planning necessary to implement an ERA for the 618-9 Burial Ground. After review of the project plan for the 618-9 Burial Ground by EPA and Ecology, an Action Memorandum was issued on February 15, 1991, initiating time-critical excavation activities for the 618-9 Burial Ground ERA.

The 618-9 Burial Ground ERA is presented in this document to describe the actions taken, and to propose methods to promote safer and more efficient ERA in the future.

LOCATION AND PHYSICAL DESCRIPTION OF THE 618-9 BURIAL GROUND

The Hanford Site covers approximately 560 square miles in southeastern Washington State. The 618-9 Burial Ground is located on the Hanford Site, approximately 1 mile west of the Columbia River, and a few miles north of Richland, Washington (Fig. 1). The Hanford Site lies within the Columbia Basin, which includes Pasco, Kennewick, Richland, and the surrounding agricultural inhabitants.

PREPARATION ACTIVITIES

Preliminary Investigations

Prior to implementation of removal activities, preliminary investigations were performed. The purpose of these investigations was to gather information that would assist in identification of the contents of the burial ground and the potential hazards posed. Activities conducted during the preliminary investigation were the following: historical research (including oral interviews) a ground-penetrating radar survey, and a soil gas survey.

Historical records indicated that the facility was operational in the early 1950's, and received 5,000 gallons of uranium-contaminated solvent used in laboratory experiments. The solvent was suspected to be methyl isobutyl ketone (MIBK), also known as hexone. The solvent was believed to have been contained in 55-gallon metal drums; however, the number of drums that were buried was not documented.

Oral interviews with personnel employed at the facility during the 1950's provided conflicting information regarding the items disposed of in the burial trench. It was suggested that chemicals other than hexone were buried, and that tanks and other debris were disposed therein. In reference to uranium in the solvents, it was suggested that the solvents would have been distilled prior to disposal for uranium recovery, and that the uranium would not have been discarded as waste.

A ground-penetrating radar survey was conducted to define burial ground boundaries and to identify the depth of buried objects. Results of the survey indicated anomalies occurring at approximately 4 feet below ground, verifying the historical documentation. A trench section and plan are shown in Fig. 2.

A soil gas survey was conducted to determine if hexone and other volatile organic compounds (VOC) were migrating through the soil at the burial ground. Positive indication of VOC suggested that some of the buried drums were breached or leaking. A total of 24 soil gas samples were collected and qualitatively analyzed via a gas chromatograph. Of the 24 samples collected, 16 identified the presence of unknown VOC. To better understand the readings, all total hydrocarbon readings were converted to a toluene equivalence. The results ranged from 0.11 to 1.95 ppm. The unknown VOC were observed in the eastern half of the burial ground.

Documentation

Prior to the initiation of field activities, preliminary investigation results were used in the preparation of regulatory and internal requirements regarding national environmental policy and cultural resources, health and safety documentation, and procedures to implement the activities on Hanford Site.

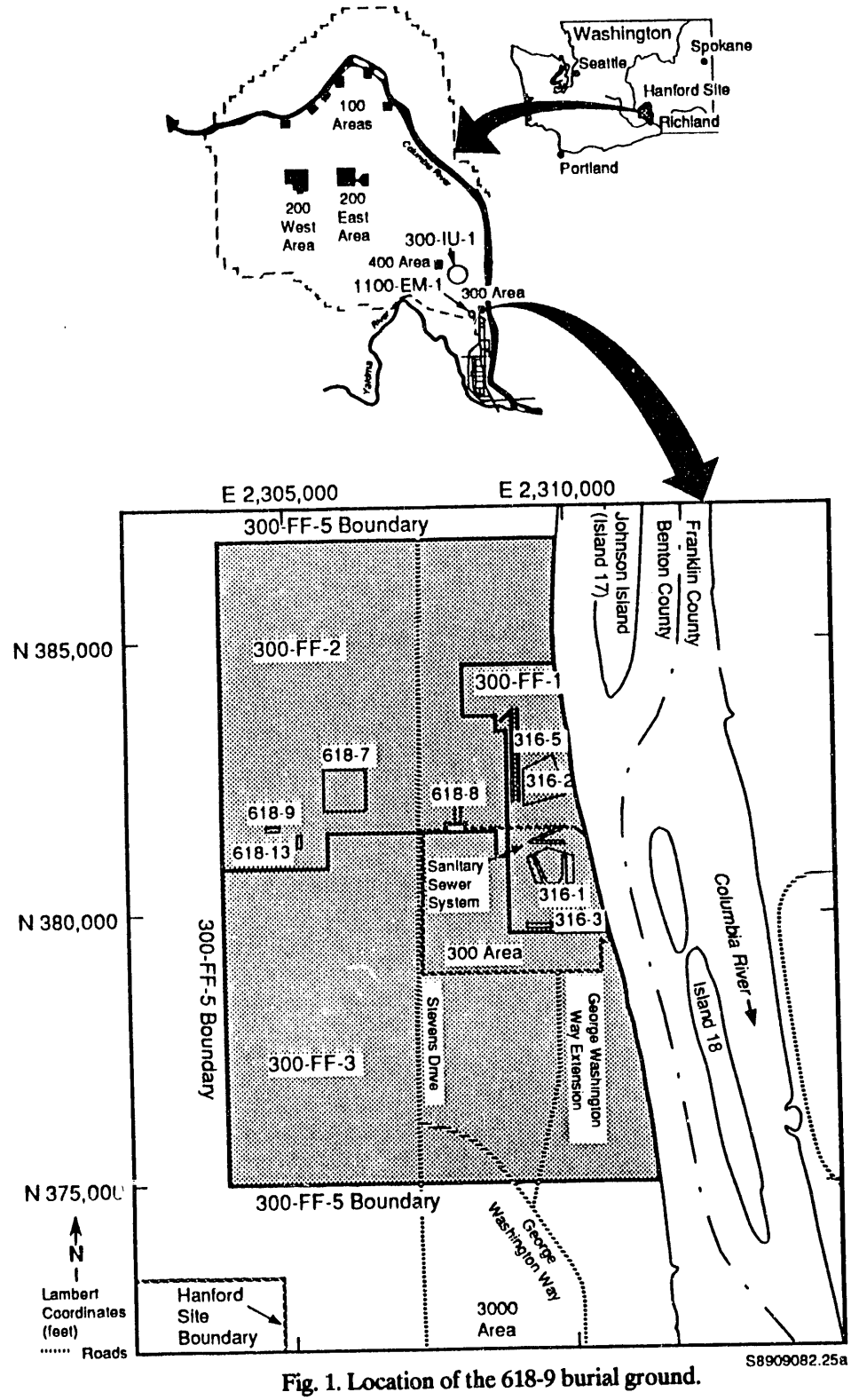


Fig. 1. Location of the 618-9 burial ground.

The National Environmental Policy Act documentation was fulfilled under the categorical exclusion for removal actions. The site does not contain any cultural resources and, as such, minimal documentation to this effect was necessary.

Two health and safety documents, one to fulfill DOE facility's safety requirements and one to fulfill Occupational Safety and Health Administration requirements were prepared. Both documents are intended to protect both onsite and offsite personnel during the course of activities at the site. While the Facilities Safety Document (DOE Order 5481.1B, "Safety Analysis and Review System") discusses the maximum potential accident at the site, the other document is a procedural document outlining site activities, personal protective equipment, and emergency procedures. While providing essentially the same benefit to the public and workers, the preparation of two sets of safety documentation requires a duplication of effort. One safety document could be prepared that would encompass the requirements of both agencies, be more thorough, and be easily accessible by all site workers.

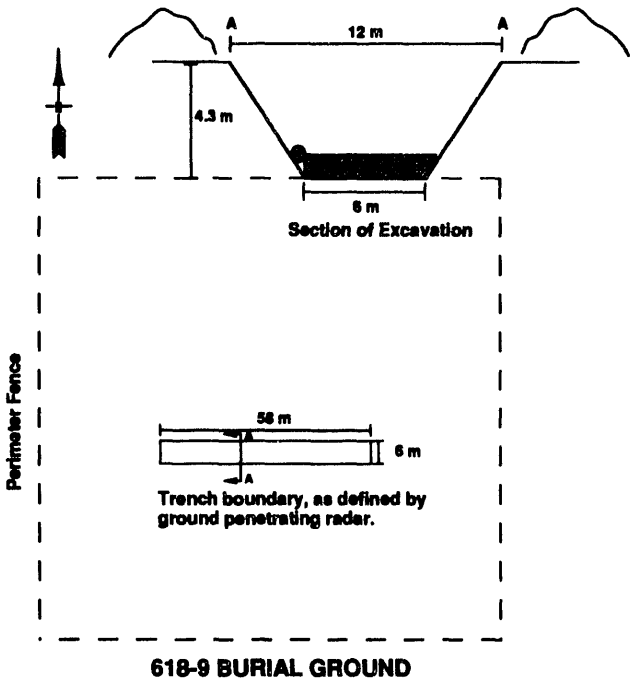


Fig. 2. Plan and section of the 618-9 burial ground.

Enough conflicting information regarding the actual contents of the trench existed prior to excavation such that the remediation team was not sure exactly what hazards would be encountered. The work procedures were prepared with some contingency for changing field conditions; however, the requirement to specifically detail each step caused a procedure to be written that was based on assumptions. Because of this, procedure changes were required with changing field conditions. Due to the relative simplicity of this ERA and the fact that the hazards were less than expected when encountered, changes in project documentation did not hinder progress to any great degree. Having skilled personnel with the ability to quickly evaluate field conditions was critical to continued operations.

EXCAVATION ACTIVITIES

Excavation of the burial ground commenced on February 28, 1991. Digging originated at the center of the trench, over areas showing anomalies in the geophysical survey. To avoid breaching the drums, soil was machine-excavated, leaving 1 to 2 feet of overburden. Hand digging (using non-sparking equipment) was performed on the remaining soil. Although extreme caution was observed throughout excavation activities, one drum was breached, causing a leak of approximately 1 to 2 gallons of a kerosene-like material. This drum had been sitting on its side, 1 to 2 feet higher than the other drums in the trench. The spill was cleaned up and the contaminated soil was contained for disposal.

The initial excavation uncovered a variety of debris covered by 4 feet of backfill. The debris included (among other items) empty waste drums, a wheelbarrow, construction debris (corrugated siding), breached bags of ammonium nitrate fertilizer, unidentified white powders, and several lead bricks. Figure 3 is a side view of the drums found in the bottom of the west end of the trench. Note that the center drums did not contain solvents. Over the years, the tops had collapsed and filled with the overlying sand.

All drums were found to be located in the east and west ends of the trench, covered by at least 10 feet of overburden (6 feet deeper than expected). Drums in the western end of the trench were fairly well preserved, and approximately 1,600 gallons of solvents were recovered. Drums in the eastern end of the trench were severely corroded and only parts of the drums remained. Figure 4 depicts the three sections of the trench (this figure is not to scale).

A nonsparking bronze spike, welded to the backhoe bucket, was used to remotely punch a hole through each drum.

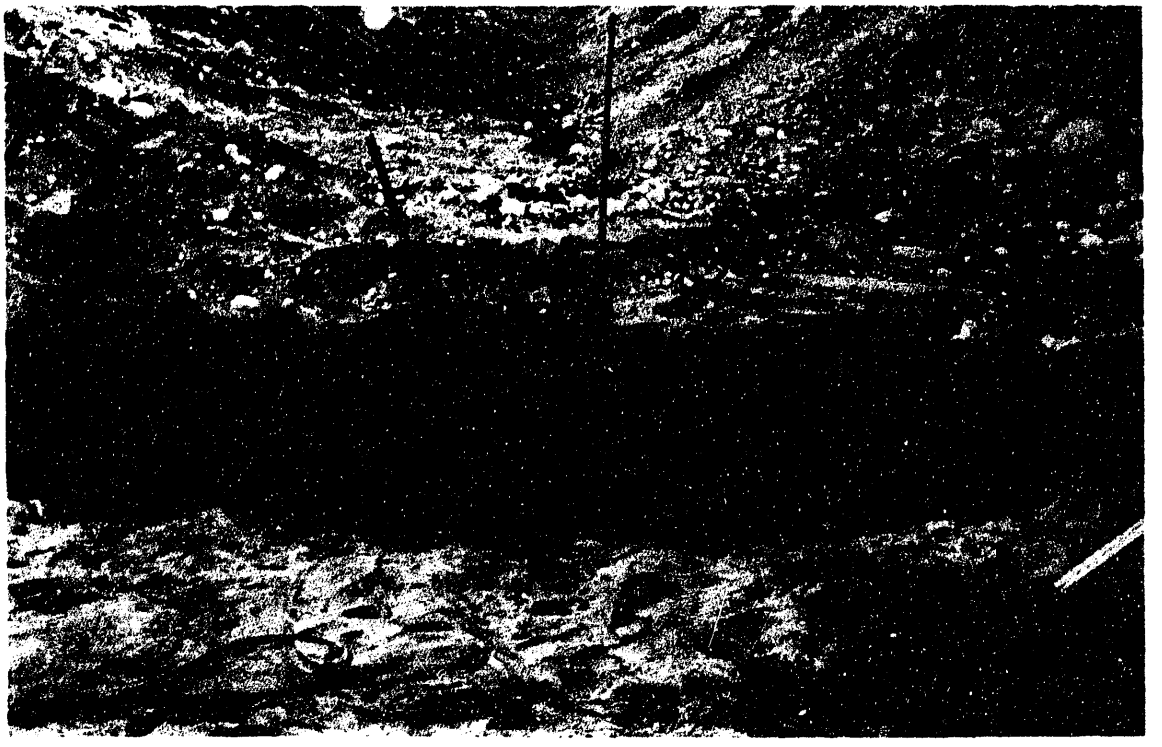


Fig. 3. Side view-west end of trench.

TABLE I
Constituents of Concern

Constituent of Concern	Reason	Analysis
MIBK (hexone)	Known buried solvent	Volatile organics
Kerosene/tributyl phosphate[a]	Known buried solvent	Semivolatile organics
Ammonium nitrate	Breached bags found in trench	Anions
Metals	From debris in trench	Metals
Uranium	Solvents suspected to have been contaminated with uranium	Total and isotopic uranium; gamma scan; total alpha; total beta; to verify no other contamination.

[a]The term kerosene, as used onsite, is actually a purified derivative of kerosene, containing straight chain hydrocarbons in the range of $C_{10}H_{22}$ through $C_{18}H_{38}$. Another term for this compound is normal paraffin hydrocarbons (NPH).

If liquid was found, it was tested with a field test kit and subsequently pumped into a new drum. Preliminary field sampling was used to determine liquid compatibility, and to test for peroxides.

Environmental and personal air monitoring for radiological and organic constituents was conducted throughout implementation of Phase I activities. Organic contaminants were collected on an activated charcoal media at flow rates between 10 and 200 mL/min, depending on personnel and site conditions. The maximum concentrations of carbon tetrachloride, hexone, and kerosene present during nonradiological monitoring activities were < 0.08 ppm, 0.22 ppm, and < 5 mg/m^3, respectively. All readings were below limits set for personnel exposure, and did not pose threats to the public.

Radioactive monitoring was conducted via continuous air monitors. Samples were collected on high-efficiency glass filters at a flow rate of 2.6 m^3/hr. Results of the radiological air samples indicated that levels were at or near background, and were not affected by field operations. It has since been discovered that the zone was not a major disposal site for radioactive wastes.

On completion of the excavation activities, sampling of the recovered liquids, potentially contaminated soil, and other miscellaneous waste items (i.e., unknown white powder) was conducted. Sampling activities were organized into the following categories: (1) preliminary solvent sampling, (2) recovered solvent sampling and miscellaneous waste sampling and (3) soil sampling.

Preliminary sampling, using a field test kit, provided a preliminary designation of the chemical compound and its compatibility with other materials found in the trench. This information was used to develop a rough estimate of the volume of hexone and/or kerosene in the trench, to calculate a conservative estimate of the volume which could have leaked, and to assist in waste segregation. From this sampling, it was estimated that 700 gallons of hexone (ketone) and 900 gallons of kerosene were recovered from the trench. (The field designation is in parentheses; chemical identification has been assumed from process knowledge.)

The recovered solvent and other items found in the trench were sampled for waste designation purposes. The recovered solvent sampling was conducted by removing solvents from the 55-gallon drum using a decontaminated sampling tube. The samples were analyzed for organics (volatile and semivolatile), inorganic anions, metals, flashpoint, total and isotopic uranium, gamma scan, total alpha, and total beta. Samples of the waste items were collected by driving a decontaminated metal tube through the material to obtain a representative sample. These samples were analyzed for the suspected constituents of concern. Sample results are pending.

Soil samples were taken from three different trench sections and the spoil piles (Table I). Analyses were selected to detect constituents of concern in the trench. These were chosen from the historical information, oral interviews, and from the items discovered during excavations.

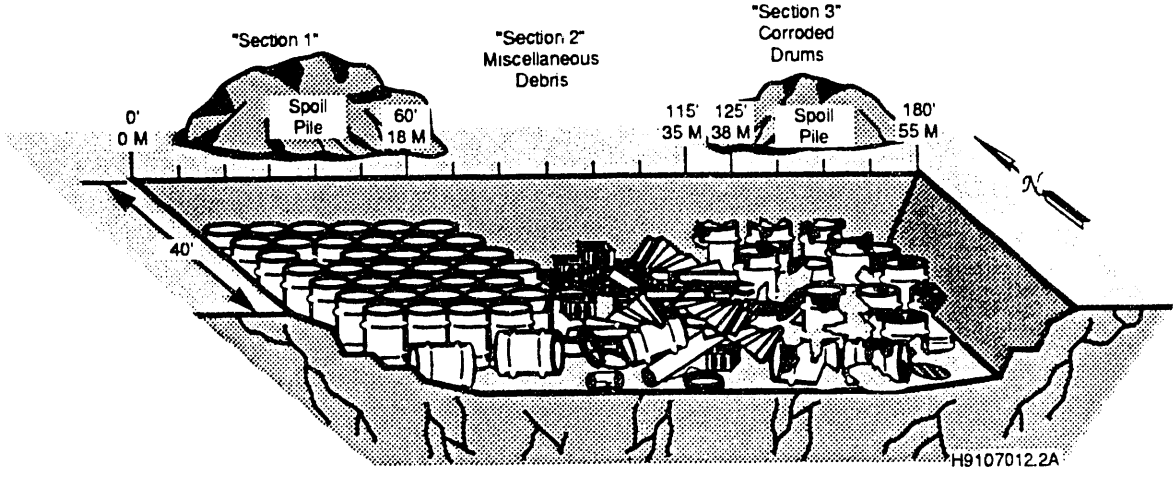


Fig. 4. Burial ground trench sections.

ENGINEERING EVALUATION

An engineering evaluation of the actions at the site will be prepared for submittal to the regulatory agencies. The evaluation will discuss the activities completed to date, and present the results of the soil sampling. If the soil analyses indicate no risk to the public, no further actions other than housekeeping will be conducted at the site. If the contamination at the site poses risks to the public or the environment, there are two paths that can be taken to remediate the site: (1) immediate soil cleanup as a continuation of the ERA if threat is immediate; (2) further investigation and eventual cleanup as part of the past practice operable unit which encompasses the burial ground.

SUMMARY AND CONCLUSIONS

The excavation and removal activities safely and successfully removed over 1,600 gallons of solvent and a large volume of debris from the 618-9 Burial Ground without any negative impacts to the environment. Sample results are pending; however, preliminary results indicated that the recovered solvents were primarily NPH/tributyl phosphate, and hexone. A few of the drums appear to be a mixture of the compounds, with trace quantities of other chemicals. Waste will be disposed offsite at a permitted treatment, storage, and/or disposal (TSD) facility pending approval by the DOE.

Removal of the trench debris facilitated further action at the past-practice unit by (1) identifying items buried in the trench, thereby exposing constituents of concern; (2) removal of potential hazards; and (3) exposing the trench bottom for soil sampling.

Conducting similar actions at sites which may not pose an immediate threat to health and safety, but will facilitate remedial actions at hazardous wastes sites should be an option at past- practice sites. The benefit from the knowledge of actual conditions, instead of continued speculation will provide a means for remediating in a more expedient and economical manner.

While the conduct of ERA provides immense benefit to the public and to successful remediation of a past-practice unit, certain issues tie the hands of project engineers in attempting to prepare for safe field operations without being certain of actual conditions. When excavating a burial ground with little documentation, the field team leader needs the authority to make immediate decisions, in conjunction with the site safety officer. While most site conditions can be anticipated in the planning phases, nothing is certain, and documentation requirements need to be flexible.

To continue to accomplish these accelerated cleanups, it will be necessary to work with the regulators and the DOE in developing flexible documentation to assure work is done safely, yet provides more flexibility in the field, and less redundancy. The ability for key qualified field personnel to make real time decisions is critical to completing actions on schedule, in a safe manner.

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REMEDIATION STRATEGIES FOR PERCHED WATER BODIES UNDERLYING THE IDAHO CHEMICAL PROCESSING PLANT AT THE IDAHO NATIONAL ENGINEERING LABORATORY

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ABSTRACT

Analysis of water samples collected from perched water underlying the Idaho Chemical Processing Plant (ICPP) at the Idaho National Engineering Laboratory (INEL) indicates the presence of low levels of radionuclides. The perching layers are formed by dense basalts and/or sediment interbeds with sufficient clay to form an aquitard. The distribution of contaminants and depth to water levels observed in the perched water well monitoring network suggest the perched water occurs as discrete bodies of water, but these are not necessarily interconnected across a large area. Present data suggests that the perching occurs as discrete "pools," and the presence of contamination is a function of vertical contaminant transport from above. The remediation of this perched water will be dependent upon the types of contaminants, the hydrogeologic conditions, the physical setting, and the size of the perched water body. Remediation strategies under consideration include the use of wells for the extraction of contaminated water and the installation of horizontal wells.

A preliminary conceptual model has been developed and is being refined as additional hydrogeologic and contaminant data are acquired. Contaminant transport hypotheses have been formulated, and tests of those hypotheses are planned to assist with the refinement of the conceptual model. The testing of transport hypotheses and development of the conceptual model will help provide the basis to evaluate the available options for remediation of the perched water and to select the most effective strategy(ies) for implementation.

OBJECTIVE OF THE PERCHED WATER WELL MONITORING INSTALLATION

A monitoring well network has been installed adjacent to the Idaho Chemical Processing Plant (ICPP) high-level liquid waste tank farm to address three types of objectives: near-term, mid-term, and long-term. The near-term objectives are to investigate the potential for release from the high-level liquid waste tank farm to the subsurface environment and to install wells/lysimeters to monitor perched and vadose zone waters. The mid-term objectives are to establish an understanding of the hydrogeologic setting associated with the perched water body and the overlying vadose zone, to characterize contamination in the perched zone, to assist with the identification of the potential source(s) of recharge to the perched water body, to identify sources of contamination, and to provide the basis to evaluate strategies for the remediation of the contamination observed in the perched water zone. The monitoring wells will be used to evaluate the changes that occur with time in the perched zone, including changes in the concentration of contaminants, depth to water, and hydraulic interconnection. The long-term objective is to provide data to measure the effectiveness of the selected remediation strategy(ies).

BACKGROUND

The ICPP is a facility at the Idaho National Engineering Laboratory (INEL), located within a fenced security area of more than 200 acres. Westinghouse Idaho Nuclear Company, Inc. (WINCO), under contract with the U.S. Department of Energy-Idaho Operations Office (DOE-ID), is charged with the mission to reprocess nuclear fuels for the U.S. Department of Defense.

Hydrogeologic Setting

The ICPP is located on alluvial materials deposited by the Big Lost River. Surficial sediments at the ICPP can be divided into two distinct layers. The upper layer is a poorly sorted gravel to gravelly sand, with traces of silt and clay. The lower layer directly overlies the basalt and is composed of fine-grained material ranging from a fine sand to a clayey silt. This layer can be up to 10 feet in thickness or may be absent altogether, and appears to be independent of the depth to the basalt as it is found on both high and low areas of the basalt surface.

Underlying the surficial sediments are 2,000 to 3,000 feet of basalt flows interbedded with sedimentary materials. Most of the interbeds are composed of fine sand to clay-sized material. There are also some rubbly flow break zones that are composed of sand to gravel-sized cinders and clinkers (1). The most significant of these interbeds, due to its proven ability to perch groundwater, is a zone of alternating thin basalt flows and clayey sediments that extends from 90 to 150 feet, with water normally perching around 110 feet.

The thickness of the individual flows is variable. In 1965, an average thickness for basalt flows was reported on the order of 10 feet for the INEL area (2), and in 1984, an average flow thickness of 20 to 25 feet was reported for the eastern Snake River Plain (ESRP) basalts (3). Considerable variation also occurs in the texture within individual flows. The top part of the flows is typically highly vesicular and fractured, and exhibits rubble zones from weathering when exposed at the surface. Exposed fractures commonly have silt and clay in-filling material. The middle portions of the flow have few vesicles and are dominated by vertical fractures formed during cooling. The base of many flows is glassy in texture and is slightly vesicular.

The Snake River Plain Aquifer (SRPA) is a regional groundwater system that underlies most of the ESRP and all of the INEL. Estimates show that it may contain more than 1 billion acre-feet of water (4 & 5). The groundwater flow direction is generally from north-northeast to the south-southeast. Groundwater flow is through intercrystalline and intergranular pores, fractures, interstitial voids, and interflows zones. The depth of the SRPA in the area of the ICPP is approximately 450 feet below the land surface, based on 1991 water level measurements. The direction and rate of groundwater movement in the vicinity of the ICPP is documented from monitoring contaminant plumes in the SRPA and is consistent with the regional trend. The rate of flow ranges from 5 to 20 feet/day (4).

Two perched water zones are routinely encountered during shallow (less than 200 feet) investigations at the INEL. The shallow perched zone occurs at the alluvium/basalt contact. Perching may occur locally as a result of the clay and silt in-filling material in the vertical fractures at the interface with the alluvium. The second, and generally more expansive perched zone, occurs at the contact between the basalts and the "110-foot interbed." The interbed material is comprised of silts and clays, which transmit groundwater at a much slower rate than overlying basalts and/or the underlying basalts that tend to be dense and massive with limited fracturing, hence a low vertical conductivity.

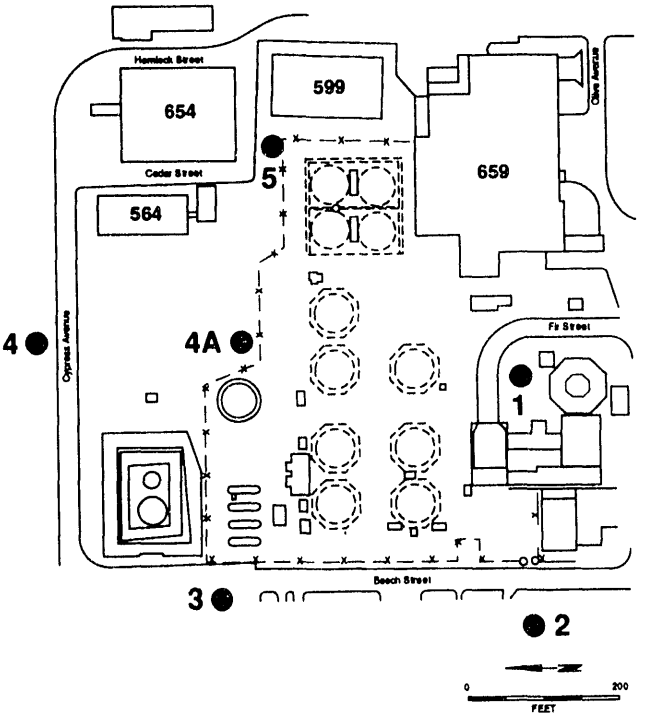


Fig. 1. Monitoring well locations, ICPP tank farm.

Monitoring Well Installation

A perched water monitoring well network has been installed around the perimeter of the ICPP high-level liquid waste tank farm as part of an investigation to identify potential releases from the tank farm to the subsurface. Fig. 1 illustrates the location of the monitoring wells and the adjacent high-level liquid waste tank farm. Two boreholes were drilled at sites 1, 2, 3, and 4. A shallow borehole was drilled to the top of basalt (34.3 to 44.6 feet below land surface), and either a well or lysimeter was installed. A deep borehole at each site was sampled and core-drilled to the bottom of the 110-foot interbed or underlying massive basalt (113.6 to 124.1 feet) with monitoring wells installed at all sites. At site 5, one borehole was drilled to 131.5 feet. One lysimeter was installed above the alluvium/basalt contact at 35.21 feet, and a deep lysimeter was installed within the 110-foot interbed (105.1 to 116.3 feet below land surface) in this borehole. Borehole 4A was drilled exclusively for sample acquisition to the bottom of the interbed and was backfilled with cement to the surface. All wells were drilled in accordance with guidance provided by the U.S. Environmental Protection Agency (EPA) Technical Enforcement Guidance Document (6).

Data from these monitoring wells have been integrated with data collected from a perched water monitoring well drilled southeast of the tank farm (well 55-06) in 1990 (refer to Fig. 2).

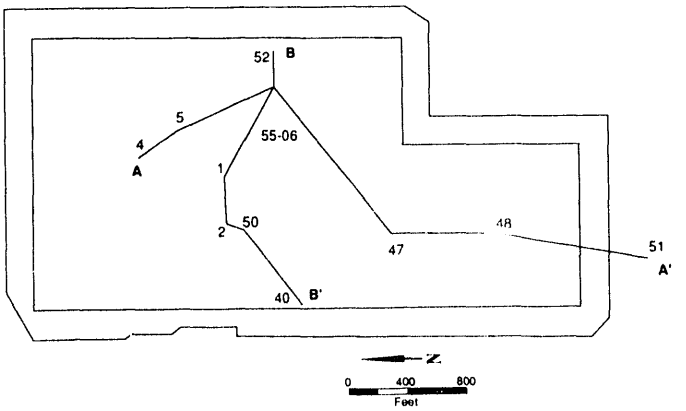


Fig. 2. Well locations used in cross section.

Chemistry of the Perched Water

Water samples collected in April 1991 from four groundwater monitoring wells were analyzed for radionuclides, volatile organic compounds, inorganic analytes, and general chemistry parameters, and are presented in Table I.

Radiochemistry results for the wells near the tank farm (identified as CPP33-2, CPP33-3, CPP33-4, and CPP55-06) detected Cesium-137 in three of the four wells at concentrations of 49.8, 1048, and 309 pCi/L, in wells CPP33-2, CPP33-3, and CPP55-06, respectively. Tritium was detected in wells CPP33-3 and CPP55-06 at 1059 and 12,394 pCi/L, respectively. Strontium-90 was detected in all four wells ranging from 5.8 to 37,143 pCi/L, with the highest result detected in well CPP55-06. Americium-241 was detected in well CPP33-2 at 25.3 pCi/L. Chloride values were lower for these wells than the percolation wells and ranged from 19.9 to 193 mg/L. The highest chloride value was detected in well CPP33-3. Nitrate was detected in CPP33-3, CPP33-4, and CPP55-06 at concentrations of 0.2, 1.5, and 4.2 mg/L, respectively.

Flow and Continuity of the Perched Water

Hydrologic and chemical data evidence suggests that perched waters underlying the ICPP are not continuous over a large area. Instead, they appear as individual bodies of groundwater that accumulate in depressions associated with the undulating basalt flow surfaces and corresponding accumulation of interbed materials as illustrated in Fig. 3.

TABLE I

Perched Water Chemistry Summary of Detected Results

Well ID (Sample Date)	CPP33-2 (4/5/91)	CPP33-3 (4/5/91)	CPP33-4 (4/10/91)	CPP55-06 (4/10/91)
	Chemical Analysis Results			
Chloride, mg/l	19.9	193	105	35.9
Conductance, umhos/cm^2	394	986	1140	492
Nitrate as N, mg/l	0.1 U	0.2	1.5	4.2
pH, s.u.	7.44	7.90	7.79	7.98
Arsenic, ug/L	10 U	10 U	10 U	10 U
Barium, ug/L	270	340	850	400
Cadmium, ug/L	1.0 U	1.0	1.0	1.0 U
Chromium ug/L	30 U	40	30	30 U
Lead, ug/L	2.0	5.0	15	4.0
Mercury, ug/L	0.2 U	0.2	0.4	0.8
Selenium, ug/L	10 U	10 U	10 U	10 U
Americium-241, pCi/L	25.3	0.1 U	0.1 U	1.0 U
Cesium-134, pCi/L	21.8	561	8 U	-
Cesium-137, pCi/L	49.8	1048	10 U	309
Neptunium-237, pCi/L	10	215	5 U	-
Uranium-234, pCi/L	9	3.1	4.6	-
Uranium-238,pCi/L	7.6	1.8	3.7	-
Tritium, pCi/L	500 U	1059	500 U	12394
Strontium-90, pCi/L	64.6	5.8	374	37143
Gross Beta Activity, pCi/L	-	-	-	-

(-) = Not Analyzed.
U = Compound was analyzed for but not detected. The value reported is the sample quantitation limit.

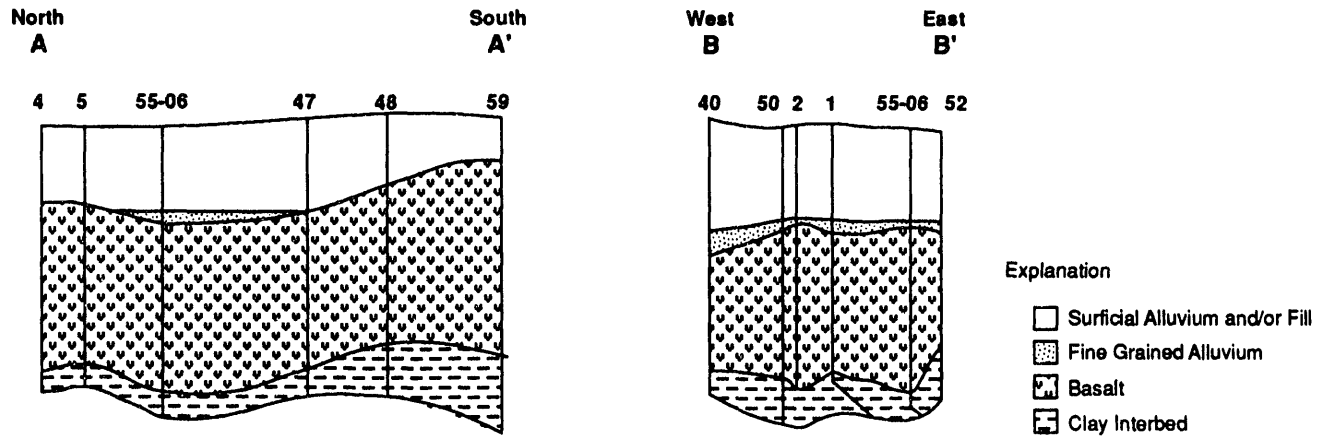


Fig. 3. Simplified cross section.

Flow into the perched groundwater is controlled by the extent of near-vertical fracturing present in the overlying basalt sequence. A conceptual model based on the hydrogeologic conditions observed is provided in Fig. 4. The model illustrates a "stair-stepped" approach to fluid and contaminant movement to the perching zone. The conceptual model is used as the basis to develop hypotheses regarding the source of water that recharges the perching layer and the source of contaminants, and to assist with an assessment of risk associated with the contamination observed.

The conceptual model of groundwater flow and contaminant transport beneath the ICPP assumes a continuous or near continuous source of water to the ground surface. Sorption and desorption of contaminants will occur throughout the unsaturated portion of the subsurface. Due to the igneous makeup of the subsurface geology, flow in both the unsaturated and saturated zones is controlled mainly by fractures. Because of this fractured nature of the bedrock geology, the potential for direct downward migration of water and contaminants is fairly small. As a release moves through the alluvium, it will descend until contacting the fine-grained layer at the basalt/surface sediment interface. At this time, it will spread laterally until sufficient head to overcome the reduced permeability of the fine material is built up or enough unfilled fractures are intercepted. Downward migration will then continue through the unsaturated portion of the rock

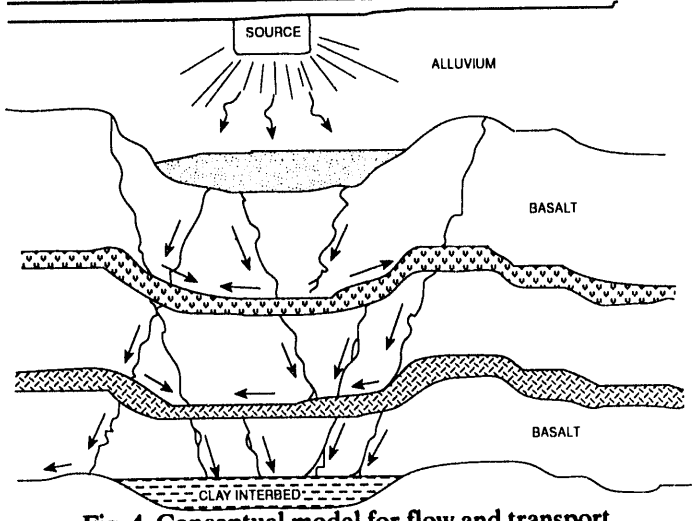


Fig. 4. Conceptual model for flow and transport.

encountering both horizontal and vertical fractures that will direct flow. Fracture density, in-filling, and fracture orientation all affect percolation rates in the vadose zone. Furthermore, the various low-permeability zones caused by sedimentary interbeds and massive basalt also play a major role in the time and direction of vertical transport through the unsaturated zone. As percolating water contacts one of these relatively impermeable zones, it begins to spread laterally. Eventually, the hydraulic head in this new perched zone is high enough to penetrate the low-permeability layer. Once breached, an equilibrium state is established between the areal extent of the perched water body and the percolation rate through the low permeability zone.

Therefore, where a release finally intercepts the aquifer may be far removed from the release point. Additionally, the potential exists for a small release to be rapidly diluted to below-detection limits by the large volume of water encountered in the SRPA. For these reasons, detection monitoring of the perched water at the 110-foot level (after only 70 feet of unsaturated travel, and encountering a substantially smaller volume of water) rather than the SRPA (after 400 feet of unsaturated travel and large volumes of water) is more likely to detect a site release.

Remediation strategies for the restoration of the perched water underlying the ICPP must address the flow of water and contaminants through the near-vertical fractures, the isolation of individual perched groundwater bodies, and a variety of potential recharge and transport mechanisms that are static in nature.

REMEDIATION STRATEGIES

Strategies to remediate the contamination measured in the perched groundwater underlying the ICPP are under development, and tests are planned to assist with the selection of the optimal configuration. The strategies involve both demonstrated and near-term (less than 5 years) technologies that are expected to be effective for these hydrogeologic conditions and for the contaminants of interest.

Site Constraints

The hydrogeologic setting associated with the ICPP will require the selection of a strategy that can be used to address the following:

- Flow and transport via near-vertical fractures in the basalt sequence
- Rapid contaminant movement through the fractured basalt with limited sorption and desorption
- Existing contamination sources in the fractured basalt above the perched groundwater
- Individual bodies of perched groundwater that are not interconnected over a large area
- Intermittent periods of flow and transport with long periods (months to years) of no sustained flow in the subsurface
- Lateral spreading of contaminants along brecciated basalt intervals
- The specific contaminants of concern found in the subsurface.

In addition to the hydrogeologic setting, existing buildings, tanks, and other structures limit the accessibility for drilling boreholes to the perched groundwater underlying the ICPP.

Identification of Potential Remediation Strategies

The type and configuration of remediation strategies that may be considered include the following:

- Conventional pump and treatment systems for the perched groundwater
- Heated air circulation system to remove moisture and inhibit vertical transport of contaminants in conjunction with a conventional pump and treat strategy
- Introduction of horizontal wells for the interception of contaminants and water above the perched water zone
- Introduction of selective sorptive materials for the collection and accumulation of contaminants above the perched groundwater
- Freezing of a target interval within the fractured basalt sequence with the installation of a fluid collection system to inhibit vertical transport and collect contaminants above the perched groundwater.

Assessment of Remediation Strategies

The remediation strategies identified generally fall into two categories: those systems demonstrated in isotropic homogeneous media and those strategies that are conceptual with limited or no demonstrated application. Therefore, the primary focus in the assessment process has been to evaluate the adequacy of the demonstrated systems to remediate the site-specific conditions and to evaluate the potential utility of the more innovative systems.

The fracture-dominated characteristics of the basalt will not be suitable for the application of techniques developed for isotropic homogeneous formations. The basalt fractures represent discrete flow paths that are near-vertical, and formation characteristics are highly variable. In addition, the limitations of space and accessibility from above the perched groundwater further limit the selection of available remediation strategies. The effectiveness of conventional pump and treat systems is further diminished by the discontinuous nature of the perched groundwater systems.

The consequence of these conditions necessitates the further evaluation and testing of innovative drilling strategies.

Particular emphasis has been placed on the use of horizontal wellbore systems with the integration of one or more of the other remediation strategies typically associated with vertical well configurations.

The horizontal well configuration has the ability to drill underneath large facilities, tanks, or structures, and will significantly enhance the ability to intercept the vertical fractures typically associated with the basalt sequence. Once completed, the horizontal wells can be used for the implementation of a variety of remediation strategies, including conventional pump and treat, the use of heated air, the introduction of selective sorptive materials, and the potential for freezing a target interval. Additionally, the horizontal wells may be used to access multiple perched zones by drilling a well that parallels the undulation in the basalt sequence at the 110-foot interbed.

Current activities have focused on an evaluation of the adequacy of the horizontal drilling systems for use in an unsaturated fractured basalt sequence and the ability to utilize proven remediation technologies via a horizontal well(s). Pilot scale testing of horizontal well systems in combination with further evaluation of potential application of the remediation strategies is planned in the next few years in a controlled setting at the INEL. Results from these tests and evaluation will be used to select the strategy that will be first tested at the ICPP.

SUMMARY

The selection of an appropriate remediation system requires a thorough understanding of the hydrogeologic setting, the target contaminants, the physical constraints, and the transport pathways. Data collected from the ICPP perched water monitoring system have assisted with the definition of these requirements and suggest that the conventional remediation technologies developed for saturated or porous media will not be effective without some modifications. Specifically, the fracture-dominated characteristics of the basalt and the hydrologic characteristics of the perched groundwater will require the development of innovative approaches to remediation of fracture-dominated systems. Horizontal well construction in conjunction with one or more of the conventional systems will be further evaluated in the future by WINCO. WINCO will use the results of the hypothesis testing in the selection of the appropriate remediation strategy and to assist in prioritizing funding expenditures associated with the development of applicable technologies.

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SITE CHARACTERIZATION FOR REMEDIAL DESIGN AT NATIONAL PRIORITY LIST AND FUSRAP SITES

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ABSTRACT

An innovative soil characterization procedure for radioactive soils developed by the Office of Radiation Programs when applied in the soil characterization stage of the RI/FS Superfund process has application to all phases of the process. Essentially an additional step to existing procedures, a selected representative bulk sample from the site is processed in the laboratory into several size fractions and a petrographic and radiochemical analysis performed on each size fraction. This additional step to the RI/FS process provides essential parameters for decisions and assessments that apply to the site characterization, risk assessment, and remedial design tasks of the process.

The utility of the soil characterization protocol for radioactive soils is described for the remedial design of volume reduction methods at the Wayne and Maywood, New Jersey, thorium contaminated FUSRAP sites and for the Montclair and Glen Ridge, New Jersey radium contaminates NPL sites. The advantages of the soil characterization that might have been provided in the earlier stages of the RI/FS process is also suggested for these sites.

INTRODUCTION

The Office of Radiation Programs, in compliance to the preference of treatment technologies over off site disposal as prescribed in the Superfund Amendments and Reauthorization Act (SARA) of 1986, initiated a laboratory investigation of radium contaminated soils from the Montclair and Glen Ridge, New Jersey, Superfund sites for a potential remediation technology. In these investigations which started in 1987 at the EPA Montgomery Laboratory, the contaminated soil was vigorously washed into several sieve fractions (1) and petrographic and radiochemical analysis performed on each size fraction (2). This initial data on 18 soil fractions from a representative bulk sample provided a grain-size distribution curve with identification of the contaminant radioactive constituents on each size fraction (mineral/material composition and physical properties) and the radioactivity levels on each size fraction. This data was instrumental in the development of a soil wash volume reduction system called VORCE, which is currently in process of being field tested for remediation of some of the radium contaminated soil at these NPL sites.

In order to accommodate testing of radioactive soils in a cost effective and timely manner, the soil characterization protocol has been tiered so that Tier 1 data and a feasibility assessment for the use of volume reduction technology in remedial design may be available in 4 to 6 weeks (3). The Tier 1 soil characterization was effectively used on thorium contaminated soils from the Wayne and Maywood, New Jersey, Superfund sites and provided information not previously developed in any other RI/FS process studies which indicated that volume reduction was possibly a feasible option for remediation of the contaminants in the clean-up process. The data provided by the Tier 1 tests, by hindcast, would have provided valuable information of immediate use in determination of objectives of the site characterization phase of the Remediation Investigation (RI) that related to source and fate of the contaminants.

The purpose of this paper is to cite an easily obtainable additional step to the guidance for conducting remedial investigations and feasibility studies under CERCLA (4). Case studies will be cited that show the need for this information in the site characterization stage of the RI process and its application to risk assessment and the remediation design in the FS process.

UTILITY OF INNOVATIVE SOIL CHARACTERIZATION PROTOCOL TO RI/FS PROCESS

A relatively simple additional test which examines fractions of radioactive soil by combined petrographic (mineral composition and physical properties of contamination and host media) analysis and radiochemical analysis provides important data applicable to several tasks of the RI/FS process. This simple additional step is shown in the schematic diagram in Fig. 1. This type of soil characterization has not been previously used in standard RI/FS procedures, however, the use could be added to Data Quality Objectives (DQO) of the Superfund process.

The Office of Radiation Programs has experience on the use of this innovative soil characterization protocol in remediation studies conducted for consideration of volume reduction soil washing methods on radioactive soils from several sites on the National Priority List (NPL) and special designated Formerly Utilized Site Remedial Action Program (FUSRAP) sites. The advantages gained by the protocol are: (1) grain size in relation to radioactivity levels, (2) minerals or materials containing the radionuclides, (3) minerals or materials comprising the host media, and (4) physical properties

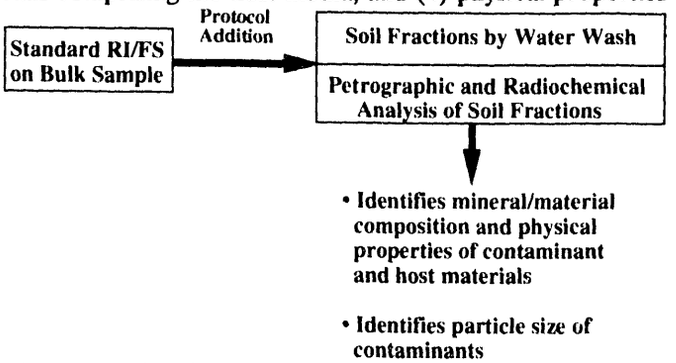


Fig. 1. Additional data provided by innovative soil characterization protocol for radioactive soils at Superfund sites.

of contaminants and host media. Examples of the use of this methodology will be cited for investigations by the Office of Radiation Programs on thorium contaminated soils of the Wayne and Maywood, New Jersey, FUSRAP sites and the radium contaminated soils of the Montclair and Glen Ridge, New Jersey, Superfund sites. Potential application for radioactive soils exists for the 45 sites on the NPL and 26 FUSRAP sites in the use of this methodology.

Wayne and Maywood, New Jersey, Sites

In March 1991, eleven representative samples from the thorium contaminated soils from the Wayne and Maywood, New Jersey, sites were tested at the Office of Radiation Programs, Montgomery, Alabama, Laboratory using the protocol methodology. Prior to that time, RI/FS standard procedures had disclosed the activity levels and radionuclides present in the average bulk soil samples and the grain size of the host media consisting of unconsolidated glacil till. The additional data provided was the disclosure that the radioactive contaminants were contained in relatively insoluble monazite and minor zircon within a narrow size range (Fig. 2). To know this was to know the speciation of the contaminant, its solubility, and physical properties that lend themselves to remedial design. The radioactivity versus particle size is depicted for the Wayne samples in Fig. 3 in which it is indicated that the thorium 232 and its daughter isotope Ra 228 with respectively 35 pCi/g and 32 pCi/g are essentially in secular equilibrium and approximately 3 times higher activity than uranium 238 and its daughter isotopes thorium 230 and radium 226. This radioassay also correlates with the percentages of monazite and zircon (Plate 1) that occur in the quantitative petrographic point count of the heavy mineral fraction examined by the petrographic polarizing microscope. The monazite is the principle ore mineral of thorium 232. This rare earth, thorium, orthophosphate contains from 3 to 10 percent thorium oxide and from 0.2 to 0.6 percent uranium 238, while zircon may contain up to 4 percent substitution of thorium or uranium for zirconium in this zirconium silicate mineral (5). The Wayne and Maywood samples are similar in showing activity levels less than 5 pCi/g until upper silt size. It can be shown by the grain-size distribution curve and the activity level curve that approximately 65 percent of the Maywood soil and 50 percent of the Wayne soil contain less than 5 pCi/g of radioactivity. Volume reduction by removal of the essentially background level 5 pCi/g soil is feasible by soil washing with wash water free of contaminants.

Montclair and Glen Ridge, New Jersey, Superfund Sites

The Montclair and Glen Ridge, New Jersey, radium contaminated soils were tested by the soil characterization protocol in several series of tests from November 1987 to June 1989. The waste contaminants, which had not been previously identified by the standard RI/FS process were found to consist of ore minerals (carnotite and uraninite), acid leach products (radium barium sulfate and amorphous silica), furnace fired materials (coal ash and slag), and adsorbed onto clay (illite, etc.). The highest concentration of radium activity occurred in the fines. The composition of the host materials and bulk contaminants in the gravel-size, sand-size, silt-size, and clay-size fractions as well as the percent weight, average Ra 226 and percent radium content of these fractions for a Montclair sample with average 180 pCi/g radium is depicted in Fig. 4. Details of the soil characterization is contained in EPA/520/1-89-012 (2). The results of the Ra 226 activity level with respect to soil washing is shown in Fig. 5. As indicated in Fig. 5, vigorous water wash, as described by Richardson et al. 1989 (1), reduced 30 to 40 percent of the Montclair and Glen Ridge soil to a target level of 12-15 pCi/g Ra 226. This investigation using the soil characterization methods has been used as data essential to the design of pilot/field test equipment which will be tested for remediation potential in the Fall of 1991.

The data provided by the examination of radioactively contaminated soils for remedial design of volume reduction methods could be obtained as a DQO in the early stage of the RI/FS process.

APPLICATION OF PROTOCOL IN RI/FS SITE INVESTIGATION

Standard RI/FS practices have limited soil characterization of radioactive soils to identification of radionuclides, their activity, and grain size on bulk samples. The utility of additional tests to determine the identity of the composition of the waste form and the limiting range of particle size of the contaminants within the host media has been discussed for the remediation design phase of the FS process. It is suggested, however, that this same data has application to the site investigation phase of the RI process. Thus the data supplied to the RI/FS process, such as described for the remedial design,

Wayne and Maywood, NJ, FUSRAP Sites

Prior to March 1991 Standard RI/FS Procedures	March 1991 Protocol Additions
No knowledge of: • Mineralogy or physical nature of contaminants	Protocol Key Additions: • Identification of Monazite and Zircon as contaminants
• Grain size range of contaminants	• Size range of contaminants
	• Feasibility of volume reduction

Fig. 2. Nature of data provided by soil characterization protocol addition to Wayne and Maywood, New Jersey, FUSRAP sites in March 1991.

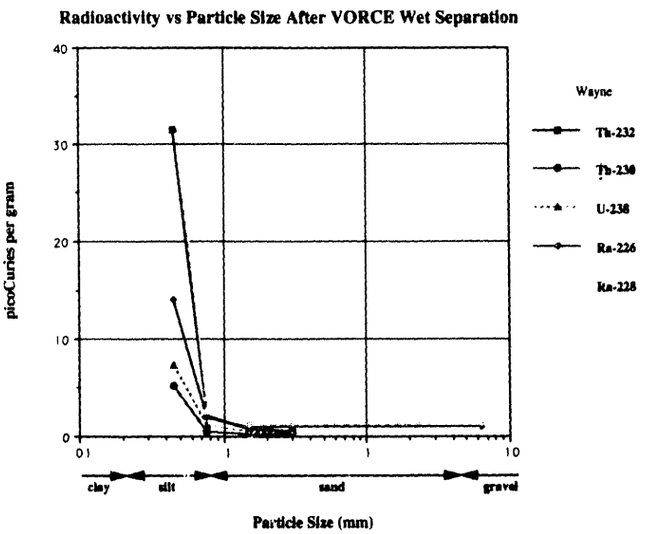


Fig. 3. Radioactivity levels of radionuclides versus particle size at Wayne, New Jersey, FUSRAP site.



Plate 1. Photomicrographs (100x, transmitted light) of Zircon an Monazite from Wayne and Maywood, New Jersey FUSRAP.

could be made part of the process at an early stage and used for several other aspects of the RI/FS process. Possible application of the protocol data from the sites previously discussed will be applied by hindcast to the site characterization phase of the RI process.

In the site characterization phase, consideration of contaminant fate and transport is usually conducted by computer modeling. Specific input parameters about the contaminants and the host media is required to access the migration potential or interactions of the contaminant with the host media. Had the insoluble nature of monazite and zircon been known for the Maywood and Wayne sites, it would have been predicted that there would be negligible migration and essentially no contamination of nearby groundwater. This is the case and it could have been modeled had the soil been characterized to identify the minerals constituting the contamination. The source of the thorium ore was from placer deposits and it is the natural condition of this mineral to be retained rather than solubilize or migrate from its deposition site. In the case of the somewhat more soluble phases of the radium contaminants, the list of contaminants could be compared to the distribution coefficients (Kd) of radionuclides to the host minerals at the Montclair and Glen Ridge sites made available by the protocol testing.

In the case of risk assessment and determination of risk-based soil clean-up levels, standard methods of modeling use a set of default values for the various calculation parameters.

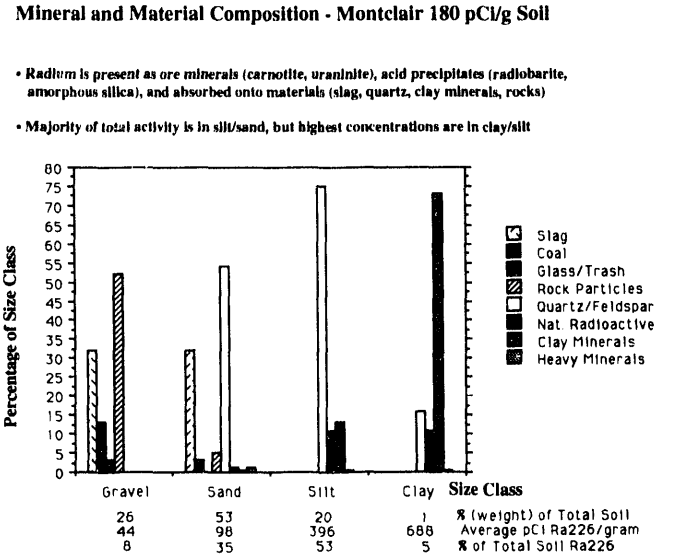


Fig. 4. Mineral/material composition, weight percent, and radium activity levels and percent radium in size classes of the Montclair, New Jersey Site.

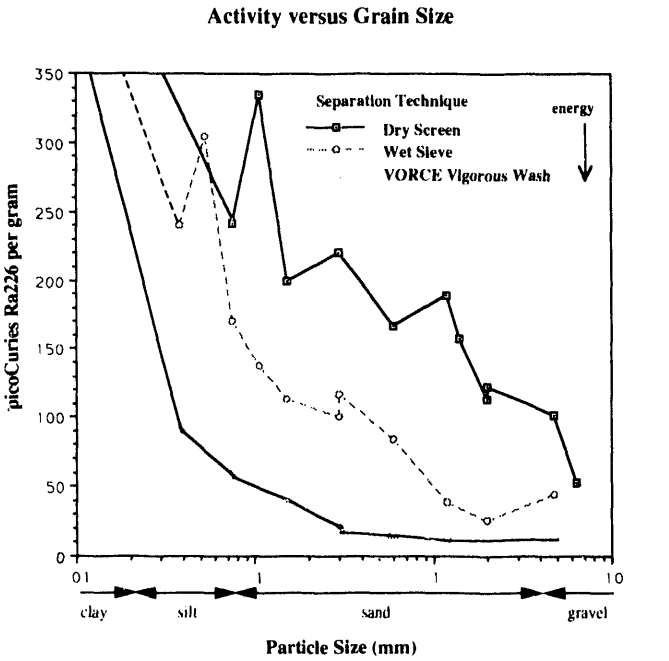


Fig. 5. Activity level versus grain size by soil washing on Montclair, New Jersey radium contaminated soil.

The use of site specific values, which reflect the local mineralogy and waste form, could have order of magnitude effect on the results of risk assessments. Because of the conservative nature of the default values, site specific values will likely result in a large reduction of the calculated risks.

In the Montclair and Glen Ridge study it was found that the major portion of the radium contamination was larger than 10 microns in size. Eighteen size fractions, including 8 in the fines were used in the tests conducted on these soils. Only 6 size fractions in the Tier 1 testing of the Wayne and Maywood

sites were used and only 2 of these were in the fines so that more points (Tier 2) need to be included to determine a precise number in risk assessment for the parameters which include soil to air resuspension factors or inhalation and dose conversion factors.

As indicated by Breckenridge et al. 1991 (6) and others, characterization of a hazardous waste site should be done using an integrated investigative approach to determine quickly and cost effectively the potential health effects and appropriate response measures at a site. We believe that the innovate soil characterization protocol for radioactive soils is suited to such an integrated approach in the RI/FS process for radioactive sites on the NPL or specially designated FUSRAP sites. Such an integrated approach may also be applicable to heavy metal toxic waste or other hazardous wastes.

In the OSWER Directive 9380.0-17FS, 1991 (3), the use of innovative technologies in the clean-up treatment at hazardous waste sites is strongly encouraged to fulfill the long-term needs of our hazardous waste programs. Included in this concept is new procedures that will provide incentives for broader use of innovative technology. In many ways, the use of the soil characterization protocol which looks at soil fractions with combined petrographic and radiochemical methods for radioactive soils is in accord with the OSWER Directive. (7)

SUMMARY

The use of an innovative soil characterization protocol to add to the standard ongoing tasks of the RI/FS process at the site characterization phase for NPL and special FUSRAP sites provides the following data:

1. Identifies the physical form and mineral/material composition of radioactive contaminants and actively levels on the various size fractions.
2. Data applicable to prediction of retention or transport of contaminants and impact on groundwater.
3. Provides explicit site specific data to key parameters in risk assessment evaluations.
4. Provides data to evaluate feasibility of Volume Reduction technologies.

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PUTTING ECOLOGY IN ENVIRONMENTAL REMEDIATION: THE STRATEGIC PLANNING PROCESS

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ABSTRACT

Traditional ecological studies have been conducted on many sites impacted by hazardous wastes. Yet in many cases, the information obtained has had limited value in the selection of remediation options. This paper discusses the importance of developing an ecological risk-based strategic plan to fulfill the scientific and social needs demanded in the remediation and restoration of hazardous waste sites. Ecological issues need to be considered seriously at the earliest phases of the scoping process. The decisions regarding selection of assessment endpoints and data quality objectives must be incorporated from the start to insure that cost-efficient and useful measurements are used. It is too late to develop effective ecological studies after the engineering decisions have been made. Strategic planning that integrates ecological concerns will minimize the frustration and the cost associated with clean up of hazardous waste sites and maximize the likelihood of successful site restoration.

BACKGROUND

Legal Requirements, and Policy Issues

The United States Department of Energy (DOE) has adopted an ambitious policy to reduce waste generated, remove existing wastes, as well as remediate and restore sites under its jurisdiction within the next 30 years. In recognition that technical capability to accomplish these tasks is limited, DOE produced a blueprint for basic research (1). In this overview document critical research and development issues were proposed.

The policy on restoration extends the requirements of CERCLA (Superfund) and RCRA. Guidelines for Superfund and RCRA have emphasized chemical-based decisions often without substantive consideration of biological phenomena. Ecological work at hazardous waste sites has been invoked to a limited extent to develop descriptions of biological resources. Occasionally, site specific information is acquired as part of the human health risk assessment. Increasingly, there have been efforts to include ecological descriptions to develop Natural Resource Damage Assessments. Yet, policies are being set to move toward comprehensive site remediation and ecological restoration. The critical strategic planning elements needed to guide the scientific phases of site assessment, risk assessment, damage assessment, health considerations, remediation options, and ecological restoration have been missing. The consequence is that volumes of data are amassed with relatively little linkage to the ultimate management decisions and policy requirements.

Ecological analysis, when performed, often follows an "encyclopedic" approach to data collection in which everything that can be measured is measured. Such data tends to lack necessary accuracy and precision needed to define risk parameters. It seldom is coordinated with other sampling efforts (spatially and temporally). This tactic generates volumes of ecological information. However, in most instances little or none, of the data is useful for the purposes of characterizing risk and evaluating remediation options.

Current Approaches to Remediation

Remediation decisions are most often driven by chemical criteria and/or human health risk considerations. These chemical criteria tend to be based on limited consideration of the exposure conditions that operate under field conditions. Human health risk values may have little relationship to ecological concerns and may be based on multiple compounded safety factors that extrapolate three- or four-orders of magnitude beyond the toxicity data used to generate the risk value. Chemical-based remediation, in the absence of biological relevance, reduces to issues of conflict between analytical detection limits and the best available technology to achieve clean-up. This can (usually) result in high cost engineering "solutions" with insignificant improvement of ecological condition for large sectors of contaminated sites.

A STRATEGIC RISK-BASED ECOLOGICAL APPROACH

Strategic Elements

Success of a remediation or restoration project is inextricably linked to the planning process. This can best be achieved through a strategic, risk based approach. This process moves through and initial information gathering or scoping effort; a thorough analysis of the context of the project; and an ecological risk assessment before management options are presented (Fig. 1.). Each portion of the project is guided by the strategic goals with iterative feed-back loops available to permit revisions. A critical component of this scheme is that the scientific feature, the ecological risk assessment, is clearly defined and isolated from the management decisions. This is done to insure the best use of scientific approaches. Linkage between the scientific component and the management component is achieved through scientifically based recommendations. The recommendations are augmented by effective risk communication.

THE CONTEXT

Following initial scoping efforts, information is organized to establish the context of the project. The ecological context is characterized from site-specific information on such items

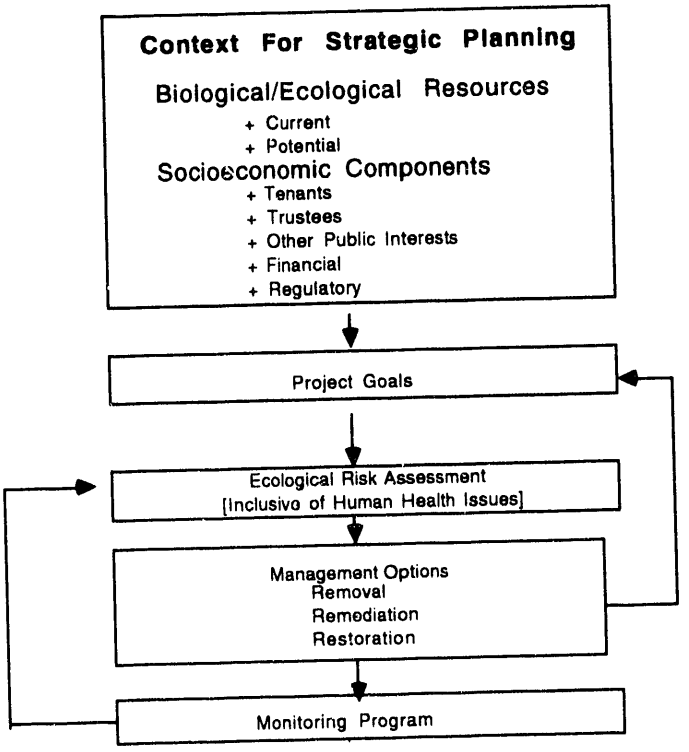


Fig. 1. Components of Ecological Risk-Based Strategic Planning [Adapted from Wyant et al. (2)].

as land use patterns, historical residue data, geological and geomorphological features, weather patterns, landscape ecology features and similar site attributes. Socioeconomic components range across diverse human interest including the potentially responsible parties, natural resource trustees, regulatory entities, and numerous technical support groups (legal, financial, social, medical, political, scientific, and engineering experts). Through such an open-door approach, each of the stake-holders (or at least their representatives) benefit from reasoned discourse on all issues. Those charged with devising the primary project goals do so from an informed position.

Ecological Risk Assessments

The Purpose: Ecological Risk Assessments are designed to define actual and potential harm to biological resources. The information must be structured so that regulatory decisions and risk management options can be scientifically based. Ideally, the risk analysis forms the critical foundation for selection of alternative remediation technology options.

Ecology is an integrative discipline which draws upon diverse sources of information (e.g. chemical, physical, geological, biological, etc.) to describe the interactions of organisms, populations, communities and ecosystems with each other and their surroundings. The challenge is to focus on the critical and relevant ecological issues from the vast array of potential ecological relationships and to do so in a manner that contributes to the risk analysis.

Adopting the terminology of Suter,(3) there are several potential assessment and measurement endpoints relevant to remediation and restoration. The specific endpoints of interest vary depending upon the ecological level of organization to be addressed. Assessment endpoints are formal expressions of the actual environmental values that are to be protected; the environmental characteristics that can indicate a need for remediation or restoration; the highest value that can be assessed operationally. Measurement endpoints are quantitative expressions of an observed or measured effect; a measurable environmental characteristic that is related to the assessment endpoint.

Barnthouse(4) has discussed the basic risk paradigm in terms of its use for ecological risk assessments. In doing so, he distinguished two broad-use categories. Traditional risk assessments are intended to predict the likelihood of some event (i.e., adverse toxicological effect) occurring. This is accomplished from analysis of the hazard or toxicity and exposure conditions. In the strictest sense the risk assessment forecasts the probability of a given effect.

Barnthouse also recognized the common usage of ecological analysis after an effect has occurred. He referred to this as "retrospective risk assessment." Perhaps a better term would be forensic ecology; the evaluation of measurable ecological endpoints in order to establish linkage between source and levels of contamination and ecological effects. In Superfund and other hazardous waste site assessment, the bulk of ecological work is forensic in nature. The information gathered in the ecological assessment should provide valuable insights into spatial distribution, risk modeling, and evaluation of remediation options.

The Paradigm: The risk assessment paradigm developed for human health includes four major components: 1) hazard identification; 2) exposure assessment; 3) dose-response assessment; and 4) risk characterization. Considerable effort has been expended over the past several years to define and refine the appropriate paradigm(s) for ecological applications. Yet the basic features remain in place. The contributions of hazard (toxicity) and exposure in the risk equation are distinguished from each other and related as follows:

$$\text{Risk} = \text{fn (Hazard, Exposure)} \qquad \text{(Eq. 1)}$$

Whereas there are variations in the innate toxicity of a given chemical to different species, ecotoxicologists attach much greater importance to defining the exposure component. In fact, because of the great differences in exposure conditions in field conditions, chemical based targets almost always predict greater risks than documented through empirical observation.

The Process: We recommend a four-stage approach to complete the ecological risk assessment (Fig. 2.).

Stage 1. Project-Specific Adaptation of Risk Paradigm--Each specific project is scoped to identify critical ecological relationships as they pertain to components of the risk paradigm. Relevant ecological considerations (e.g. critical species and habitat impacted) are placed in a conceptual model that guides all subsequent review and analysis of the exposure and hazard components.

Stage 2. Delineation of Risk Assessment Requirements--The conceptual model developed in Stage 1 is used to create a matrix that targets key elements focused on the specific risk scenarios. Project-specific Data Quality Objectives (DQOs) are formulated taking into account the precision, accuracy and uncertainty associated with the methods used. This information provides direction for development of the project work plan.

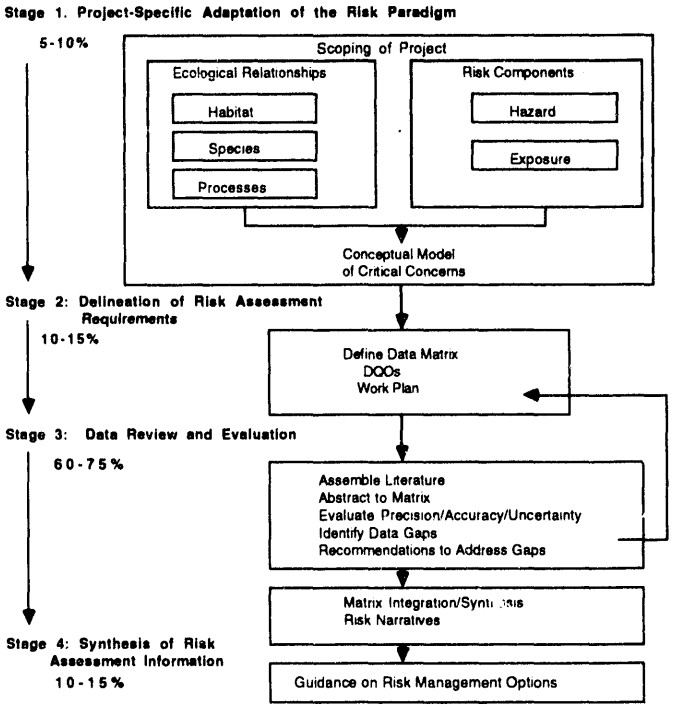


Fig. 2. Four stage process for completion of Ecological Risk Assessments.

Stage 3. Data Review and Evaluation--The literature is assembled and abstracted to the matrix; reviewed, and critically analyzed for quality and relevance according to the criteria established in the DQOs (Stage 2). The matrix is used to facilitate the identification of data gaps, develop recommendations for additional data, and generate the risk statements.

Stage 4. Synthesis of Risk Assessment Information--The synthesis of the information assembled through Stages 1-3 completes the ecological risk assessment. The individual factors (i.e. matrix cells) are integrated into a comprehensive risk summary. In addition to numerical analyses, narrative descriptions of the salient ecological and risk components are presented.

This approach is structured to provide a quantitative determination of the risk to plant and animal inhabitants of a site Precision, accuracy, and uncertainty of the measurements are used in developing a comprehensive risk analysis and recommendations of management options. Depending on the details required, it may be possible to develop a reasonable estimate of ecological risk from published data. New studies may be required to forge a site-specific assessment. In most cases, limited surveys targeting specific data gaps should suffice for the initial risk analysis. By addressing the data gaps in an iterative process, the overall effort and cost of conducting the risk assessment can be held to a minimum. The entire process is guided by the strategic project goals.

Upon completion of the risk assessment, scientifically based recommendations are prepared regarding various remediation and/or restoration options. Through the risk-based process the basic information assembled can be applied independently for each management option. The recommendations also can include a specific monitoring plan keyed to the specific context elements of the site. The monitoring plan can specify meaningful and economically rational biological endpoints derived from the risk assessment. The program can signal the approach or actual occurrence of unacceptable exposure or effects and provide an objective means of evaluating the success of the project.

The Consequence

The importance of connecting a risk assessment approach to the remediation and restoration efforts cannot be overemphasized. There must be formalized agreement in the planning stage to select and accept specific goals of the project, to assure that these goals are appropriate to all concerned, and realistically achievable. The key to successful remediation is the linkage of measurement endpoints to support evaluation of the status of the remediation goals broadly embraced in the assessment endpoints. These endpoints become the basis to determine relative success of a project. Perhaps the most significant consequence of the risk based approach is that ecological relevance is incorporated in the decision process.

Detection limits of analytical instruments and chemical procedures have advanced to extremely sensitive capabilities and often surpass by orders of magnitude the levels known to cause biological effects. This is a relatively new phenomenon. Twenty years ago, detection limits of chemical analytical techniques typically were one or two orders of magnitude higher than biological effects measures. The "conservative" approaches adopted to be protective, took into account this general inability to measure chemicals in environmental samples. Through the risk assessment process and through direct measures of biological effects it is becoming feasible to rely on biological detection limits. This has major implications on costs for remediation and restoration (compare Fig. 3 with Fig. 4.) It can in general be anticipated that biological detection limits will reduce the volume of material that requires "cleaning." Furthermore the seemingly interminable question of "how clean is clean" can be addressed in an objective manner.

Finally, it is critical to consider our generally poor capability to restore damaged ecosystems. Ecological consensus is that no ecosystem can be restored to full capacity once it has been grossly perturbed. Certainly large removal actions and many interventive remediation technologies impose additional stresses on ecosystems. Thus to the extent that portions of a site can be exempt from intrusive remediation efforts (i.e., limited to those zones where biologically significant risks are present), the restoration process can be enhanced (compare Fig. 5a, 5b, and 5c). The risk based approach permits objective comparison of the consequences of removal, remediation, and no action alternatives. It therefore fosters a more rational discussion that results in maximization of environmental conditions.

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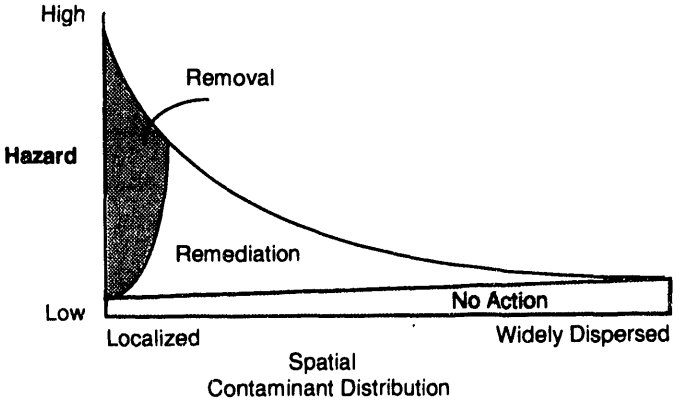


Fig. 3. Management options related to hazard and contaminant distribution.

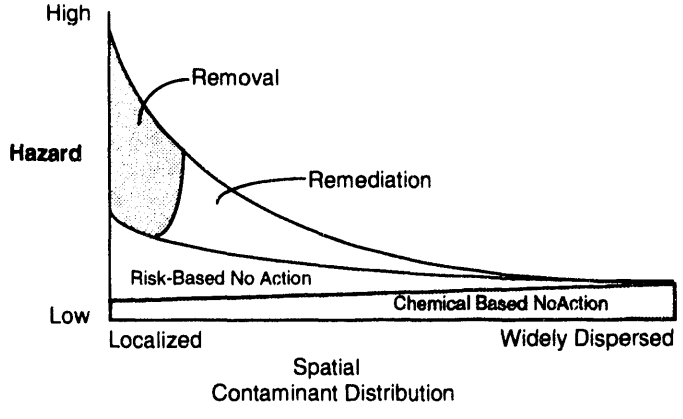


Fig. 4. Comparison of chemical-based versus risk-based action level targets.

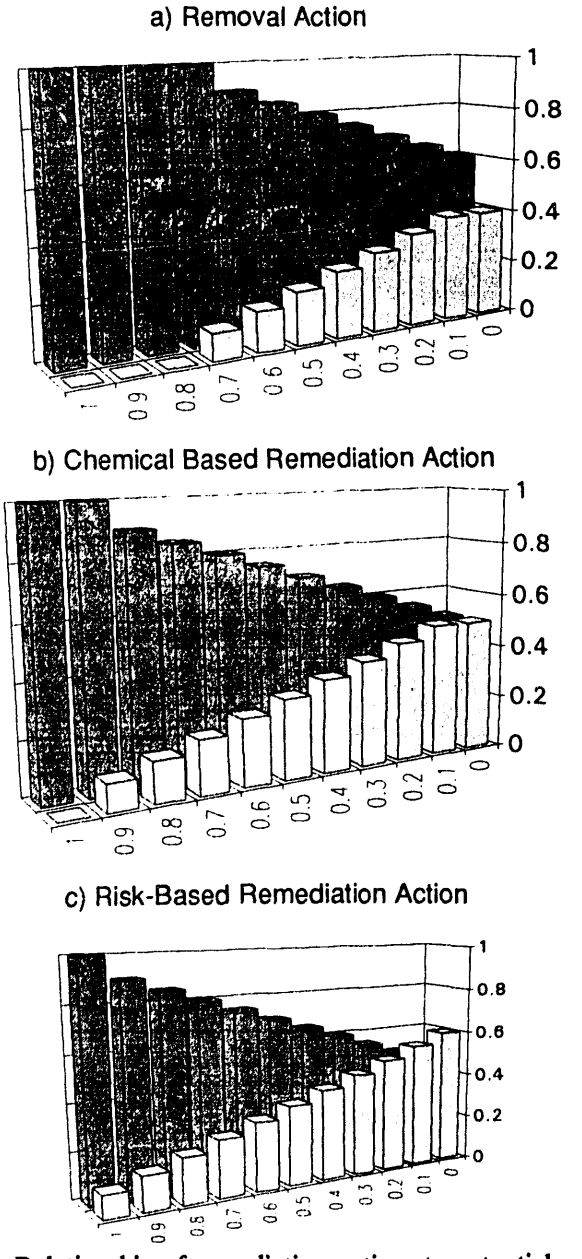


Fig. 5. Relationship of remediation options to potential restoration success. The filled bars represent *cost* or *effort* while the empty bars represent *chance of success*. The X axis is scaled for Ecological Complexity (1.0 is most complex) and the Y axis is units of cost or success: a) removal action; b) chemical-based remediation action; c) risk based remediation action.

NATURAL RESOURCES DAMAGE ASSESSMENTS AT DEPARTMENT OF ENERGY FACILITIES - USING THE CERCLA PROCESS TO MINIMIZE NATURAL RESOURCES INJURIES

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ABSTRACT

Fifty years of research, development and production in support of national defense have left the Department of Energy (DOE) with numerous radioactive, hazardous and mixed waste sites requiring environmental restoration and remediation. The responsibilities for DOE associated with releases of these wastes into the environment are driving major efforts to characterize contamination problems and identify and implement environmental restoration and remediation alternatives. The subject of this paper is the recently issued DOE guidance to minimize the basis for damage claims for injuries to natural resources on, over and under lands owned or controlled by DOE associated with the releases of hazardous substances from DOE facilities. Depending on the regulatory authority governing the facility, the preferred means of evaluating the possibility of injury to natural resources is the preparation of an ecological risk assessment or an environmental evaluation. As both the natural resource trustee and lead agency at facilities under its control, DOE receives dual responsibility requiring site remediation if necessary, and that any injured natural resources be restored, or that compensation for the injuries is made. Several executive and legislative sources of authority and responsibility with regard to lead agencies and trustees of natural resources will be detailed. Also, ongoing remedial investigation/feasibility study work at the DOE Fernald Environmental Management Project near Fernald, Ohio will be described as an example of how this guidance can be applied.

INTRODUCTION

Federal facilities have a unique role in carrying out the response requirements of the National Oil and Hazardous Substances Pollution Contingency Plan (NCP) and the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA). In many instances, federal agencies are in charge of responding to releases of hazardous substances from their own facilities. DOE has a dual role at its environmental restoration sites: 1) lead agency for CERCLA response actions being undertaken; and 2) primary federal Natural Resource Trustee. The NCP defines a "lead agency" as one which either performs or oversees the response actions necessary for the assessment, removal or remediation of threats to public health and the environment. The Natural Resource Trustees determine whether natural resources or the services they provide have been injured by a release and assess "residual" damages following remediation. Trustees can also recommend specific mitigation measures (to be implemented by the lead agency) to reduce or eliminate the injury, thereby reducing or eliminating possible residual damages.

The DOE has recently issued guidance to assist its environmental restoration program managers (ERPMs) in complying with its lead agency and natural resource trustee responsibilities. This paper will discuss the authority and requirements of this dual responsibility, and examine the way in which the CERCLA process is working to achieve compliance with both requirements at the Fernald Environmental Management Project (FEMP), a DOE site in southwestern Ohio.

Even though DOE is the primary federal trustee for resources on, under or over Departmental lands, trusteeship is not solely a function of geographical location, nor is it strictly tied to land ownership or management. Trusteeship derives primarily from resource management responsibility. Therefore, other federal agencies, states, or tribal governments could be co-trustees for certain natural resources located on, or affected by releases from, DOE facilities. As such, these co-trustees could present claims for natural resource damages to DOE or its operating contractors.

The actions of natural resource trustees are not intended to supplant the actions of the CERCLA lead agency. The two roles have separate purposes and are distinct from one another. Each is authorized by different sections of CERCLA and carry separate regulatory requirements. Figure 1 provides an overview of the multiple trustee and lead agency actions and authorities with which DOE may be involved during the remediation of a CERCLA site.

When CERCLA hazardous substances have been released from RCRA-regulated facilities and have caused natural resource injury, DOE's responsibilities to notify and coordinate with other natural resource trustees may be applicable to the releases being addressed under RCRA's corrective action provisions, or under other state authorities.

CERCLA §101(16) defines natural resources as "land, fish, wildlife, biota, air, water, groundwater, drinking water supplies, and other such resources belonging to, managed by, held in trust by, appertaining to or otherwise controlled by the United States, any state or local government, any foreign government, any indian tribe, or, if such resources are subject to a trust restriction or alienation, any member of an indian tribe." Section 300.600(b) of the NCP indicates that natural resources may include not only the biotic and abiotic resources listed above, but the "supporting ecosystems" associated with the biotic resources.

Section 107(a)(4)(C) of CERCLA imposes responsible party liability for damages for the injury, destruction or loss of natural resources, including the costs of assessment. Section 107(f) indicates that such liability is to the United States and to states and indian tribes. Section 120 of the Superfund

Amendments and Reauthorization Act (SARA) extends this liability to federal facilities. The effect then, is that the natural resource claims of state and indian tribe trustees may be enforceable against DOE in court.

The Natural Resources Damage Assessment Process

A Natural Resource Damage Assessment (NRDA) is the process natural resource trustees use to determine monetary damages which a trustee may pursue in a CERCLA §107(a)(4)(C) action, which is called a "natural resource damage claim." The damage claim of a Natural Resource Trustee receives the evidentiary status of "rebuttable presumption" in an administrative or judicial hearing, provided that the trustee used federal regulations* for natural resource damage assessment (NRDA) to develop the claim.

The formal NRDA process is performed to assess "residual damages", i.e., those which are not or can not be addressed by the remedial or corrective actions. It is important to distinguish between injuries, which are conditions of harm to the natural resources, and damages, which are financial compensations sought by the trustees for the harm done to natural resources.

Before initiating a formal NRDA, a Preliminary Natural Resource Survey (PNRS) may be conducted to determine whether a more detailed investigation is warranted. The PNRS is an informal survey, and need not be very detailed, consisting merely of a desk-top review of information about the trust resources in the area. The PNRS is not a requirement of a natural resource damage assessment. A formal NRDA does, however, require the performance of another formal preliminary study called a "preassessment screen." Through the preassessment screen, the trustee must decide whether to perform a formal damage assessment. The decision criteria include:

- a release of a hazardous substance has occurred;
- natural resources for which a federal or state agency may assert trusteeship under CERCLA have been adversely affected by the release;
- the quantity and concentration of the released hazardous substance is sufficient to potentially cause injury to those natural resources;
- data sufficient to pursue an assessment are readily available or are likely to be obtained at a reasonable cost;
- response actions, if any, carried out or planned do not or will not sufficiently remedy the injury to natural resources without further action (will result in residual injury).

This last criterion will be difficult to predict in the early stages of any significant response or remedial action. As work progresses and more complete information becomes available, estimates of effectiveness at minimizing residual injury should be possible.

The assessment component of the NRDA process is divided into three phases: Injury Determination, Quantification and Damage Determination. The Injury Determination phase establishes that one or more natural resources have been injured as a result of the discharge or release. The Quantification phase establishes the extent of the injury to the resource in terms of loss of services that the injured resource would have provided had the release not occurred. The Damage Determination phase establishes the appropriate compensation for the natural resource injuries expressed as a dollar amount.

Methodology for Calculating Damages

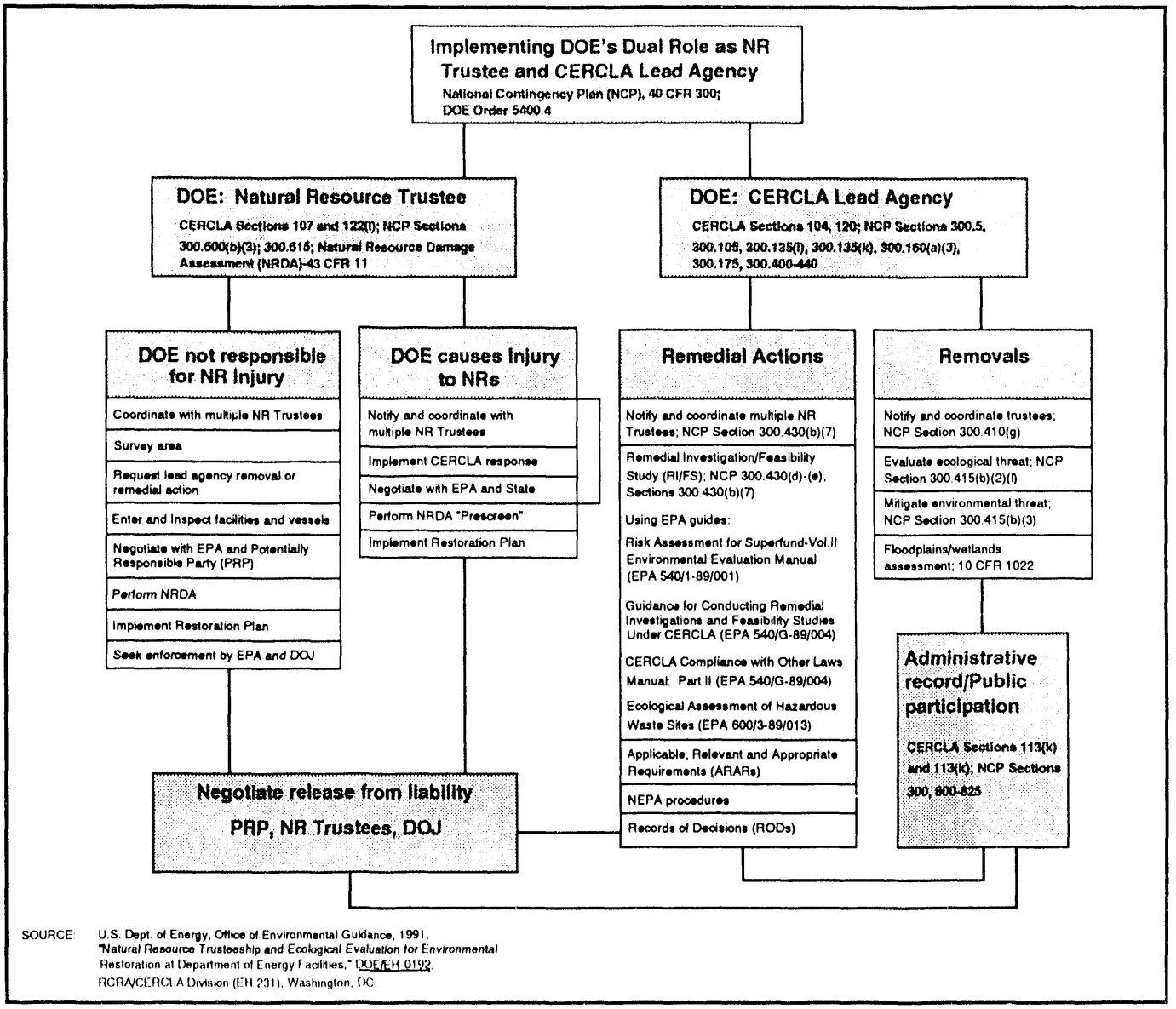
In July, 1989, the U.S. Court of Appeals for the District of Columbia remanded to the U.S. Department of the Interior (DOI), parts of its NRDA regulations at 43 CFR 11 (880F.2d 432 D.C. Cir. 1989-referred to as Ohio). On April 29, 1991, DOI issued a Notice of Proposed Rulemaking which addresses the court-ordered revisions (56 FR 19753). While no fundamental procedural changes to the NRDA process were made, the implications of Ohio for DOE's environmental restoration projects are noteworthy nonetheless.

DOI's new interpretation of the way damages should be calculated is most significant, because it now holds that CERCLA's preferred measure of natural resource damages is restoration costs plus compensable values. By striking down the existing "lesser of" standard (which limited damages to the lesser of restoration costs or lost use values), the Ohio court greatly expanded the scope of recoverable damages. Since it would not be unusual for restoration costs to be significantly greater than lost use values, Ohio petitioners successfully argued that the so-called "lesser of" standard incorrectly limited their ability to fully protect the public's interest.

Proposed changes resulting from the Ohio decision also include the court's direction that the trustees be allowed to use non-market based methodologies to value resource services whenever such methods are appropriate, and not just when market-based methodologies are unavailable. Thus, potentially higher "existence values" of certain resources could supplant lower, market-based valuations in damage assessments, particularly when vigorous markets for the particular resources and associated services in question do not exist. A case in point may be when the injured natural resource is outdoor recreation or a similar "amenity" service.

An ecological evaluation which assesses biological and ecological resources is required of DOE during the CERCLA response process and, as appropriate, for RCRA corrective actions. The information obtained from a properly performed ecological assessment can provide DOE ERPMs with a greater understanding of and a larger measure of control over the potential residual damages. If natural resource injuries and residual damages are known, or can be estimated during the investigatory phase of an environmental restoration project, ERPMs can use the information to plan

* Pursuant to CERCLA §301(C), the U.S. Department of the Interior published damage assessment regulations at 43 CFR 11. Even though the burden of proof remains with the natural resource trustee, obtaining a "rebuttable presumption" means that a court will presume that the amount of the damage claim is correct if it has been established by following the procedures spelled out in these regulations. When available, a rebuttable presumption may be successfully rebutted by showing that it has been improperly established.



SOURCE: U.S. Dept. of Energy, Office of Environmental Guidance, 1991, "Natural Resource Trusteeship and Ecological Evaluation for Environmental Restoration at Department of Energy Facilities," DOE/EH-0192, RCRA/CERCLA Division (EH-231), Washington, DC

Fig. 1. Overview of DOE trustee and lead agency responsibilities.

mitigation measures for the remedial phase. Even if the mitigation measures can not eliminate all residual damages, the damages may be sufficiently reduced to satisfy the concerns of the co-trustees.

The ultimate goal should be to work with the appropriate natural resource trustees to devise remedies which incorporate early appropriate resource restoration plans, while at the same time avoiding costly and time-consuming litigation. Under the proper circumstances, an appropriately performed ecological assessment may supplant the NRDA process altogether. However, performance of a NRDA can serve as an appropriate basis upon which the Department can develop its own natural resource restoration plan for any particular DOE site, regardless of whether a rebuttable presumption is applied to any damage claim.

It is recommended that in all instances involving potential natural resource injuries, DOE should consider performing or coordinating the preassessment screen of a NRDA, or as an alternate procedure, should perform the ecological assessment for the CERCLA Remedial Investigation/ Feasibility Study (RI/FS). When DOE performs a RI/FS, the ecological assessment performed during the baseline risk assessment of the RI/FS is not optional. The only option is whether DOE will use the same ecological assessment as a substitute for the "Preassessment Screen" of the NRDA. Such a substitution is allowed by the current 43CFR11 and is not expected to change. The ecological assessment process can provide a scientifically defensible basis for an agreement between DOE and other natural resource trustees, potentially obviating the need for a formal NRDA. A third party agreement of this nature is not prohibited, and is in fact described by the NCP as appropriate under certain circumstances. DOE could agree to take appropriate remedial or corrective actions beyond the required clean up of existing contamination, or other actions to protect, restore, or replace injured or lost natural resources. A release from further natural resource liability (a "covenant not to sue") could be issued by the other natural resource trustees in this case.

Ecological Risk Assessment

Notwithstanding DOE's Natural Resource Trustee responsibilities, the Department must perform an ecological assessment as part of the RI/FS for a CERCLA remedial action, and in some cases for a removal action as well. The ecological assessment will provide information on threats to the environment and natural resources which could result from exposure to the contaminants themselves or from remedial actions. Assessment of ecological factors by DOE should be considered "consistent" with the NCP approach to hazardous substance response, regardless of any natural resource trustee activities which may be underway at any particular DOE site.

Because ecological factors are important components of the remedy selection process, a well-documented ecological assessment may also provide a basis for addressing natural resource injuries. While not as explicit as the NCP requirement for a baseline ecological risk assessment, current RCRA regulations implicitly require an ecological assessment, including consideration of potential threats to biological and other natural resources.

The assessment of potential ecological risks is performed during the baseline risk assessment phase of the RI/FS. Data collection and laboratory and field study planning performed during the scoping phase of the RI/FS are critical to supporting a successful ecological assessment. The results of the ecological assessment are considered during the evaluation of the alternatives in subsequent phases of the RI/FS.

Data collection for the ecological assessment should be planned at the RI/FS scoping phase as part of the SAP, and may include: field surveys; toxicity testing; bioaccumulation studies; determining the extent of contamination (including planning for environmental media and environmental receptor sampling). Just as with the human health evaluation, different levels of effort in collecting ecological data may be required at different environmental restoration sites. Existing ecological data should be collected and analyzed for use in developing a site conceptual model. The site conceptual model is a useful tool for understanding the nature and extent of contamination. It will help investigators identify the site-specific potential exposure pathways to humans and environmental receptors. In addition to the known or potential receptors, the site conceptual model should include known and suspected sources of contamination, types of contaminants and affected media, and known and potential routes of migration. The site conceptual model thereby assists in identifying locations where sampling is necessary.

As a general principle, EPA advises its own on-scene coordinators and remedial project managers to collect only the data that are necessary to determine the potential ecological risks and to develop appropriate response actions, and not to allow the data collection efforts to evolve into independent research projects.

In the feasibility study, the remedial alternatives should be evaluated for their overall protectiveness, including protection of organisms and ecosystems, and for compliance with ARARs. In essence, just as is done for the evaluation of human health risks, the ecological assessment performed for the baseline risk assessment of the RI/FS should be performed for each of the remedial alternatives retained for the detailed analysis of alternatives.

At this writing, there is no single consensus method published for ecological risk assessment. Generally speaking, quantitative ecological risk assessments have been modeled for a complex array of factors involving the types and number of organisms, the pertinent contaminants or ecosystem stressors, and the specific exposure conditions at sites under investigation. DOE Headquarters (EH-23) and other federal agencies have been participating with EPA in a guidelines development project.

Integration of Ecological Assessments with National Environmental Policy Act (NEPA)

Current DOE policy is to fully integrate the RI/FS and NEPA Environmental Impact Statement (EIS) requirements. NEPA reviews typically include mention of fish and wildlife and other ecological resources in environmental assessments (EAs) and EISs. It should be noted however, that the ecological evaluation performed for a CERCLA RI/FS baseline risk assessment may, in terms of source, exposure pathway and ecological effects analysis, frequently require a more detailed and focused effort than that provided by a NEPA review.

The CERCLA baseline risk assessment looks at the conditions resulting from past contamination, and strives to make a probablistic statement (with associated uncertainty analysis)

about expected site conditions in the absence of any remedial actions. The detailed analysis of the alternatives during the feasibility study, like the NEPA review, looks at the effects of the remedial action itself.

The degree and nature of the information required for a CERCLA analysis depends on the specific contaminants present, their potential ecological effects, the exposure pathway(s), as well as a detailed receptor organism analysis, including life stage and trophic level effects. Potential ecological effects, in terms of individual, population, community and ecosystem level endpoints, might have to be estimated or determined. In short, the data incorporated to the RI/FS has to be sufficient to allow project managers to learn enough about the site conditions, such that protective and ARAR-compliant remedies can be selected. In addition, the recent DOE natural resources damage assessment guidance adds the suggestion that information requirements of the RI/FS be sufficiently comprehensive. This will ensure that the needs of the NRDA Preassessment Screen are satisfied, and that the RI/FS can serve as a defensible position from which to negotiate, if necessary, restoration activities with natural resource trustees (if warranted and appropriate).

The Fernald Environmental Management Project (FEMP) - A Case Study

As an example of how the requirements of the RI/FS process can serve the information needs of natural resources trustees, we will examine the work to date at a DOE Superfund site in southwestern Ohio.

The FEMP is a government-owned facility established in the early 1950s for the production of pure uranium metals, operated for the last five years by Westinghouse Materials Company of Ohio for DOE. Production at the facility has been suspended. Responsibility for the facility has been transferred from the DOE Defense Programs Office to the Environmental Restoration Office. The FEMP is located on a 1,050-acre site in a rural area approximately 18 miles northwest of downtown Cincinnati, Ohio, in Hamilton and Butler counties. Production facilities occupy approximately 136 acres in the center of the FEMP (Fig. 2). Land use outside the production area and waste storage areas includes 425 acres of grassland and woodlot leased for cattle grazing. Two pine plantations established in 1973 are located in the northeast and southwest portions of the facility, and Paddys Run, an intermittent ungauged stream, runs roughly parallel to the western boundary of the FEMP. The storm sewer outfall ditch, a major tributary to Paddys Run, enters the stream near the southwest corner of the property, and a number of smaller ditches drain into the stream. Paddys Run and its main tributaries are bordered by a wooded corridor. Treated effluent from process operations and runoff collection systems is discharged to the nearby Great Miami River through a National Pollutant Discharge Elimination System (NPDES) permitted outfall.

In April 1990, DOE signed a Consent Agreement with the U.S. Environmental Protection Agency (EPA) under CERCLA Sections 120 and 106(a), concerning environmental impacts associated with the FEMP. These impacts are related to past activities which have produced a variety of wastes, including general scrap and refuse, sanitary waste, contaminated and noncontaminated metal scrap, waste oils, asbestos, and fly ash. Additionally, radionuclide wastes have been disposed of in silos and in open pits. The major identified off-property impact of the FEMP is a plume of uranium-contaminated groundwater, the South Plume, which has maximum uranium concentrations of 907 ug per liter.

Pursuant to the Consent Agreement, DOE is conducting a RI/FS to facilitate appropriate remedial activities at the FEMP. In addition, DOE is preparing an EIS to examine the impacts of potential remedial activities and to comply with NEPA requirements for environmental evaluations of major federal actions. In order to expedite remedial actions at the FEMP, separate RI/FS reports are being prepared for each of five operable units. They are:

- Operable Unit 1 - Waste Pits 1 through 6, Clearwell, and Burn Pit
- Operable Unit 2 - Other Waste Units
- Operable Unit 3 - Production Area and Suspect Areas
- Operable Unit 4 - Silos 1, 2, 3 and 4
- Operable Unit 5 - All Environmental Media

RI/FS-SPECIFIC ECOLOGICAL INVESTIGATIONS AT THE FEMP

A number of ecological investigations have been conducted at the FEMP specifically to support the requirements of NEPA, CERCLA, and PNRS/NRDA, as outlined above. These studies and their specific roles in the remedial process are outlined below (Duke 1991).

Radionuclide Uptake by Ecological Receptors

Vegetation and aquatic organisms within and adjacent to the FEMP have been analyzed for isotopic uranium, cesium, and strontium. These data contribute to RI assessments of the nature and extent of contamination at the site, and serve in the baseline risk assessments as a partial basis for estimating the risks of radionuclides to ecological receptors. As a baseline for the effects of past releases of radionuclides from the FEMP, the study contributes to evaluations of the overall protectiveness and long-term effectiveness of proposed remedial actions, as well as to NEPA evaluations of the ecological impacts of the no-action alternative. These assessments in turn contribute to the PNRS and NRDA.

Threatened and Endangered Species Surveys

Among the ARARs with which remedial actions at CERCLA sites must comply is the Endangered Species Act (ESA). The FEMP lies within the range of the Indiana bat (Myotis sodalis), a federally listed endangered species, and the cave salamander (Eurycea lucifuga), an Ohio state-listed threatened species. Habitat and population surveys of these organisms have been conducted at and adjacent to the FEMP, but no individuals were captured on the property and no critical habitat was identified. Indiana bats were captured three miles east of the facility, but the nesting colony was not located.

The Indiana bat and cave salamander surveys contribute to the baseline risk assessment in that risks to these species have been shown not to be of concern. The study addresses the NCP requirement that remedial actions meet ARARs by eliminating the ESA as a concern. Thirdly, protection of threatened and endangered species and critical habitat would be a concern for both long-term and short-term effectiveness

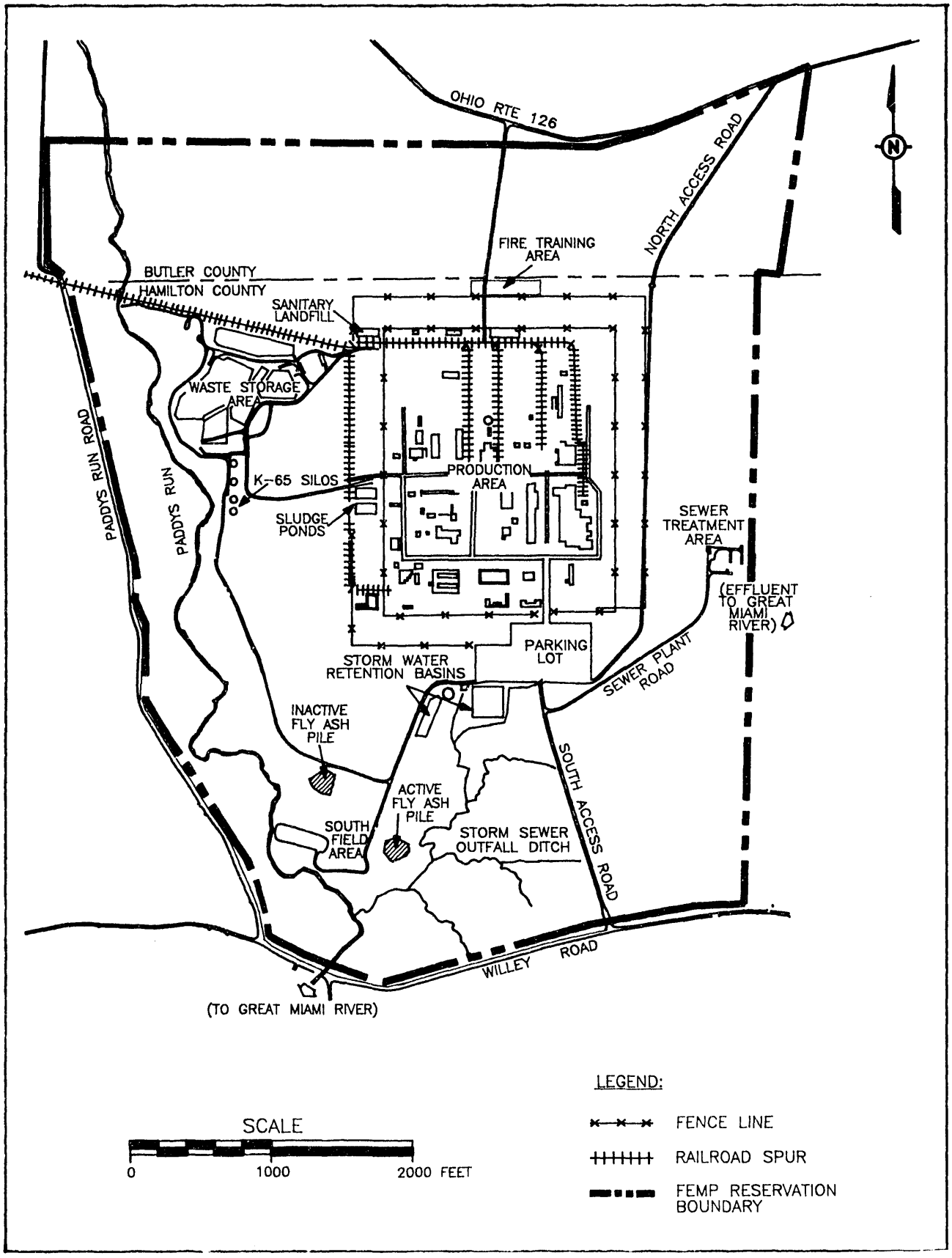


Fig. 2. Major features of the FEMP.

in the feasibility study, as well as for NEPA analyses of impacts of remedial actions on these organisms. PNRS and NRDA concerns are also addressed insofar as impacts on endangered species, if present, could be a key issue in a NRDA-based claim for damages. In confirming that no individuals were present on the DOE property or in the area, the surveys enable DOE and other cognizant natural resources trustees having jurisdiction over threatened and endangered species to delete them from further consideration.

Wetlands Delineation

Remedial actions at the FEMP must comply with the dredge and fill provisions of the Clean Water Act and associated regulations and executive orders (E.O.), including E.O. 11990, Protection of Wetlands. NEPA also requires particular attention to the environmental impacts of proposed actions on sensitive environments such as wetlands. Wetlands, like endangered species, could be of particular concern for the NRDA as environments of unusual ecological value. It was therefore necessary to identify and delineate any wetlands currently affected by the FEMP or likely to be affected by remedial actions.

Toxicity Tests of FEMP Effluent

Runoff and wastewater discharges from plant operations are collected in a general sump, treated and discharged under a NPDES permit into the Great Miami River. This effluent has been tested for acute and chronic toxicity to algae, invertebrates and fathead minnows, following EPA protocols. This study provides a baseline for determining the possible effects of existing uranium loading on the biota of the Great Miami River. It thus contributes to the baseline risk assessment in the remedial investigation and to evaluations of overall environmental protection and long-term effectiveness in the feasibility study, and potentially to the PNRS/NRDA. In addition, proposed remedial actions, for example pumping of contaminated groundwater, may affect the quality or quantity of effluent discharged to the river. A study of the potential toxicity of existing effluent provides information important to evaluating the environmental impacts of any changes in the nature of the effluent.

Toxicity Tests of Soils and Sediments

Soils and sediments at the FEMP have been contaminated with a variety of substances, principally radionuclides. Although radionuclide levels have been extensively characterized, data on inorganic and organic contaminants are limited. Further, because of the complex nature of soils and sediments and their interactions with organisms, it is difficult to predict the effects of contaminants in these media using only data on contaminant levels. The results of toxicity tests reflect not only the concentrations of the materials present, but also their availability to organisms, thus simultaneously addressing the problems of both multiple contaminants and complex media.

A preliminary study was therefore conducted to determine the toxicity of soils and sediments at the FEMP. Two soil and two sediment samples were collected from the facility, based on their expected relative radionuclide levels, and tested following standard protocols.

This study contributes directly to the baseline risk assessment and to the evaluations of overall environmental protection and long-term effectiveness in the feasibility study. In addition, proposed remedial actions involving excavation of contaminated soils may have ecological effects not predicted from contaminant data alone. This study therefore provides information important to the short-term effectiveness (environmental) section of the feasibility study, to the EIS, and to NRDA evaluations of possible residual damage to natural resources.

Macroinvertebrate Surveys

Potentially contaminated runoff from the FEMP drains into Paddys Run, and treated effluent from the facility is discharged to the Great Miami River, as described above. The FEMP may therefore affect aquatic communities in these two surface waters. This is an immediate concern for the CERCLA evaluation of ecological risks, and is also important to the PNRS/NRDA, particularly since the Ohio Environmental Protection Agency evaluates water quality in streams partially on the basis of the health of fish and macroinvertebrate communities.

Macroinvertebrate surveys address concerns about the effects of FEMP contaminants on aquatic communities for purposes of the baseline risk assessment and PNRS/NRDA, as well as the overall environmental protection and long-term effectiveness criteria in the FS process. In addition, potential remedial actions, for example, excavation of contaminated sediments, may affect the macroinvertebrate community, which would be of concern to the CERCLA evaluation of short-term effectiveness and to NEPA analyses of environmental impacts.

DISCUSSION AND CONCLUSIONS

CERCLA allows any person to seek relief from the United States Government or any of its officers for an alleged inadequate response to release of a hazardous substance, including an inadequate execution of natural resource trustee responsibilities. Further, even if the lead agency or PRP intends to perform remedial actions, such a suit could force unplanned remedial actions or restoration of the injured natural resource. It is clear that, when gathered early in the process, the information gathered in compliance with the NRDA provisions of CERCLA and the NCP will enable managers to make better decisions concerning remedial action alternatives.

Regulatory guidance on NRDA published by Department of Interior is the subject of a recent Notice of Proposed Rulemaking (55 FR 19753). The revisions to these regulations significantly expand the possible recoverable damages available to natural resources trustees. It is clearly in the best interest of the DOE as a natural resource trustee, lead agency or PRP to ensure that all trustee responsibilities are fully and properly implemented. Early and extensive identification of ecological risks is vital to fulfilling that role. The breadth of ecological studies conducted at the FEMP, a 1,050 acre site without extensive wetlands or critical habitats, suggests the future importance of implementing the DOE NRDA guidance at larger and more complex sites.

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MANAGING A SITE CLEANUP UNDER AN ACCELERATED SCHEDULE THE LOWMAN STORY

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ABSTRACT

This paper is intended to shed some light on the multitude of problems and issues related to the acceleration of remedial action activities at the Department of Energy's Lowman, Idaho Uranium Mill Tailings Remedial Action (UMTRA) Project site. The pre-remedial action and construction activities were accelerated to accommodate limited funding. This paper will concentrate on several major activities that were accelerated to enable construction activities to begin one year ahead of schedule and the issues and problems that arose during cleanup and construction.

THE UMTRA PROJECT

Following the development of scientific evidence that uranium mill tailings may pose a radiation related health hazard, Congress passed the Uranium Mill Tailings Radiation Control Act of 1978 (UMTRCA), Public Law 95-604. Title I of the UMTRCA authorized the Secretary of Energy, with the concurrence of the affected States and Tribes and the U.S. Nuclear Regulatory Commission (NRC), to provide for the remediation of residual radioactive materials at 24 inactive uranium processing sites in 10 states. The remediation is being performed under the direction of the Uranium Mill Tailings Remedial Action (UMTRA) Project Office in Albuquerque, New Mexico, which the U.S. Department of Energy (DOE) established in 1983.

Under the UMTRA Project, processing sites are remediated to levels defined in standards developed by the U.S. Environmental Protection Agency (EPA) for the Title I sites (40 CFR Part 192). The States are required to fund 10 percent of the cost of remedial actions. To date, surface remedial actions are complete at nine of the 24 sites, and are in progress at six other sites. The design and regulatory compliance process for tailings disposal at the remaining sites is well advanced, with the remaining sites scheduled for completion by 1996 (State and Federal funding permitting).

Within the framework of the UMTRA Project, the DOE oversees the technical assistance contractor (TAC) (Jacobs Engineering, Roy F. Weston, Sergent, Hauskins, and Beckwith, and Geraghty and Miller) and the remedial action contractor (RAC) (MK- Ferguson). The TAC is responsible for the front end planning, conceptual design, and environmental documentation. The RAC is responsible for final designs and construction management of the remedial actions.

THE LOWMAN SITE

The Lowman, Idaho, UMTRA site is located approximately 121 kilometers northeast of Boise, Idaho, and 1 kilometer east of the town of Lowman. The site is located on 14.2 hectares. The former mill site mechanically processed radioactive sands taken from the Bear Valley area located approximately 29 kilometers north of the Lowman site. The site is heavily wooded and mountainous and is bordered to the west by Clear Creek.

The site contained piles of radioactive sands left over from the mechanical processing of the Bear Valley sands. The sands covered approximately 3.2 hectares of the site and comprised a volume of 47,430 cubic meters. An additional 15,300 cubic meters of contamination in the mill yard, ore storage area, and evaporation ponds and windblown and waterborne contamination existed within the site boundary. Because of the site's small size (other UMTRA sites contain up to 4,360,000 cubic meters of contaminated materials), the construction schedule would only require seven months of activity.

Within the UMTRA Project, vicinity properties are locations away from the mill site where residual radioactive material in excess of the EPA standards was transported by either man or nature. There were 30 vicinity properties identified in 1989 through inclusion surveys when the schedule was accelerated.

PLANNING

Initially, the vicinity property remediation was scheduled for two construction seasons, to be followed the next season by the remediation of the mill site. This three-season remedial action schedule was determined by the integrated project schedule developed from the projected Federal budget requests and planned work at other mill sites.

This three-season effort scheduled to begin in 1990 and continuing in 1992 and 1993 was not the most cost effective, however. The State of Idaho had obtained a one-time appropriation from the Legislature effective in July of 1990 to complete all remedial actions at the Lowman site. This appropriation, in addition to a donation from the former mill site owner, was not enough to cover the estimated cost of the three-season remedial action plan, but would meet the requirements of a two-season remedial action schedule. The State expressed a very strong desire to compress the remedial action into two construction seasons beginning in 1990.

A series of meetings took place between the State and the DOE, including a meeting with Governor Andrus to discuss the feasibility of accelerating the Lowman remedial action schedule. The DOE expressed a willingness to work with the State and make a good faith effort to complete all activity by the end of 1991. At this time, the engineering design for the stabilization of the tailings was only 30 percent complete. The

designs for the vicinity properties were not much more advanced.

In accordance with the cooperative agreement between the State of Idaho and the DOE, the State is required to acquire the processing site from the owner. At that time, the State was negotiating with the mill site owner to acquire the property. The site acquisition activities were tied together with the State Legislature funding bill. The site owner agreed to donate the mill site to the State in addition to providing $300,000 to partially fund the State's share of the remedial action costs. The legislation and the site transfer were all to be effective on July 1, 1990, and the DOE had concerns regarding the timing of the property transfer until the documents were signed in early July. The uncertainty over the property transfer delayed the start of remediation on the vicinity properties until mid-July.

VICINITY PROPERTIES

Designs for 14 vicinity properties were quickly completed, allowing a substantial portion of the vicinity property work to be completed in 1990. Contracts were awarded to two contractors for the remediation of these 14 properties. An additional 9 properties were added later in 1990, making a total of 23 vicinity properties remediated during the 1990 construction season. Although these 23 properties were not the most difficult ones, they still represented a significant amount of the vicinity property work to be completed in the Lowman area.

The UMTRA Project has many unique requirements in the health and safety areas necessitated by the nature of the material being dealt with and the requirements of the DOE. These requirements far exceeded any requirements the contractors had experienced in other construction projects they had previously been involved with. The contractors were quickly educated in the necessary requirements by the RAC. The MK-F field personnel worked closely with the two contractors to help them develop the necessary reporting systems required by the DOE. They also assisted the contractors in establishing the required health and safety programs. Without the extra effort expended by the RAC field staff, the 1990 construction season would not have been nearly as productive as it actually was.

Many people became aware of the UMTRA Project as a result of the vicinity property activity during the summer and fall of 1990. Several of these people became concerned that contamination might exist on their property and requested the DOE to perform radiological surveys to identify potential tailings contamination. As a result of these new inclusion survey requests, an additional six vicinity properties were identified and scheduled for remedial action in 1991.

The additional vicinity properties, along with the site activities, made 1991 an extremely busy construction season. This was compounded by the fact that the remaining 13 vicinity properties were more difficult than the ones completed in 1990. Many of the 1991 properties involved extensive structural activity to remove tailings from or below foundations.

Construction activities began in February 1991 while snow still covered the ground. Interior remediation was accomplished while the weather was too harsh to allow outside activities. With the application of years of construction knowledge and experience of MK-F, an aggressive schedule for remediation was established that meshed with the site remediation schedule. The biggest key in keeping the vicinity property schedule meshed with the site schedule was to include all but four of the vicinity properties in the main site bid package. This action put the burden on the site contractor to be directly responsible for completing the vicinity property work on schedule and not to impact the site activities.

COORDINATION

Several other activities were occurring simultaneously with the vicinity property remedial action in 1990. These activities included the completion of the site remedial action design and the environmental documents necessary to satisfy the National Environmental Policy Act requirements, both of which will be described in detail later. The coordination of all these activities presented a major challenge for the DOE site manager. The activities of the DOE, two contractors, the State, the U.S. Forest Service, and the NRC had to be coordinated to ensure that all major milestones were met and that reviews were provided in a timely manner. All parties were not always in total agreement, and a method of timely communication and problem resolution was needed.

A weekly telephone conference call was instituted between representatives of the DOE, State, and contractors. The conference call addressed outstanding issues and actions raised during the previous week, and identified actions required for the following week to speed activities to timely completion. Surprises and confusion over responsibilities decreased markedly after initiation of the conference calls.

Close coordination with the State of Idaho Division of Environmental Quality (IDEQ) was required to keep them involved in the development of the design and associated activities. The UMTRCA specifies that the State and the NRC are to concur in the remedial actions performed at the mill sites. The weekly conference calls were used to discuss design development details and solicit the State's input. The State also attended design review meetings at the 30 and 60 percent design development stages.

In addition to the development of the design for the mill site, work continued with the vicinity property owners in the Lowman area and with the development of the remaining vicinity property designs. The State played a key role in discussions with the property owners concerning the identification of special requirements for the remedial action designs. The State was viewed as being more in tune to the property owners' interests than "outsiders" from the Federal government, and was thus able to have a great deal of success explaining the requirements of the remedial actions to the owners.

Some substantial time- and cost-saving measures were implemented as a result of decisions by the DOE, the State, and MK-Ferguson. Several contaminated structures were bought by the DOE and demolished by the contractor rather than being reconstructed. This decision was discussed with the property owners, who were given the option of having the structures rebuilt or having the government buy them. The State played a key role in discussions with property owners in obtaining these time- and cost-saving alternatives. Without careful coordination with State representatives, the remediation at Lowman might not have taken place in just two construction seasons.

The State was also able to assist in coordinating activities with the Idaho Department of Parks and Recreation (IDPR),

whose Boise office was the former laboratory building for the mill owners and was contaminated. Special coordination was required for this property, because the IDPR desired to move to new facilities at the start of remedial action and have the UMTRA Project demolish the existing facility rather than rebuild it. The UMTRA Project would reimburse the IDPR the difference in cost between the demolition option and the complete restoration option. This coordination required several meetings to discuss the details of timing, what would be left on the property, and what the IDPR would salvage from the facility. The IDEQ was instrumental in assisting the DOE with these activities.

Throughout these developmental activities, both the DOE and the State remained committed to the accelerated schedule. Governor Andrus kept in touch with DOE Headquarters to ensure adequate Federal funding was available for the Lowman remedial action activities, and to reemphasize the State's firm commitment to completing the Lowman site in 1991. The DOE also remained committed to completing the Lowman site on the accelerated schedule and directed the UMTRA Project Office to complete the site in 1991, if possible. Without the support of upper management in both the State and the DOE, the acceleration of the Lowman site would not have been possible.

THE REMEDIAL ACTION PLAN

The Lowman site has been unique in many respects. Not only was the design and concurrence schedule shortened by over one year, but it was the first site in the UMTRA Project to utilize new procedures for both the remedial action plan (RAP) and the environmental assessment (EA) and finding of no significant impact (FONSI).

The DOE and the NRC executed a revision to their existing Memorandum of Understanding (MOU), which was designed to streamline how business on the UMTRA Project was conducted between the two agencies. The new MOU outlined a new format for the RAP that followed the NRC's format for its technical evaluation report (TER). This change was designed to assist the NRC in its review of the RAP, since the information would be organized in the same format as the TER they would produce in evaluating the RAP.

One other change to the RAP review process as a result of the MOU revision was the elimination of the formal review of the draft RAP which contained the 30 percent design. Instead of formal review comments, a site visit would be held with representatives of the DOE, the NRC, the State, and contractors present. Informal comments would be provided by the NRC. These changes to the RAP reviews would create significant problems for the development of the design and associated documents, and for obtaining concurrence from the NRC.

In between NRC reviews of the draft RAP in June 1990 and the review of the preliminary final RAP in December 1990, the NRC changed hydrologists. As a result, the hydrologic comments received on the preliminary final RAP were quite different than those received on the draft RAP. The DOE prepared a comment and response document to address the NRC's comments provided in the draft TER of the preliminary final RAP. The comment and response document addressed each individual open issue raised by the NRC during its review of the Lowman RAP. This document addressed 31 comments and was compiled and prepared in just two weeks. The preparation of the comment and response document required total dedication from the technical staff. The majority of the required data had been previously collected. However, a large amount of effort was needed to compile the responses to all the open issues. The NRC agreed to a quick review of the comment and response document and scheduled a meeting at its offices to discuss the DOE responses to the NRC open issues.

The NRC agreed that the open issues were correctly addressed and that if all the agreed upon responses were incorporated into the final RAP, they would concur with the planned remedial actions. The NRC agreement to the resolution of the open issues led to the award of the remedial action contract for the mill site.

Technical staff members received letters of commendation for their diligent and dedicated efforts after the successful conclusion of the discussions with the NRC. In addition to letters of commendation, the DOE and the technical assistance contractor site managers arranged a party after work to thank the technical staff members for their successful efforts. The appreciation was well received and will go far in assuring a committed staff when other crises arrive.

ENVIRONMENTAL DOCUMENTS

The Lowman environmental assessment (EA) was the first for the UMTRA Project under the requirements of Secretary of Energy Notice (SEN) 15-90. This notice requires additional formal State involvement in the preparation of the EA. SEN 15-90 provides the States with the option to waive their review of the final EA. Due to the severe time constraints associated with the accelerated schedule and the State's involvement in the selection of remedial action alternatives and review of the draft EA, the State formally requested to waive review of the final EA. This action saved a minimum of four weeks of time in the extremely compressed EA schedule. However, due to increased headquarters involvement required under SEN 15-90, the review time was doubled nearly delaying the start of remedial action. Weekly discussions were conducted with headquarters personnel to track the progress of the EA review and quickly answer any questions which arose during the review. Upon signature by the appropriate DOE headquarters staff, the remedial action contract was awarded.

PERMITS

Substantial cost savings were realized when the waste water retention basin and accompanying drainage ditches for the mill site construction were eliminated. Eyewitness accounts of a major rainfall event at the site by MK-Ferguson personnel supported the fact that due to the sandy nature of materials at the site, runoff from even a 25-year storm event would not occur. The State agreed and facilitated discussions with the appropriate state permitting agency to waive a water discharge permit for the site.

Some of the contaminated material was discovered on the steep slopes leading to Clear Creek and in the steep forested areas along the northern boundary of the site. The EPA standards for the UMTRA Project contain provisions for leaving contamination in place using supplemental standards if certain criteria are met. Discussions between the DOE, State, contractors and the U.S. Forest Service who owned some of the property were conducted to give assurance that

the conditions of the EPA standards were met and that the materials could be left in place.

The remediation of this material at the Lowman site would cause excessive environmental harm and create a greater danger to the workers removing it than the health benefits gained through the removal. This data was presented to the NRC for its concurrence. Due to the accelerated schedule to assemble the design, one area where supplemental standards should be applied was overlooked until the very end of the contaminated material excavation. The additional justification for this area was quickly assembled and provided to the NRC for concurrence.

PROBLEMS DURING CONSTRUCTION

The remediation of the Lowman site and vicinity properties produced additional quantities of contaminated material that exceeded the existing disposal cell capacity. The design engineers had allowed for additional quantities to be incorporated into an area adjacent to the tailings cell in the event of the discovery of additional quantities. Quick design alterations by MK-F and timely review of the change by the DOE, the NRC, the State and technical staffs provided for timely resolution of this matter.

The Department of Transportation provided a new interpretation of its regulations regarding the transportation of radioactive material in May of 1991. This interpretation had possible impacts to the vicinity property remedial action, since public roads were used to transport the tailings to the mill site. In response to this new interpretation, MK-F suspended the transport of tailings at active UMTRA sites, including the Lowman vicinity properties. This had a profound effect on an already tight schedule. The shutdown lasted approximately four weeks and was partially offset by an MK-F decision to continue excavation and begin stockpiling activities at the vicinity properties. Clearance was obtained to resume hauling, and the shutdown had only a minor impact to costs and schedules thanks in part to the stockpiling activities during the shutdown.

During excavation of contaminated materials at the Lowman site, an old diesel spill (20 to 30 years old) was encountered. The material was tested both for both total petroleum hydrocarbons and toxicity characteristic leaching procedure (TCLP). The TCLP results were negative, indicating no hazardous materials could leach out of the soil. The DOE wanted to be sure that the diesel contaminated soil would not impact the disposal cell groundwater compliance strategy if disposed of in the cell. The State coordinated with the appropriate agencies and concluded that the material did not represent a hazard and the material was disposed of in the tailings embankment.

LESSONS LEARNED

The acceleration of these activities produced problems that had to be expeditiously dealt with as they occurred. Several lessons learned became obvious as the site activities progressed. Some of these included the following:

- Coordination and communication are the key to any remedial action activities. This is especially important where schedules are accelerated. Weekly conference calls between the DOE, the State, the technical assistance contractor, and the remedial action contractor were implemented. These weekly calls ensured that tasks and other issues were clearly defined, and that schedules were either met or completed ahead of time.
- Commitment of all parties involved is essential. Commitment of all levels of the various parties and organizations involved is necessary to aid in cutting red tape that could delay certain activities. Lines of communication and cooperation were established within and between organizations to ensure rapid response to changing requirements. Both upper management and technical staff commitments are required for the success.
- The Lowman remedial action activities were almost derailed by changing and unexpected comments from the NRC due to the new procedures for review of the draft RAP and new reviewers. The NRC has agreed to emphasize characterization requirements in its reviews of future draft RAPs.
- The measures taken to provide increased communication and coordination, along with the total commitment of everyone involved, provided the capability to quickly react to these and other unexpected events that emerged during the life of the project.
- Budget underruns in both planning and construction can be achieved under an accelerated schedule using aggressive management techniques.
- Be prepared for the unexpected!

IN-SITU STORAGE: AN APPROACH TO INTERIM REMEDIAL ACTION - RECENT CASE STUDIES IN CANADA

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ABSTRACT

The Low-Level Radioactive Waste Management Office (LLRWMO) acts on behalf of the federal government to manage historic low-level radioactive wastes. Recent interim remedial work in the Town of Port Hope, Ontario has included the consolidation of radium and uranium contaminated soils into temporary storage facilities on two sites to await final disposal elsewhere. Simple containments constructed and sited on already contaminated sites have been found effective as part of an interim remedial strategy. The approach has been accepted and supported by the local public. Lessons have been learned from a project management, environmental remediation and engineering design point of view.

INTRODUCTION

The Low-Level Radioactive Waste Management Office (LLRWMO) is Canada's national office for resolving "historic" low-level radioactive waste problems. Interim remedial work projects were completed at two locations in the Town of Port Hope, Ontario in 1988 and 1990 by the LLRWMO. While further work remains at other sites in the Town, these projects have provided lessons in project management, environmental remediation and engineering design.

This paper reviews the experience of the LLRWMO in undertaking its program of interim waste consolidation and short term temporary storage in the Town of Port Hope. Simple containment structures built at the Cavan Street site and the Strachan Street site are described here. Lessons learned in undertaking waste excavation and consolidation activities at these sites are also discussed. Simple containments have been found cost effective and of environmental benefit. They have been recommended and accepted by local residents.

The LLRWMO was established by the federal government in 1982 to resolve historic waste problems (those for which the original producer can no longer reasonably be held responsible) that are a federal responsibility, to ensure that a user-pay service is established for the disposal of low-level radioactive waste (LLRW) produced on an on-going basis, and to address public information concerning LLRW. High level waste and uranium mill tailings are not within the mandate of the LLRWMO. The LLRWMO is operated by AECL Research through an agreement with the Department of Energy, Mines, and Resources (EMR), the federal department which provides the funding and establishes national policy.

The LLRWMO is located in Ottawa, with a field office and laboratory in Port Hope, Ontario. It operates primarily as a project management organization, and contracts projects to private sector contractors and consultants, and to other divisions of AECL Research.

The LLRWMO has completed projects in Quebec, Ontario, Alberta, and British Columbia where historic wastes have been cleaned up and put into interim storage. Small volumes of waste are packaged and transported to a storage facility operated for the LLRWMO by the Chalk River Laboratories (CRL) of AECL Research. Larger volumes are temporarily stored through the use of several types of engineered containments at the original sites. These interim actions have eliminated health risks and remediated environmental problems. Substantial progress towards selecting a site for the long-term management of these historic wastes, and other similar wastes in the Port Hope vicinity for which the federal government is mainly responsible, has been made by an independent Siting Task Force appointed by the Minister of Energy, Mines and Resources for this purpose.

BACKGROUND

The Town of Port Hope, Ontario lies on the north shore of Lake Ontario, approximately 100 km to the east of Toronto. A radium refinery operated in Port Hope from 1933 until the 1950's. Starting in 1942, the refinery plant site became the home to various uranium refining and conversion facilities. In 1975, radioactive contamination resulting from practices in the early years of radium and uranium production was discovered in parts of the Town. A Federal/Provincial Task Force on Radioactivity, headed by the Atomic Energy Control Board (AECB), was established to develop cleanup criteria and to carry out remedial work at properties exceeding these criteria in Canada, and specifically in Port Hope, and in the uranium mining communities of Elliot Lake, Ontario and Uranium City, Saskatchewan.

The primary criteria established by the Federal/Provincial Task Force for initiating remedial work were 0.02 Working Levels (WL) for indoor radon progeny, 0.05 milliroentgen per hour (mR/hr) for interior gamma radiation, and 0.100 mR/hr for exterior gamma radiation.

Over 4000 properties in Port Hope were surveyed for compliance with the criteria and remedial work was carried out on about 400 properties between 1977 and 1981. However, the radioactive waste management site at CRL of AECL Research, where the Port Hope wastes were trucked, had a limited capacity. Remedial work was thus concentrated on developed residential and commercial properties.

The remaining contamination is distributed as follows. Large volumes of contaminated soil in mainly vacant areas (major on-land areas) and the contaminated sediments in the Port Hope harbour were left for cleanup at a later date. As well, small quantities of slightly contaminated soils, that is soils with above background radioactivity content but which do not

exceed the cleanup criteria, exist along some roads and on some private and public properties.

The LLRWMO inherited the records of surveys, and of remedial actions taken at developed properties. All properties identified by the Federal/Provincial Task Force as exceeding their cleanup criteria are believed to have been addressed by the original cleanup work and in a follow-up program carried out by the LLRWMO on about 40 properties.

This follow-up work was the initial program initiative of the LLRWMO in the Town. However the Task Force criteria do not fully address future land use. Specifically, compliance with the outdoor gamma radiation criterion does not preclude the possibility that indoor radon concentrations could exceed the radon criterion in future construction at undeveloped locations.

A second initiative of the LLRWMO, the Construction Monitoring Program, was developed in cooperation with the Town of Port Hope. It addresses contaminated soil found from time to time at excavations at new construction sites. This program, which began in January 1990, enables the cleanup and interim storage of contaminated soil from such sites, and thus eliminates the possibility of perpetuating a problem created in the past.

A third initiative is the Interim Waste Consolidation Program which addresses the large sites in Town. Extensive consultations, on interim remedial work at the major on-land areas, were initiated with site neighbours, Council and the community at large in 1986, when it became clear that a new site for the long-term management of these wastes, and the similar wastes at the Welcome and Port Granby waste management areas in nearby communities, would not be available for some years. These consultations resulted in resolutions by Port Hope Council in mid-1988 requesting the LLRWMO to proceed with certain interim actions including the remediation of the Cavan Street and Strachan Street sites discussed here. The consultation process with local residents and municipal government is discussed in a companion paper (1) also prepared for this conference.

IN-SITU STORAGE

Definition

For the purposes of this paper, in-situ storage is a short term remedial strategy. It is a standard approach now used by the LLRWMO for sites where remedial action should be undertaken, but where the volumes of contaminated soil or other materials are too large for transfer to the warehouse type of storage facility at CRL. This approach eliminates the time consuming step of trying to find a temporary storage site at a new location well away from the location of the contaminated site. Efforts in the early 1990's, by the LLRWMO and its predecessors, to locate such sites were unsuccessful due to opposition by residents near the proposed new sites. Contaminated soil is now consolidated and held in storage on the parcel of land, defined by ownership, where it was first encountered. Where this is not possible, an abutting or nearby parcel may serve as an alternate. Agreement with the owner of the contaminated site may be more readily and quickly attainable given the potential for immediate action afforded by this approach. The community and environmental benefits of being able to implement improved waste management practices promptly are obvious.

Technical Merits

The storage facility or containment, while engineered, need not have a long design life and need not address all the aspects which would be addressed by a facility for long term management of the wastes. In the short term it may be advantageous to delineate and cover contaminated areas in order to secure the site, to prevent inadvertent relocation of the problem material by man, to afford containment against wind and surface water erosion and to reduce environmental impacts. Where the affected surface area of the site is reduced by consolidating contaminated soil into a stockpile in a smaller area, land is freed up for other uses. Typically, a containment period of only a few years is expected at sites in Ontario and British Columbia.

Complete excavation of all contaminated soil is not necessarily required in this approach. The base of the storage stockpile may itself consist of contaminated material awaiting future removal. This has been found advantageous where a heavily contaminated area is surrounded by pockets of scattered surface contamination and where a major reduction in the affected site surface area can be realized simply by relocating the pocket of material to the more heavily contaminated centre. Where subsurface conditions are complicated or involve large volumes, then dealing first with easy to address problems at the surface may net cost effective returns. Surface-first initiatives can reduce groundwater impact but do not solve significant groundwater problems if these exist at a subject site.

Volume and scale are significant considerations in adopting an in-situ storage approach. Where volumes are small, future double handling costs are less significant. Lost value of construction materials and resources consumed to design and construct the interim containment is also less with smaller scale problems. However, other factors may outweigh present cost in favoring an immediate in-situ storage approach rather than waiting for the availability of a new facility for long term management of the wastes. Among these are the obvious environmental benefits and also more subtle ones.

LLRWMO Experience

LLRWMO experience in consolidation and storage projects has shown a number of advantages of this approach. Containment of the waste prevents further spread of contamination thereby limiting the problem and it helps cap remedial costs. Barriers applied over the waste protect potential intruders from any hazards and also lessen the probability that unsuspecting parties will relocate and further spread the problem. Covering the waste affords physical shielding to eliminate gamma fields and a barrier against radon emanation. In fact, the act of excavating and stockpiling waste provides self-shielding layers. An accurate understanding of the characteristics and volume of the waste requiring further long term management is obtained when the materials are delineated and excavated for interim consolidation. Progress is made toward final completion of remedial activities since most of the affected areas are cleaned and restored to the ultimate desired level. Material is also prepared for easy future removal.

The LLRWMO has used a number of in-situ storage approaches including: ravine fills, small mounds, concrete block walled bunkers, and drummed storage within a fenced

area. These have occurred at sites in Ontario and British Columbia. Such storage sites have held as little as 50 and as many as 30,000 cubic meters of contaminated soil but it is most likely that this approach will typically apply to inventories of a few thousand cubic meters.

STRACHAN STREET CASE STUDY

Context

The Strachan Street site was the first waste consolidation effort undertaken by the LLRWMO in Port Hope. It was part of a simultaneous multiple site initiative that also saw the construction of a storage facility at a new site for the Construction Monitoring Program, and the preparation of the Cavan Street property for future activities there. The work was requested by resolution of Town Council in June 1988 following a series of public meetings. Construction started in October 1988 and was completed by January 1989 at a cost of approximately $250,000. Temporary in-situ storage was used at Strachan Street because the town residents supported in-situ storage over moving significant quantities of contaminated material to any potential centralized storage area within the town. Most of the contaminated soil was located on a parcel owned by the Town.

Setting

The site is located within the developed urban area. Before remedial work began a fenced area measuring approximately 100 by 300 meters surrounded the area of most highly contaminated soil at a ravine beside the paved roadway. The slopes of the ravine were heavily treed and overgrown. Contaminated soil and artifacts could be found on the surface within the fenced area, primarily along the north slope, which fell steeply down from the Strachan roadway surface. Eight houses abutted the ravine on the south and west, and an undeveloped lot was located to the east. Several of these private properties showed pockets of contamination extending from the ravine property into their rear yards. Contaminated soil was also known to extend under the paved roadbed itself.

Work Undertaken

The nature of work undertaken may be described as follows. Trees and vegetation were cut, surveyed for contamination, and removed from the site when confirmed clean. The contaminated soil was consolidated into a smaller area, by excavating it and moving it to a designated area with contaminated surface soil on the north side slope of the ravine. Pockets of contaminated soil were removed from the abutting residential back yards and placed into the consolidation site. Contaminated soil and artifacts were removed from 4 adjacent private properties and from 4 sites on Town owned land. A multi-layered engineered cover consisting of sand, a high density polyethylene (HDPE) cover, and topsoil was installed over the consolidated waste site. The 700 cubic meters of contaminated material under the asphalt roadbed, which is well contained and causing no current impacts, was not removed. The site was landscaped, and the waste stockpile area fenced and signed to warn against excavation. It has been monitored regularly since January 1989.

Criteria and Performance

The cleanup criteria set for this project were 0.3 becquerels per gram (Bq/g) radium-226 (^{226}Ra), 35 micrograms per gram (μg/g) uranium, and 50 μg/g arsenic. The results achieved based upon 27 composite samples were 0.02-0.09 Bq/g ^{226}Ra, 1.3-17 μg/g uranium and 0.8-19 μg/g arsenic. Gamma radiation fields up to 5,000 microroentgen per hour (μR/hr) on contact were reduced at surface to background levels, typically 4 to 5 with a maximum of 10 μR/hr. Previous impacts on environmental radon and groundwater were minimal at this site. Reduction in environmental impacts due to consolidation of the waste and environmental monitoring of the area is discussed in detail elsewhere (2).

The Strachan Street Consolidation Site now contains approximately 1300 m^3 of consolidated material plus approximately 400 m^3 of original contaminated soil beneath the consolidated material for a total of 1700 m^3. The mean concentrations of contaminants are 2.6 Bq/g ^{226}Ra, 232 μg/g uranium and 8.8 μg/g arsenic. The resulting inventory of contaminants licensed by the Atomic Energy Control Board (AECB) is 8.0 gigabecquerels (GBq) of ^{226}Ra, 709 kg of uranium, 27 kg of arsenic.

Results

Generally, this project went quite well and was well received. As the first interim consolidation project for the LLRWMO in Port Hope, it provided an opportunity to conduct an extensive public consultation and review process in parallel with regulatory agency review and approval of the undertaking, and to design and contract a soil excavation remedial project based upon conceptual reports and subsurface contamination surveys. Conduct of an environmental screening process as required by federal guidelines was also an important element.

As a small project, compared with other civil works such as highway reconstruction and excavation for land development and urban servicing, it afforded local contractors the opportunity to bid upon this type of work and to gain experience in contamination control procedures. This experience will serve future remedial activities.

Experience was gained by the LLRWMO in dealing with property owners' anxieties and concerns. This opportunity for the LLRWMO to be seen performing, and establishing a track record for evaluation, by the community and the regulatory agencies, was also important in this initial Port Hope project.

Key Lessons

Key lessons which arose from this project can be listed as follows. First, the interactive nature of waste delineation, removal, verification, and further removal was confirmed. It is not easy to delineate contamination at depth in advance. The solution is not conservative mass removal but rather closely directed excavation. In order to keep tomorrow's waste management problem as small as possible, the volume excavated today requires close control.

The importance of good community relations is vital. Agreement with affected land owners is more easily attained and then expectations fulfilled if communications and objectives are honest, openly declared and commonly held. Public

suspicion of waste management proponents is overcome by establishing initial trust followed by delivered performance.

Finally, it is acknowledged that such remedial projects are special or custom efforts that require a degree of circumstance-specific crafting. The standard rule of thumb estimates of contractors and agents do not apply. Frequently time, cost, volume forecasts and method must be adjusted to respond to discoveries or circumstances encountered during the conduct of the work. The experience garnered in actually undertaking projects in the field guarantees future success.

CAVAN STREET CASE STUDY

Context

The Cavan Street property and abutting land is the site of the largest waste consolidation effort undertaken to date by the LLRWMO. The work was requested by a resolution of Town council of August 1988. Trees were cleared from the site of the proposed consolidation area in Rollins Ravine in October 1988 and waste consolidation construction followed the next year resulting in a total project expenditure of approximately $1,500,000. The work occurred over a 40 week period beginning in August 1989 and including a winter shutdown period from January through April 1990. On-site in-situ storage is provided in a ravine fill with the contaminated soil covered with an engineered multi-layer cover.

Setting

Prior to the consolidation of wastes at this site, the total area affected by contamination was approximately 33 000 m^2 (3.3 hectares, or just over 8 acres). The Cavan Street parcel, an area of undeveloped land about 13 hectares in size containing much of this contaminated material was purchased in 1988 by the LLRWMO on behalf of the federal government. The most heavily contaminated soils were located in three fenced areas. These areas were known locally as Rollins Ravine, Monkey Mountain, and Brewery Pond Dam. Larger areas with slight surface contamination carried by wind and water over the last 30 to 40 years, as well as extensions of this surface contamination into abutting residential back yards, were also addressed in the project.

Work Undertaken

Initially, dialogue with the site neighbours and local citizens (1) helped shape this project also. Formal environmental screening documents were prepared and reviewed (3,4). The regulatory agency review process involved the AECB, Environment Canada and Ontario Ministry of the Environment. This confirmed the technical merit of the design and provided an agency consensus on protocols for verification of performance.

The nature of the construction work undertaken was as follows. Trees were close cut in the Rollins Ravine depression, surveyed for contamination, and removed from the site when found clean. The contaminated base and side slopes of the upper part of the ravine were rough graded where necessary to facilitate equipment movement but largely left undisturbed. Tree stumps were left in place to stabilize the slopes. This area was now ready to receive additional contaminated soil from elsewhere on the project site. Stumps, and any contaminated debris from grubbing the areas to be excavated, were retained and placed below the additional contaminated soil.

Brewery Pond was partly dewatered, a coffer-dam installed, and the contaminated earthen dam structure was removed and replaced. Roughly 9600 m^3 of contaminated material was removed. Excavations reached depths of as much as 6 meters.

The Monkey Mountain site, a residue storage site in the 1940's which had already been partly rehabilitated, was excavated to depths as great as 7 meters. Approximately 14 000 m^3 of contaminated material was removed.

Large open surface areas of the LLRWMO property were scraped clear of surface contamination, usually to depths of 0.3 m or less after sod was stripped.

Neighboring back yards of twelve private residential properties were excavated to shallow depths and restored.

All contaminated material was added to the stockpile accumulating in the Rollins Ravine depression. The stockpile, named for its location as the Pine Street Extension Consolidation Site, was designed by engineering consultants for the LLRWMO, and licensed by the AECB, as a temporary storage facility for the consolidated contaminated soils. It was closed at the conclusion of the project.

Criteria and Performance

The cleanup criteria set for this project were 0.3 Bq/g ^{226}Ra, 35 $\mu g/g$ uranium and 40 $\mu g/g$ arsenic. The results achieved based upon 38 composite samples were 0.03-0.25 Bq/g ^{226}Ra, 1.1-8.7 $\mu g/g$ uranium and 0.8-21 $\mu g/g$ arsenic. Gamma radiation fields up to 5,000 $\mu R/hr$ on contact were reduced at surface to background levels, typically 4 to 6 with a maximum of 10 $\mu R/hr$. Reductions in environmental radon which was the major pathway for radiation exposures to the residents of adjacent properties, has been very satisfactory. Groundwater impacts indicate local improvement but the entire improvement has yet to be realized. Reduction in environmental impacts due to consolidation of the waste and environmental monitoring of the area is discussed in detail elsewhere (2).

Results

The Pine Street Extension Consolidation Site now contains approximately 31 000 m^3 of soil with a mean ^{226}Ra content of 2.9 Bq/g, a mean uranium content of 258 $\mu g/g$ and a mean arsenic content of 13.5 $\mu g/g$. The consolidated material overlies some untouched contaminated material also awaiting transfer to a new site for long-term management. A one meter thick multi-layer cap provides intrusion resistance and physical containment at the site. The site is fenced and signed to provide notice that contaminated materials are stored under a protective cover. Monitoring and maintenance of the site will be done by the LLRWMO until the wastes are removed. At that time approximately 35,000 to 37,000 cubic meters of material will require disposal from this site.

The material licensed by the AECB consists of 181.7 GBq of ^{226}Ra, 16 186 kg of uranium and 846 kg of arsenic.

Key Lessons

Key lessons also arose in this project. A more thorough review of lessons learned is categorized and presented later, but a few are highlighted here.

First and foremost, flexibility must be maintained by the proponent. It was confirmed that contracts, commitments and design aspects of the work must reflect this. The proponent must be ready to redirect the work depending on conditions encountered. To do so the proponent must have technically competent staff in-house and must be vigilant to the need to act. Next, experience showed that the unexpected must be expected even after as many variables as possible have been anticipated.

Specific devices which can be used to maintain flexibility and enhance preparedness include the following: work should be staged and review points should be pre-set; separate contracts should be established for construction, engineering and environmental contractors; an environmental auditor should participate throughout the work; multiple construction parties, possibly under separate contract, should work separate sites, especially if work progress lags; and, penalty provisions for environmental performance in all contracts should be considered.

The work at the Cavan Street site provided experience over a range of conditions. Severe fall and winter weather required a winter shutdown at an unplanned point in the schedule. Contamination quantity forecasts were overrun due to both lateral and vertical extension of areas excavated. Some second excavations were required when soil testing indicated criteria had not been achieved in localized zones on the first excavation. Deliberate over-excavation was required in circumstances where the physical arrangement of contamination demanded it. A desire to ensure that the cleanup fully reflected sound application of the "As Low As Reasonably Achievable" (ALARA) principle, added to the rigour in the field.

LESSONS LEARNED

The Strachan Street project and the Cavan Street project together provided lessons and new experience in successful remedial activities. Several elements common to all LLRWMO projects provide evidence of suitable approaches for future application. Observations on aspects of public acceptance, design and operations, project management and environmental benefit are presented below.

Common Elements

Certain common elements have evolved in LLRWMO projects to date. They provide a check list for future projects.

The community must shape and support the project. Therefore selection of a preferred strategic approach must be done in partnership with local stakeholders. Dialogue on options and later, focus on a review of environmental screening documentation have been the two steps used by the LLRWMO.

Technical review and approval of the engineering design and the verification protocol by regulatory and environmental agencies is sought as the design is developed. Later as the project unfolds, communication with participating agencies continues.

Thorough initial site investigations, including radiological surveys of the surface and subsurface conditions are undertaken and factored into conceptual engineering plans. However, supplementary investigations during the progress of the excavation work, as well as direct supervision at the work face, is now common practice in LLRWMO projects. Rigourous attention to materials excavated reduces volumes for future management and ensures site cleanup to criteria levels.

Strong emphasis on contamination control and health physics procedures enhances responsible conduct of the work. Clear delineation of the contaminated work zones, thorough briefing of workers, and policing of procedures is required. Where practical, site dedicated equipment and vehicles are preferred. Continuous environmental monitoring during the work and post project environmental tracking is the norm in LLRWMO projects.

Public Consultation

Public acceptance of projects is earned not assumed. Competent work and a local track record in the community appear to build credibility and acceptance. The assurance of an independent regulatory review also enhances acceptance. Free flowing information and staff accessible to local citizens are necessary. Providing suitable forums for dialogue is mandatory.

A number of LLRWMO activities contribute to public consultation in the Town of Port Hope and as performance is demonstrated there, serve as a model for other settings. The LLRWMO has operated a local information office in the Town for several years. This office also functions as a base for operating our Construction Monitoring Program and houses a field laboratory to support remedial work. Periodically issued newspaper supplements have been used to advise residents of progress of LLRWMO activities. Annual talks at local public schools and an annual high school science essay competition are supported by the LLRWMO. Tours of sites at various phases of remediation have been organized by the LLRWMO for interested groups. The key activity, though, is the conducting of project specific meetings, at the beginning of the planning phase and thereafter as required, with site neighbours, municipal groups and the general public. To date, formal resolutions of Town Council have been passed as the formal mechanism to authorize remedial work.

Design and Operations

The reality of remedial work circumstances can be described as follows. No one can control the weather. There is always more of everything involved than originally expected. Therefore flexibility and quick response must be included in remedial work plans.

Some of the watchwords of LLRWMO engineering approaches are: "small sequential stages", "controlled access zones", "no contamination tracking", "excavation control at the excavation face", "progressive restoration", "employ soil verification sampling", and "monitor environmental conditions".

The aim of LLRWMO project specifications and designs is to effect a successful remedial action and at the same time anticipate the potential for undesired environmental consequences. Rain falls, dust blows and things break down. However, with mitigating strategies prepared and with equipment and supplies on standby, the site team can intervene.

Project Management

The LLRWMO has had success with contracting most project elements out to experienced remediation contractors but retaining some technical elements for its own core staff. Engineering design, health physics protocols, soil sampling

and analysis, and contamination delineation are all areas of close technical involvement of LLRWMO staff.

Separating contractors for remedial engineering, versus environmental screening and audit has been found useful. The value of having an engineering contractor in place to supervise construction has been demonstrated repeatedly. This is especially true if a seasoned field superintendent is available.

Effective cost control of projects requires close attention. Great uncertainties at the outset can be provided for by regular communication and short interval cost reporting. Weekly or bi-weekly site meetings and daily cost recording (reported bi-weekly) have been found effective.

New contract penalty clauses involving loss of bonuses and/or financial penalties for contractor-caused incidents of environmental non-compliance are being explored. In addition, bonus provisions could be considered for work saving and schedule shortening.

Environmental Monitoring/Assessment

Waste consolidation and temporary in-situ storage has been shown to have substantial and immediate environmental effect at Port Hope sites. Reduction in environmental radon has been the most significant effect in terms of reducing off-site exposure. On-site, surface gamma radiation has been reduced to background levels at project sites. Initial post-project groundwater monitoring has also shown improvement. Contaminated soils are now isolated and secured (2).

The importance of environmental screening followed by an environmental performance audit is apparent in this work. Prescribed action levels and a continuous program for environmental monitoring are required to meet environmental screening commitments and support an effective audit.

SUMMARY AND CONCLUSIONS

This paper has reviewed two recent waste consolidation and in-situ storage projects undertaken by the LLRWMO. Benefits of undertaking the consolidation work have been discussed. Benefits of in-situ storage indirectly include all of these because in the absence of an off-site option, consolidation can only proceed with in-situ storage.

On its own merits, in-situ storage is attractive because it is a cost-effective option on some sites, it need not be as rigorously designed as would a permanent facility, and it provides a quick payback in environmental improvement.

The combined benefits of consolidation and in-situ storage at LLRWMO remedial sites completed to date include the following.

Major reduction In environmental impacts have been found. These include reduction of ambient radon concentrations to background, or near background, values around sites. Surface water contamination is eliminated. Gamma radiation levels are reduced to background, or near background, values.

Contaminated wastes are isolated by secure engineered covers. Therefore the potential hazard from intrusion into the wastes by people is eliminated. Further spread of contamination by surface water erosion is eliminated. Further spread of contamination by groundwater is substantially reduced.

Constraints on productive use are removed from a portion of the contaminated land. Negative public perceptions due to the presence of the contaminated sites are reduced.

Benefits accrue to be realized in future. Contaminated waste is stockpiled ready for future removal. Future management resources will be able to focus on the major project, that of establishing a new waste management facility and relocating all of the Port Hope area wastes to this facility, rather than on scattered excavations and restoration activities. A better understanding of the volume and characteristics of waste for future management is realized.

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SURFACE WATER MANAGEMENT AT A MIXED WASTE REMEDIATION SITE

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ABSTRACT

The Weldon Spring Remedial Action Project (WSSRAP) deals with chemical and radiological contaminants. MK-Ferguson Company is managing the project under contract with the U.S. Department of Energy. Remedial activities include demolishing buildings, constructing material storage and staging areas, excavating and consolidating waste materials, and treating and disposing of the materials in a land disposal facility. Due to the excavation and construction required during remediation, a well-planned surface water management system is essential.

Planning involves characterization of source areas and surface water transport mechanisms and identification of applicable regulations. System components include: erosion control, sediment control, flow attenuation, and management of contaminated water. Combinations of these components may be utilized during actual construction and remediation to obtain optimum control. Monitoring is performed during implementation in order to assess the effectiveness of control measures.

This management scheme provides for comprehensive management of surface water at this site by providing control and/or treatment to appropriate standards. Although some treatment methodologies for contaminated water are specific to site contaminants, this comprehensive program provides a management approach which is applicable to many remedial projects in order to minimize contaminant release and meet Clean Water Act requirements.

INTRODUCTION

Site History

The Weldon Spring Site Remedial Action Project (WSSRAP) is a federal facility being remediated by the United States Department of Energy (DOE). It is located in St. Charles County, Missouri, approximately 48 km (30 miles) west of St. Louis. The site is comprised of the Weldon Spring Chemical Plant/Raffinate Pits (WSCP/RP) and the Weldon Spring Quarry (WSQ).

In the early 1940s the Department of the Army (DA) constructed a 6,900 hectare (17,000 acre) facility, the Weldon Spring Ordnance Works (WSOW), to produce explosives for World War II. In the mid 1950s the Atomic Energy Commission obtained about 80 hectares (200 acres) of land from the DA, decontaminated the area to some extent, demolished the WSOW structures, and constructed the Weldon Spring Uranium Feed Materials Plant (WSUFMP) to process uranium ore to uranium metal. This facility operated until the mid 1960s. Following shutdown of the WSUFMP, the DA regained custody of the land and facilities with the intent of producing herbicides during the Vietnam War. Again, some decontamination of the area was performed, but this effort was abandoned before the facilities became operational. Throughout these periods of operation and shutdown, various waste materials were disposed of in the WSQ.

Environmental monitoring was performed on part of the site from the late 1970s to 1985 by National Lead Company of Ohio and Bechtel National Inc. In 1985 the entire site was placed under the custody of the DOE. In conjunction with this transfer, the Weldon Spring Remedial Action Project (WSSRAP) was created as DOE Major Project Number 182. The project is currently operated by the Project Management Contractor (PMC), MK-Ferguson Co.

Current Status

Since 1986, the PMC has conducted environmental monitoring of the site in order to characterize contamination and determine remedial strategies. Several Interim Response Actions (IRAs) have been conducted in order to protect the public and the environment. Documentation of remedial activities has progressed through a Record of Decision (ROD) related to excavation and removal of bulk wastes from the WSQ. A Site (WSCP/RP) Remedial Investigation/Feasibility Study is currently nearing completion.

Proper management of surface water is required throughout these remedial activities. This management system includes planning, development of system components, and implementation. Simple control measures may be implemented before, during, and after remediation, with beneficial results. This paper focuses on surface water management at the WSCP/RP. Similar control measures are employed at the WSQ, although the quarry pit itself serves as a control for contaminant migration through surface water.

Surface drainage patterns at the WSCP/RP are indicated in Fig. 1. Major drainage paths come from three watersheds and from building drainage through process sewer piping.

Planning

Surface water management must first be planned and then implemented. Two key steps during the planning process are to review applicable regulations and to characterize contaminant sources and surface water transport mechanisms.

Regulations and Orders

Reference standards for design and monitoring of surface water features are found in the site National Pollutant Discharge Elimination System (NPDES) permits, DOE Orders, and other applicable and/or relevant and appropriate requirements (ARARs). Table I summarizes regulations and Orders that are applicable to the site.

Characterization

Characterization is also required during the planning stages of surface water management. Planning includes

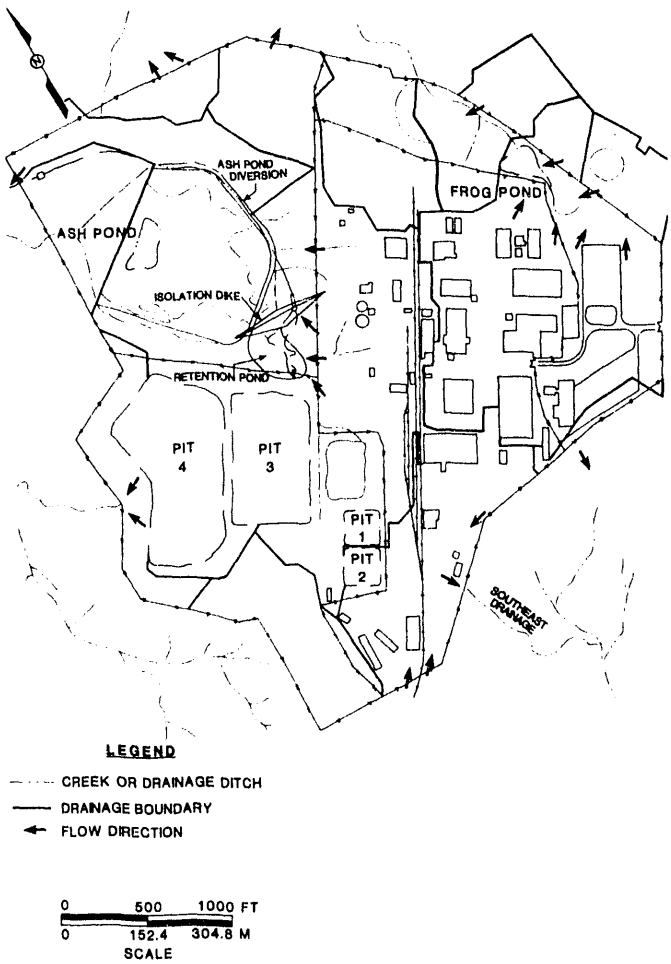


Fig. 1. Existing drainage patterns.

TABLE I

Summary of Surface Water Requirements

Source Regulation	Summary of Requirement
DOE 5400.5	550 pCi/l, Total U DCG
DOE 5400.1 & 5400.xy	Requires Environmental Monitoring Program
DOE General Design Criteria	Specifies Design Storm Criteria for Various Facilities
Regional Codes and Standards	Provides Design Criteria for Surface Water Control Components
NPDES Permits	Specifies Effluent Limitations for Physical/Chemical Contaminants, Monitoring Requirements, Design Storm Criteria
Resource Conservation and Recovery Act (RCRA)	Specifies Design Storm Criteria for Certain Impoundments

identification of contaminant source areas followed by characterization of surface water flow and contaminant transport. NPDES stormwater permitting requirements are considered during initial characterization in order to provide background data for subsequent permit compliance monitoring. Time-series sampling (both discreet and composite samples) coupled with flow monitoring provide insight into contaminant transport, which dictates subsequent application of control measures. Additional monitoring of flow and contamination is required following implementation of control measures in order to assess their effectiveness.

System Components

Surface water control may be broken into four components: erosion control, sediment control, flow attenuation, and contaminated water management. These components are described below.

Erosion Control

Several methods of erosion control are utilized by the WSSRAP. These include minimizing soil disturbance in construction areas, diversion of water away from exposed soil areas, temporary cover of disturbed areas, and final seeding and mulching or sodding.

Soil disturbance is minimized during construction by restricting subcontractor activities to their respective construction areas and protecting adjacent areas of existing cover. Subcontractors are also required to place water diversions and other erosion control components prior to excavating large areas. These measures minimize creation of erodible areas.

Temporary cover is utilized when areas are left idle for relatively long periods of time before earthwork or seeding and sodding is completed. Flat or gently sloping areas are covered with mulch (straw, hay, or wood chips), and steeper slopes are covered with anchored mulch or erosion control netting or blankets.

Either seeding and mulching or sodding is applied to exposed soils that could be eroded by either wind or water. Application is completed as soon as possible following completion of construction or remediation activities. Fertilizer is applied immediately prior to seeding or sodding. Application rates are determined by soil testing or by using general guidelines developed for the area. When an area is seeded, a variety of plant species are used in the seed mixture in order to provide a quick cover (annuals) in addition to long term vegetation (perennial grasses). Seed mixtures are varied depending on the time in the growing season during construction or remediation. If stable cover is needed immediately, sod is used.

Sediment Control

Control of sedimentation is achieved by utilizing natural cover and placing sediment barriers and check dams near disturbed areas and construction or sediment detention basins near the site perimeter.

The topography of the Weldon Spring site generally consists of gentle slopes vegetated with timber or grasses. When possible, naturally occurring vegetation is preserved in construction areas, providing an excellent sediment filtering mechanism.

zones of natural vegetation on the downstream slope sides of sediment barriers provide additional protection. These linear barriers are positioned perpendicular to the direction of water flow. Barriers are inspected after storms, and damaged sections are repaired or replaced. Accumulated sediment is removed periodically to maintain effectiveness.

Check dams are placed within channels in order to trap settleable particles. Commonly used dam materials include straw bales in dikes and berms composed of granular materials. Granular material berms are designed to minimize particle transport while providing permeability through the berm.

Excavated sediment traps serve a function similar to check dams by providing control of settleable particles. Typical applications of these structures are within channels at the toes of slopes or at the outlets to diversion channels. These structures may require inlet and outlet protection to inhibit erosion. Protection may be provided by vegetation, erosion control netting, or riprap.

Sediment detention basins are the final line of defense in sediment control and also provide for flow equalization. These basins are self-dewatered through perforated standpipes. Emergency spillways are provided in case of extremely heavy storms. Sediment storage capacity is designed by calculating potential soil loss using the uniform soil loss equation and providing storage for a three year removal schedule. Hydraulics and sedimentation are optimized in design through use of computer models. Figure 2 is a cross section of a typical sediment detention basin as defined above.

Flow Equalization Hydraulics

Hydraulics of surface flow are analyzed by reviewing flow data, watershed cover, and precipitation. By analyzing inflow and outflow hydrographs of sediment detention basins, flow attenuation may be determined in addition to retention times which provide for sedimentation. Diversion channel slope and geometry may be designed to provide channel storage and thus provide some measure of flow attenuation.

Contaminated Water Management

Contaminated water is minimized by controlling contact between contaminated materials and surface water. This is achieved by covering contaminated materials or providing surface water diversions around contaminated areas. Surface water may be impounded adjacent to contaminated material storage areas and within contaminated material excavations. Impounded water is sampled and tested to determine if it meets release criteria, and is subsequently either released or transferred for treatment prior to release. Water treatment is provided at both the chemical plant and the quarry by state-of-the-art treatment systems which employ sequential treatment units for all target contaminants. Figure 3 is a schematic of the primary treatment system, including major components and sequence.

Implementation

Control components for specific construction or remedial activities are selected during design. Components which provide surface water control for several activities are constructed in advance of projects within each watershed.

The effectiveness of control measures is monitored by periodic assessment of control features by visual inspection, flow monitoring, and monitoring of contaminant concentrations.

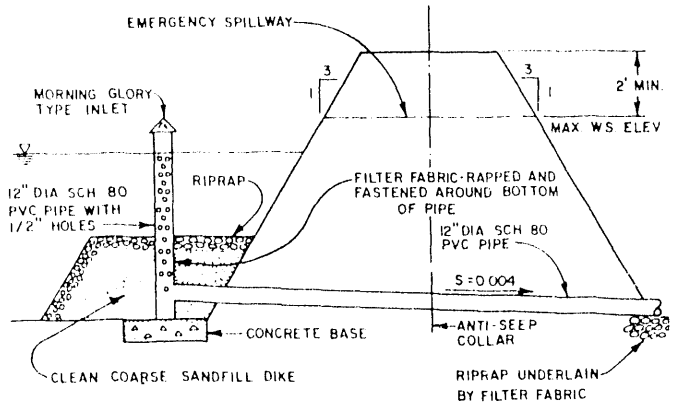


Fig. 2. Sediment detention basin.

Subcontractors are required to perform necessary maintenance, including watering, reseeding, sediment removal, and repair of barriers in order to ensure development of stable vegetative cover and proper function of barriers.

Lessons Learned

A specific example of the effectiveness of surface water management at the WSSRAP is the Ash Pond diversion channel (Fig. 1). Prior to construction of the diversion channel, drainage patterns in this area passed through an area of radioactive contamination (impounded ash and partially exposed drums and other debris). Construction of a retention basin and diversion channel around this contaminated area resulted in a significant reduction in release of radioactive contaminants in surface water while also providing flow attenuation. Prior to construction of the diversion channel, uranium levels averaged over 1,000 pCi/l. After construction, the average uranium concentration dropped to 140 pCi/l.

Communication among all project departments is required to ensure proper planning, design, construction, and monitoring of surface water control mechanisms. All personnel involved must be familiar with the purpose and function of all control mechanisms in order to produce a functional product.

Local codes and standards are often available for many of the control measures mentioned in this paper. By utilizing these components in an overall surface water management plan, redesign is minimized. This also enables local subcontractors to bid and construct familiar facilities efficiently.

CONCLUSION

Given the technical difficulties of waste treatment and groundwater remediation, surface water is often a less visible but no less important segment of remedial work. However, many control measures are readily available from municipal engineering and related fields to provide for management of surface water. A simple and efficient surface water management strategy may be developed by thorough planning and use of existing technology. This surface water management scheme optimizes the use of existing technology in applications to a specific remedial action project. Contaminated water treatment may vary widely, depending on target contaminants; however, this overall strategy is applicable to the majority of remedial action projects.

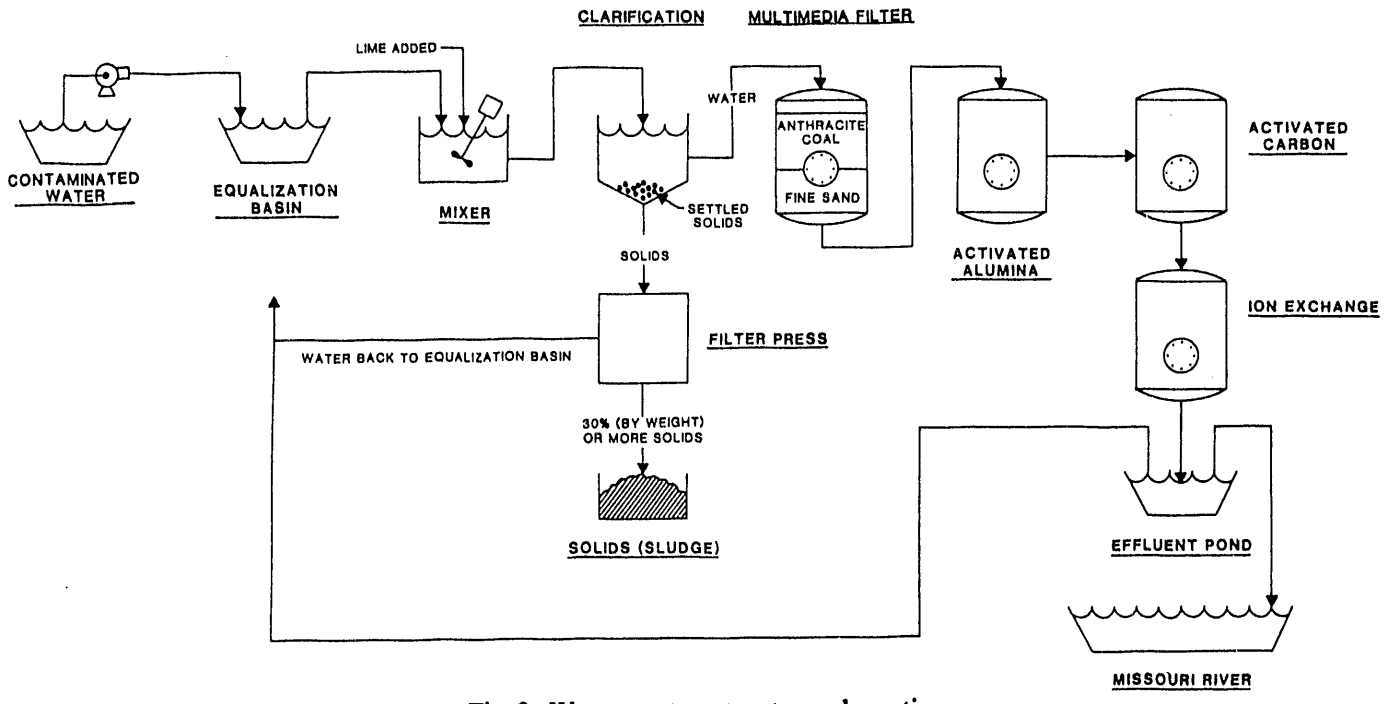


Fig. 3. Water treatment system schematic.

AIR STRIPPING OF VOLATILE ORGANIC CHLOROCARBONS: SYSTEM DEVELOPMENT, PERFORMANCE, AND LESSONS LEARNED (U)*

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ABSTRACT

The Savannah River Site, which has been in operation since the 1950's, is a 780-square kilometer reservation that produces tritium for the national defense program. As a result of past waste handling practices, the ground water at several locations on the Site has become contaminated with solvents, metals, and radionuclides. In 1981, the ground water located under the Site's fuel and target rod fabrication area (M-Area) was found to be contaminated with degreasing solvents, specifically trichloroethylene (TCE) and tetrachloroethylene (PCE). In 1983, a program was started to evaluate air stripping and determine its applicability to cleanup of M-Area contamination. Lessons learned regarding the efficiency and effectiveness of air stripping technology are presented.

INTRODUCTION

The Savannah River Site is a Department of Energy weapons complex facility that has been in operation since 1953. The Site mission is to produce tritium, a component of nuclear weapons, for use in the national defense program. From 1958 to 1985, effluent waste from the reactor fuel and target rod fabrication area (M-Area) was discharged to a settling basin. Organic contamination, primarily trichloroethylene (TCE) with smaller amounts of tetrachloroethylene (PCE), was found in the ground water surrounding the basin in 1981. In 1985, release to the basin was discontinued when the M-Area Liquid Effluent Treatment Facility was brought online. At the same time, full-scale cleanup of the organic contamination was implemented through the application of air stripping technology. Two experimental units preceded a full-scale system, which has now been in operation for six years. This paper briefly describes the M-Area remediation program with respect to system development, performance, and cost.

PACKED-TOWER DESIGN

Air stripping is one of the most common methods used to remediate ground water contaminated with volatile organic compounds (VOCs). A schematic of a simple process is shown in Fig. 1. Contaminated water is pumped to the top of a packed-tower and distributed evenly across the packing material. As the water flows downward, air is blown upward through the tower, contacting the water and volatilizing the contaminates. The VOC-laden air is discharged from the stack, while the clean water is pumped from the bottom of the tower. The system removal efficiency is dependent on Henry's Law constant of the contaminant, the inlet concentration, relative liquid-air flow rates, and the liquid-air contact area. A brief description of air stripping theory and the governing equations will show the impact of each physical parameter on the system efficiency.

Henry's Law constant

Air stripping technology is based on the relative volatility of a compound, i.e the ability of the compound to vaporize or evaporate. The measure of volatility is characterized by Henry's Law constant, H_a. Henry's Law states that the partial pressure of component 'a', at constant temperature and pressure, is linear for a dilute solution ($x_a \sim 0$). The slope of the line is equal to Henry's Law constant (1). In mathematical terms,

$$H_a = \frac{x_a}{P_a} \qquad \text{(Eq. 1)}$$

H_a = Henry's Law constant of component a, dimensionless

x_a = mole ratio of component a in solution

p_a = partial pressure of component a in equilibrium above solution, mole ratio

The above relationship can be derived through laboratory analysis of ground water samples, or estimated through the use of tabulated empirical data as follows:

$$\ln K_a = A - \frac{B}{T} \qquad \text{(Eq. 2)}$$

K_a = H_a = Henry's Law constant for component 'a' at the specified temperature

A, B = empirically determined constants

T = process temperature, K

As shown by Eq. 2, Henry's Law constant is inversely related to temperature. An important consideration in packed-tower design is whether or not the system will operate isothermally. If a temperature change exists across a packed-bed, Henry's *constant* is not constant. In this case, the equations for mass transfer must be evaluated on a stage by stage basis, assuming isothermal operation at each stage.

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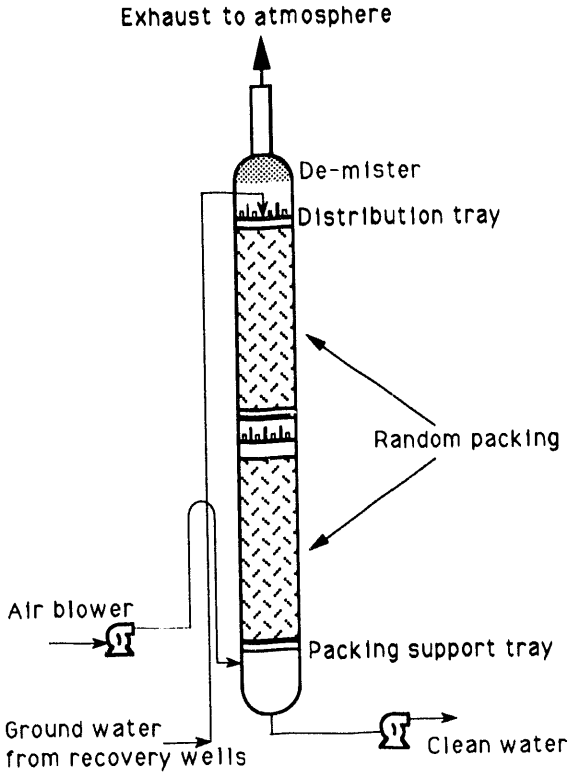


Fig. 1. Air stripper operation.

Mass Transfer

Effective mass transfer between a gas phase and a liquid phase is commonly expressed as the height of packing required to achieve gas-liquid equilibrium, or the height of a transfer unit (HTU). For experimental purposes, a packed-tower can be operated at measured inlet and exit liquid VOC concentrations, and controlled liquid and gas flow rates. The number of transfer units (NTU) necessary to achieve a desired removal can then be calculated using a form of the Kremser equation: (2)

$$NTU = \frac{\ln\left(\left[\frac{x_i}{x_o}\right]\times\left[1-\frac{1}{S}\right]+\frac{1}{S}\right)}{\left(1-\frac{1}{S}\right)} \qquad \text{(Eq. 3)}$$

NTU = number of transfer units necessary to achieve measured separation

x_i = mole ratio of organic compound in inlet liquid stream

x_o = mole ratio of organic compound in exit liquid stream

S = stripping factor = H_a * G/L

G = molar flow rate of gas stream, moles/unit time

L = molar flow rate of liquid stream, moles/unit time

It should be noted that a transfer unit, although quantitatively determined by experiment, is not physically distinguishable, since no plates are present in a packed-tower. However, once the number of transfer units is known for a set of experimental conditions, the height of a transfer unit can be calculated according to Eq. 4.

$$HTU = \frac{Z}{NTU} \qquad \text{(Eq. 4)}$$

HTU = height of a transfer unit, m

Z = packed-tower height, m

When the HTUs for given liquid loadings are plotted versus the air flow rate, the resulting curves can be used for designing a full-scale unit. These curves show the importance of the choice of packing material, since a more effective packing will require less height to achieve the desired separation, and thus lower the capital equipment cost for the unit.

PROGRAM DESCRIPTION

Air stripping viability is based on the volatility of a given compound, and in the case of TCE and PCE, the relative volatilities of both are extremely high. Based on this information, air stripping was chosen as the technology to be implemented in M-Area. The initial program involved field testing of both pilot and prototype air stripping columns. The successful experimental programs resulted in the design and operation of a production (full-scale) air stripper in 1985. A description of each unit is given in Table I.

TABLE I

Air Stripper Comparison

Column	Pilot	Prototype	Production
DIAM (cm)	35.5	50.8	137.2
HT (m)	10.4	14.0	21.3
MATERIAL	PVC	304ss	304ss
CAP (l/m)	75	190	2300
PACKING			
2 BEDS (m)	2.75	4.27	5.18
MATERIAL	poly	poly	poly
RING TYPE	pall	pall	pall/cmr

Pilot Air Stripper

The M-Area remediation program began in September 1983 with the construction and operation of a pilot air stripper. The tower was constructed of PVC and stood over 10 meters tall with a diameter of 35.5 cm. The system was operated for 24 months, and more than 7300 kg of VOCs were removed from the ground water. The pilot air stripper was used to develop the correlation between the HTUs and the air flow rates at a given column liquid loading. A full-scale tower can be designed by using this relationship in connection with Eqs. 3 and 4. Because removal efficiencies of greater than 99% were observed during operation of the pilot unit, air stripping technology was further investigated.

Prototype Air Stripper

The second experimental unit to be tested in M-Area was a prototype air stripper. The system was constructed of stainless steel and could treat 190 l/min. Operation of the unit spanned 14 months in an effort to verify the mass transfer rates obtained by the pilot unit and to further characterize air/water flow rate effects. At the end of the testing period, over 7200 kg of VOCs had been removed by the air stripper. Although

originally leased as a temporary facility, the prototype unit has been purchased and moved to another location on Site for continuous, full-scale operation. The system will complement and enhance the effectiveness of the production air stripper described below.

Production Air Stripper

Layout for the M-Area production air stripper is shown in Fig. 2. The system consists of the control building, the air blower, tails pump, control and monitoring equipment, and eleven recovery wells. The stainless steel tower is over 20 m tall and 1.37 m in diameter, and can treat 2300 l/min of ground water (based on an influent VOC concentration of 50 mg/l). The recovery well influent lines consist of more than 3500 m of carbon steel piping; the effluent line is more than 760 m in length. A typical recovery well consists of a 15-cm stainless steel casing, with a screen zone from approximately 50 to 60

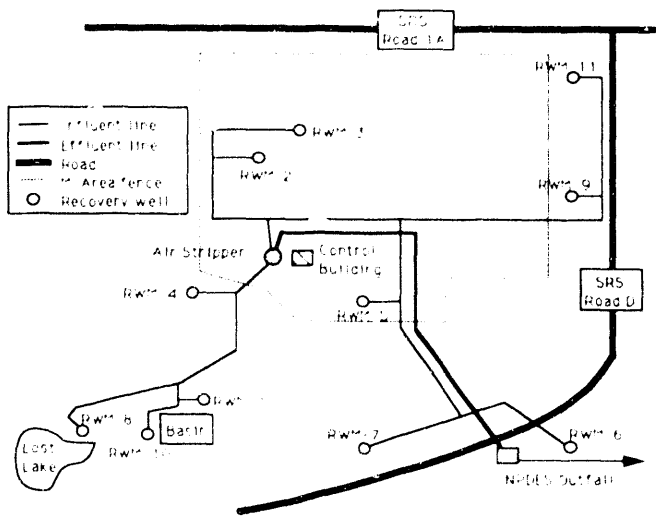


Fig. 2. Recovery system layout.

m. The ground water flows delivered from each well range from 95 to 225 l/min. Current flow to the system is 1900 l/min, the maximum flow obtainable from the recovery wells.

Permitting

The production air stripper is part of the M-Area Hazardous Waste Management Facility, permitted under the Resource Conservation and Recovery Act (RCRA). The unit is permitted as a waste water treatment facility, requiring a South Carolina certified Class-B (or higher) operator. The system is not regulated as a RCRA Treatment-Storage-Disposal (TSD) facility, based on the waste water treatment facility classification.

The system also has a South Carolina Bureau of Air Quality Control permit for air emissions. The permit allows a total of 31000 kg/yr (34 ton/yr) of VOCs to be discharged to the atmosphere; current emissions are approximately 12000 kg/yr. When the system was originally permitted (1985), South Carolina regulations considered greater than or equal to 36000 kg/yr (40 ton/yr) to be a major emission source, so this facility was not regulated as such. This meant no control device was required for the flue gas. However, recent amendments to the Clean Air Act require that the system be retrofitted with an off-gas treatment system by 1995.

Effluent water from the production air stripper is released to a National Pollutant Discharge Elimination System (NPDES) outfall. The outfall consists of a weir box to monitor and sample discharged flow, and a concrete ditch to deliver the water to a stream without erosion. Discharge limits for the outfall are less than 5 μg/L for both TCE and PCE, as per current Maximum Contaminant Levels (MCLs).

Sampling and Analysis Requirements

Ground water sampling at various locations in the system is required by the RCRA Part B permit. The sampling scheme is shown in Table II. No permit violations or elevated concentrations have ever been detected in the effluent stream.

TABLE II

Sampling Schedule

Component	Constituent	Frequency
Wells	TCE/PCE	Monthly
Inlet/Exit	TCE/PCE	Weekly
	PP	Quarterly
Outfall	TCP/PCE	Weekly
	pH	Bi-weekly
	Flow	Weekly

PERFORMANCE

The production air stripper went into continuous operation in September 1985. An overall performance summary is given in Table III. Since the beginning of the cleanup program over 4.92 billion liters of ground water have been treated, removing approximately 114000 kg of degreasing solvents. The stripping efficiency has always been greater than 99%, with no detectable VOC concentration in the effluent. The decrease in contaminant concentration is shown as a function of time in Fig. 3. The VOC concentration dropped dramatically during the first ten months of operation and then leveled out to a slow decrease with time. The dotted line shows the expected concentration trend for the next thirty years. The curve eventually reaches a plateau without removing all contamination from the ground water. The explanation for this behavior is given below.

TABLE III

Air Stripper Performance

UTILITY (%)	95.3
THROUGHPUT (MI)	4920
INLET CONC (mg/l)	
March 1985	47.1
June 1991	11.0
EFFLUENT CONC (mg/l)	< 1.000
TOTAL VOCs REMOVED (Mg)	114

Removal Efficiency

The amount of VOCs present in the ground water beneath M-Area are approximately 225,000 kg (3). Based on this assumption, Fig. 3 also shows the removal efficiency of the system with time. As of June 1991, over half of the original

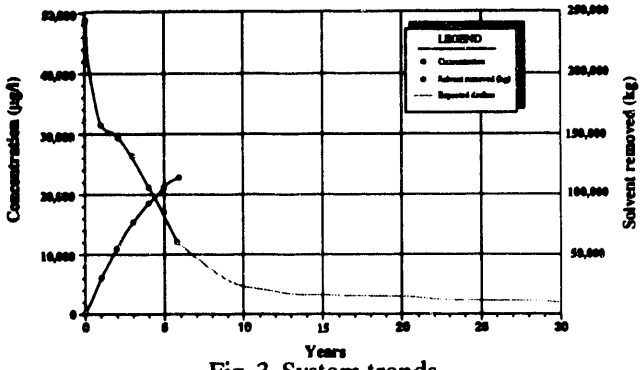


Fig. 3. System trends.

estimated inventory had been removed from the ground water. This number must be put in perspective, however, since contamination in the vadose (unsaturated) zone continually leaches through the soil, recharging the amount of VOCs present in the aquifer. This is why the expected decline curve in Fig. 4 eventually reaches an equilibrium, or plateau. Until contamination in the vadose zone is removed, residual saturation will continue to leach into the ground water. A program is currently underway at the Site to remove vadose zone contamination, and long-term system effectiveness will be strongly dependent on the combined remediation of the saturated and unsaturated zones.

PROJECT COST

The production air stripper was designed and constructed in 1984-1985. The major project elements and associated costs for the system are given in Table IV. The contract costs include permitting and modeling tasks. The control building cost is a combination of the foundation, structural, and heating and ventilating systems. Electrical costs include both equipment and wiring charges for the entire system. The tower installation cost represents the concrete pad, platforms, anchors, and ancillary equipment. The control system includes all equipment and piping associated with the pneumatic control system. The total reflected in the table does not include reserve account, accrual, or depreciation monies. Including these non-field-related elements, the final project cost is in excess of 4.7 million dollars.

TABLE IV

Project Cost Summary

PROJECT ELEMENT	COST (K$)
DESIGN	420
CONTRACTS	368
SITE DEVELOPMENT	28
QA ENGINEERING	18
CONTROL BUILDING	211
ELECTRICAL	877
INSTRUMENTATION	466
PIPING/CONSTRUCTION	925
TOWER INSTALLATION	132
CONTROL SYSTEM	230
ERECT/TEST TOWER	428
TOTAL PROJECT COST	4,103

OPERATING COST

The annual operating cost of the production air stripper was evaluated in 1990, after five years of operation. The cost was broken down into three categories: electrical power usage, maintenance requirements, and operation. Material and labor costs were based upon the actual time and material charges incurred during the first five years. The average operating cost was determined to be $150,000/yr.

Electrical Power Usage

Electrical power for the entire system is fed through a 480-volt, 400 amp, 3-phase power line. Based on the Site electrical cost rate, currently estimated at $ 0.052 per kWh, the yearly cost would be $55,000 if the system used the maximum current. However, direct measurements of the inlet power line indicate 170 amp of current flow during normal operation. Assuming the stripper operates 95% of the time, electrical power costs are $26,000 per year for the system.

Maintenance

Maintenance requirements, which include material and labor, were obtained by averaging the yearly cost since startup of the unit. Equipment repair and replacement average $13,000 per year, with low and high values of $55 and $22,700, respectively. The first case was a result of the minimal maintenance required during the first year of operation; the latter was caused by the stainless steel tower being hit by lightning. Assuming an operating utility of 95%, the average labor requirement for maintenance on the system is 35 hours per month, or $13,500 per year. This is based on an Operator cost, including overhead and benefits, of $32 per hour. Thus, the total maintenance cost for the system is $26,500 per year.

Operation

Manpower requirements for the system include daily inspections and operation, well sampling and lab analysis, and engineering technical support. Operation and inspection tasks require 4 hours per day, or $45,700 per year. Well sampling and lab analysis are estimated to cost $15,000 per year, while engineering support requires 15 hours per week, or $36,000 annually. This is based on an average Engineer cost, again including overhead and benefits, of $48.00 per hour. The total operation manpower costs are $96,700 per year.

SYSTEM OPTIMIZATION

Packing Replacement

The original packing chosen during design of the system was a 2.54-cm (1-in) Pall ring. In 1988, the Pall ring packing was replaced with a 5.08-cm (2-in) Cascade mini-ring packing. The Cascade mini-ring (CMR) provides more surface area for mass transfer, while reducing the pressure drop through the system. A measure of the relative efficiency of a packing is its aspect ratio, defined as the length of a packing component divided by the diameter (L/D). The Pall ring has an aspect ratio of 1, while that of the CMR is 0.3. A reduced aspect ratio improves stripper performance by exposing more internal surface area for formation of thin films, thus increasing the efficiency of mass transfer between the liquid and gas phases.

The flow capacity of the CMR packing is greater than that of the Pall rings due to a smaller pressure drop per transfer

unit. In any packing, entrainment is strongly influenced by liquid pooling and the length of liquid film surface over which waves can form. Because of the design of the CMR packing, is less liable to pool and channel than other random packing. The lower aspect ratio means that liquid film wave formation is reduced, wave height is kept low, and as a result, entrainment is low.

Pressure drop across a packed height may be calculated using the Sherwood-Eckert correlation (4). The correlation relates a packing factor to gas and liquid flow rates for pressure drops of varying magnitudes per foot of packed height. Results of calculations using the Sherwood-Eckert correlation show that the Pall rings cause a pressure drop of 43-cm of water through the tower, while the CMRs cause a pressure drop of only 13-cm of water. These pressure drops are based on air and water flow rates of 85 m^3/min and 2300 l/min, respectively. Including the pressure drops caused by the distribution trays and the de-mister, the Pall rings would cause the system to approach flooding at the described flow rates. However, the pressure drop during operation with the CMRs is still well beneath the flooding line.

Reduced pooling and pressure drop also lead to less foaming as well as a lower probability of solids being retained within the packing. This is important if the ground water being treated has been injected with a solubility-enhancing agent such as a surfactant, many of which tend to foam. Current experience with the production air stripper indicates that the packing must be removed and cleaned once every 6 months due to the buildup of scale and hard water deposits.

Future Plans

Future plans for the system include re-evaluation of the recovery well network to ensure that the system continues to provide optimum removal rates. Some wells that have recently experienced concentration drops to less than 100 μg/l may be temporarily taken off-line and new wells added to the system. The affected wells will continue to be monitored and pumped as appropriate.

Future plans for the production air stripper also include its use as a treatment facility for the Site monitoring-well purge water. Design is underway to modify the inlet transfer lines to accommodate flow from a 100,000-l carbon steel tank that will receive the purge water. The carbon steel tank was obtained from another location on Site where its use was no longer necessary. Substantial cost savings have been achieved by utilizing the existing facilities in lieu of constructing a new system.

CONCLUSIONS

For compounds that are sufficiently volatile, air stripping is a proven technique that will clean ground water to below regulated standards. It is a relatively simple, economical process that is easy to implement, with a low operating cost and maintenance requirement. The air stripping program in M-Area is providing knowledge and experience for a remediation alternative that will have many applications at SRS. A full understanding of operational requirements is imperative if the cleanup goals are to be met. A knowledge of system characteristics is also necessary to evaluate costs and manpower needs for future air stripping systems. As data continues to be collected during the operation of the system, the answers to these questions will become more clearly defined.

ACKNOWLEDGEMENT

The information contained in this article was developed during the course of work done under Contract No. DE-AC09-89SR18035 with the U.S. Department of Energy.

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REMOVAL ACTION UNDER CERCLA SECTION 104 FOR PCB-CONTAMINATED SOIL AT DOE MOUND PLANT

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ABSTRACT

A removal action was completed for polychlorinated biphenyl (PCB)-contaminated soil at the U.S. Department of Energy (DOE) Mound Plant in Dayton, Ohio. Mound Plant is a National Priority List (NPL) site and removal was completed by authority of Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) Section 104. The Toxic Substances Control Act (TSCA) was considered to be a relevant and appropriate requirement and, accordingly, its sampling and analysis guidelines and disposal standards were used in the removal action. Significant aspects of the removal are listed below.

- It is one of the first removal actions conducted by the DOE explicitly using authority under Section 104 of CERCLA.
- It encompasses cleanup at an NPL site for a substance regulated under TSCA.
- No remedial investigation/feasibility study was done prior to removal, so characterization of the extent of PCB contamination was done as part of the removal.
- On-site screening was used to identify PCB contamination.
- Project time from conception to completion was 7 months including the writing of a work plan, the sampling and analysis, the excavation and disposal, and the writing of an on-scene coordinator (OSC) report.

INTRODUCTION

The Mound Plant near Dayton, Ohio (Fig. 1), is operated by EG&G for the U.S. Department of Energy (DOE). It was placed on the CERCLA NPL in November 1989. A Federal Facility Agreement between the DOE and the U.S. Environmental Protection Agency (EPA) Region V became effective in October 1990. The DOE Environmental Restoration Program is conducting remedial investigations and feasibility studies (RI/FS), removal actions, and remedial actions at approximately 110 potential release sites to fulfill the terms of the agreement.

On April 27, 1990, an oil leak was discovered at a spare transformer than had never been energized and was stored on a curbed concrete pad on the west side of the Powerhouse at Mound Plant (Building P). Because a portion of the transformer extended beyond the concrete pad and curbing, approximately 2.5 quarts of oil were released to concrete- and gravel-covered areas beyond the containment structure. Initial samples taken of the oil in the transformer contained 275,000 parts per million (ppm) of PCBs (Aroclor 1260, a registered trademark of Monsanto). Wipe samples taken atlocations within the affected area and samples of the spilled oil also contained PCBs (maximum of 415 μg/wipe and 64,500 ppm, respectively).

The chronology of the events related to this and subsequent TSCA and CERCLA responses is presented in Table I. Cleanup was initiated as required by the TSCA (40 CFR 761), using an on-call environmental response contractor. Initial response included several stages of sampling to define the extent of the area affected by the leak, removal of the transformer from the site, and removal of contaminated concrete and contaminated soil to a depth of approximately 6 ft. The sampling and concrete and soil removal were accomplished in several stages, continuing through November 1990.

In the latter stages of the TSCA response, soil concentrations were nearing the target cleanup level (40 CFR 761) of 10 ppm of PCBs. However, during soil excavation on October 31, 1990, a pocket of oil and water was encountered below a concrete footer at approximately 5 to 6 ft below the soil surface, as shown in Fig. 2. Samples of this liquid taken on November 1, 1990, contained 230,000 ppm of PCBs (Aroclor

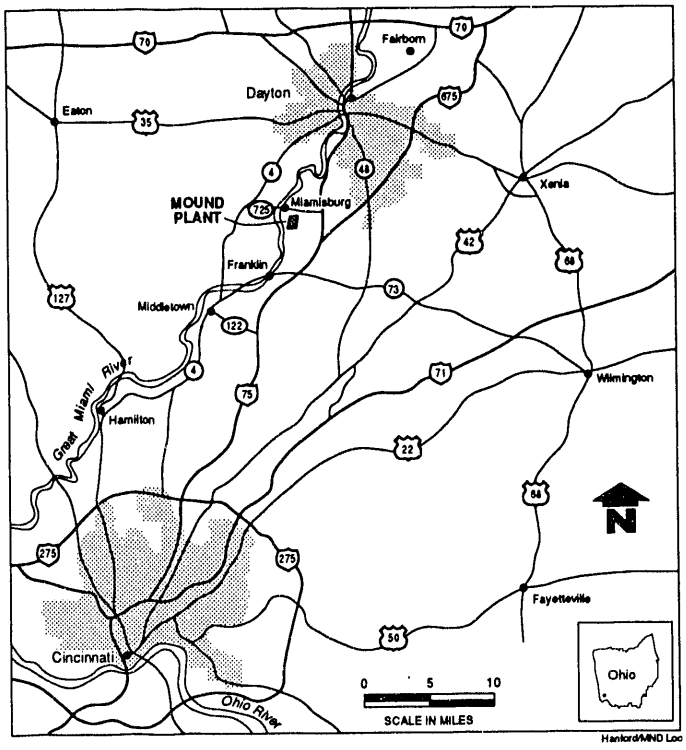


Fig. 1. Location of Mound Plant.

1260). On November 8, 1990, state and federal authorities were informed of the discovery of the subsurface oil.

TABLE I

Chronology for the West Powerhouse PCB Site

April 1990	Transformer leak is discovered
May 1990	First subsurface clean-up (TSCA)
September 1990	Cleanup complete to 40 ppm
November 1990	Additional contamination found at depth
January 1991	CERCLA work plan complete
March 1991	Sampling and Analysis Decision to initiate a removal
July 1991	OSC Report complete

DISCUSSION

Analyses of the transformer oil that leaked in April 1990 and of the contamination at the bottom of the excavation identified the same PCB (Aroclor 1260). It is believed, however, that the two areas of contamination resulted from separate incidents because of the small volume of the recent spill

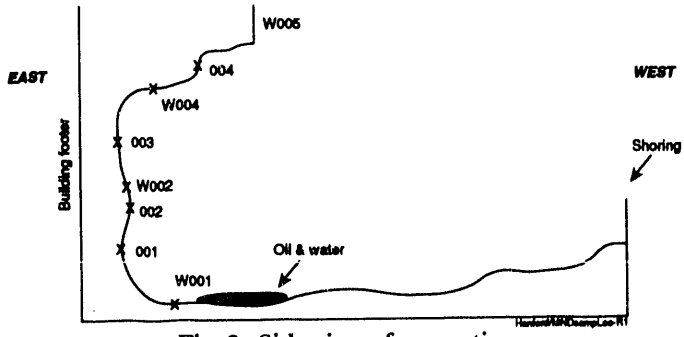


Fig. 2. Side view of excavation.

(2.5 quarts) and the depth (6 ft) at which the contaminated liquid was encountered in October and November. In addition, the oil encountered at 6 ft appeared to be a "light" oil, more closely resembling mineral or cutting oil than transformer oil. Based on the belief that the deeper contamination resulted from past practices, the TSCA response was terminated. A CERCLA investigation was started immediately because of a concern that the PCBs, in contact with groundwater, could migrate rapidly due to the presence of numerous buried utility corridors and the more permeable sandy backfill associated with them.

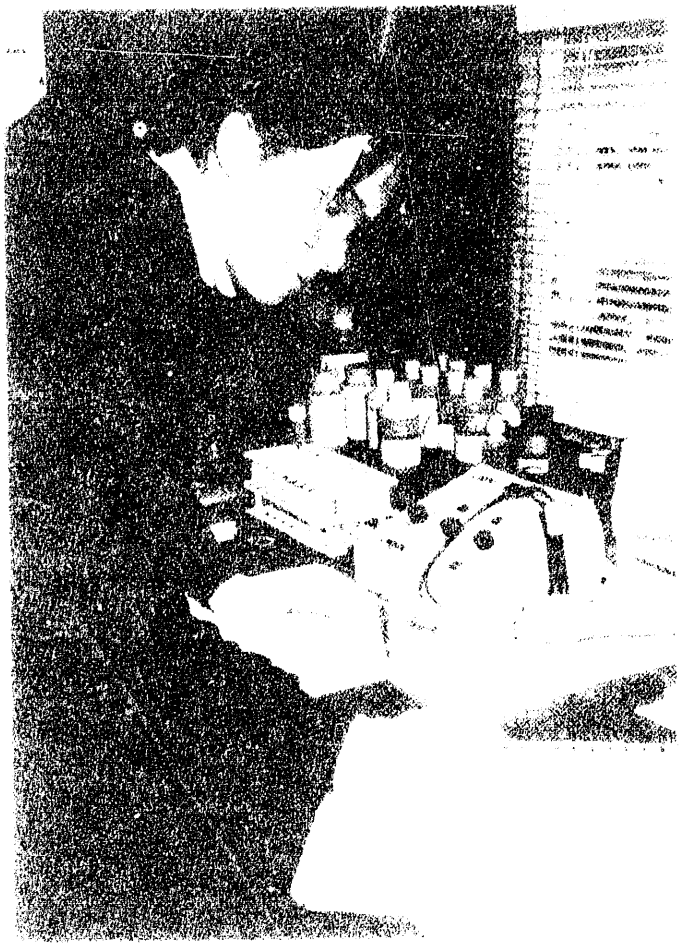
The timing of the PCB investigation in the sequence of the RI/FS at Mound Plant was such that there were no existing cleanup standards for the plant. Because PCBs are regulated under TSCA, this act was considered to be a relevant and appropriate requirement under CERCLA. Therefore, a sampling and analysis plan (1) was developed based on guidance for the verification of cleanup at a PCB spill site. This sampling strategy can also be used to design a characterization plan (2,3).

Also considered to be relevant and appropriate requirements are the TSCA cleanup requirement for PCB spills for non-restricted access areas (40 CFR 761) and the municipal solid waste landfill disposal limit (40 CFR 268.32), which are 10 ppm and 50 ppm, respectively.

The sampling and analysis plan was a scheme to expand a sampling grid until the limits of contamination were reached. It was desirable to have analytical results available rapidly to avoid expanding the grid needlessly while waiting for data. Therefore, one of the chosen analytical methods was an on-site method using a portable instrument that measures PCB content, using an electrochemical method and a chloride-specific electrode to quantitate chloride content, which is then converted automatically into a PCB equivalent. The detection limit using the portable instrument is 5 ppm with a planned precision of ± 40 percent, compared to the relevant and appropriate TSCA cleanup requirement of 10 ppm. The on-site analysis is shown in Fig. 3.

Once soil sampling and analysis were initiated, logistical difficulties were encountered. The west side of the Powerhouse Building, where the release occurred, has a utility corridor where several utilities including water, sewer, and high voltage electric lines are located below ground surface. Due to the abundance of underground utilities in proximity to the release area (shown in cross section in Fig. 4), boreholes could not be drilled, dictating the use of backhoe and hand excavation techniques, shown in Fig. 5, with subsequent soil analyses. When it became apparent that this sampling method was generating large volumes of soil, it was obvious that it would be cost-effective to dispose of soil already taken from the excavation. Another complication was that water was flowing into the excavation, although in small quantities, and had to be pumped out and containerized. This water would need to be disposed of.

Once the decision was made to dispose of excavated soil, the DOE formally notified the EPA and the Ohio EPA that it was conducting a removal action under the authority of CERCLA Section 104. The other requirements for a removal action were also initiated: public notices and notification of the Natural Resources Trustee. Thus, the removal action was done concurrently with characterization of the extent of PCB contamination, and no formal RI/FS was done.





CONCLUSION

The DOE explicitly exercised removal authority under Section 104 of CERCLA. This facilitated a flexible investigation and the combination of removal with characterization. The initial concern that PCBs were migrating with groundwater and were widespread was determined to be not true. As a result, the West Powerhouse PCB Site was cleaned up in an expedited manner and a potential threat to the environment was eliminated.

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ACKNOWLEDGEMENTS

The DOE Mound Plant is operated by EG&G Mound Applied Technologies. This work was completed under University of California, Los Alamos National Laboratory, Subcontract 9-XS8-0146R-1, by Roy F. Weston, Inc. The opinions expressed are solely those of the authors.

REMEDIATION TECHNOLOGY NEEDS AND APPLIED R&D INITIATIVES

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ABSTRACT

The U.S. Department of Energy (DOE) recently consolidated its environmental restoration and waste management activities. Within that new organization, DOE has committed to support Research, Development, Demonstration, Testing and Evaluation (RDDT&E) activities with the following objectives: rapidly advance beyond currently available restoration and waste management technologies; provide solutions to key technical issues that will improve effectiveness, efficiency, and safety; and enhance DOE's ability to meet its 30-year compliance and cleanup goals.

Four general categories have been identified where R&D (and DT&E) efforts need to be focused: waste minimization technologies, site characterization and assessment methods, waste treatment technologies, and remediation technologies with emphasis on in-situ methods. The DOE has already supported a number of R&D activities in these areas and plans to continue that support in the future. For technology development, the DOE is committed to forming cooperative partnerships and eliciting broad participation from qualified organizations who can contribute to RDDT&E activities. The new technologies resulting from these R&D initiatives will enhance DOE's ability to meet its 30-year cleanup goal, reduce risk, and provide significant cost savings over existing technologies. Even modest investments in these emerging technologies now can be expected to generate a high rate of return.

INTRODUCTION

The Secretary of Energy established the Office of Environmental Restoration and Waste Management (EM) in November 1989 to coordinate and manage the Department's activities that deal with remediating contaminated sites in the DOE Defense Complex and to manage waste generated from current operations. It is the EM goal to ensure that risks to human health and safety and to the environment from past, present, and future operations are either eliminated or reduced to prescribed, safe levels by the year 2019. To this end, EM seeks to establish and maintain an aggressive national program for applied RDDT&E to resolve major technical issues and rapidly advance beyond currently employed technologies for environmental restoration and waste management.

The EM is divided into three major offices. The Office of Waste Operations (WO) is responsible for the treatment, storage, and final disposal of currently generated waste. The Office of Environmental Restoration (ER) is responsible for the remediation of sites no longer in use. The Office of Technology Development (OTD) is responsible for the Technology Development (TD) program to address the needs identified by three customers: Waste Operations, Environmental Restoration, and, in the case of waste minimization techniques, the Office of Defense Programs.

The TD program responsibilities include R&D on potential new technologies and DT&E on the more promising technologies. Close coordination with offices of Environmental Restoration and Waste Operations will ensure that specific problems related to DOE sites or the DOE needs for new technologies are identified. The DOE has recognized the importance of resources available in various sectors and has elicited broad participation from national laboratories, DOE facilities, universities, research organizations, and the private sector in developing technologies that will allow environmental restoration efforts to proceed faster, safer, cheaper, and better.

The TD program is designed to make new, innovative, and effective technologies available and transfer these to the users. New technologies are sought to meet legal and regulatory requirements; to reduce risks, operating costs, operating time; and to minimize the generation of new waste. The R&D Division of OTD identifies innovative technologies and is responsible for the generation of data to support engineering decisions to proceed to the DT&E phase. The DT&E Division acts as the conduit to full-scale implementation through demonstration and testing of technologies. Program coordination offices have been established for Innovative Technology, Applied R&D, and DT&E programs at DOE's Idaho, Chicago, and Oak Ridge Field Offices, respectively. The purpose of these offices is to facilitate movement of technologies from conceptualization to implementation.

REMEDIATION TECHNOLOGY NEEDS

The EM is currently developing roadmaps for solution of many of the problems at DOE sites requiring remediation technology. Roadmaps are derived from a planning process that focuses on identification of critical issues, root-cause analysis, and issue resolution (1). This process forms the basis for EM strategic planning to carry out waste management

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operations and environmental restoration in a manner that achieves regulatory compliance within budget and on schedule. Table I lists the major DOE sites and the related corrective actions and/or problems requiring remediation technologies at each site.

The roadmap process also prioritizes specific technology needs to meet scheduled compliance milestones. Once these priorities are established, OTD requests internal and private sector institutions to submit technical task plans (TTPs) and proposals, respectively, to address the identified technology needs.

The OTD activities described here address technology needs in three broad areas: 1) characterization and assessment, (2) remediation, and (3) decontamination and decommissioning. It should be noted that these areas by no means constitute all of the key needs which DOE foresees.

Present site characterization methods are imprecise, costly, time-consuming, and overly invasive. Improved site characterization methods will require better technologies for accurately describing the subsurface geohydrologic features of a site. For example, more efficient nonintrusive sampling strategies and practical methods are necessary for understanding and predicting subsurface contaminant transport. Also needed are more reliable procedures for interpreting characterization data and understanding how clean is "clean."

Intrusive activities, such as sampling and excavation during remediation of a site, often involve immediate hazards to workers in the form of exposure to radioactive and/or toxic materials. Remote real-time analyses of ambient levels and rapid assessments of potential hazards in air, water, and soil during characterization, as well as in the remedial action phase, would help ensure worker safety and allow continuous operation. Instrumentation capable of detecting low levels of broad classes of hazardous materials and specific compounds is needed to indicate cleanup status. Better characterization methods based on real-time analyses are especially important to confirm the most effective use of certain in situ remediation technologies. In the absence of real-time monitoring, excessive volumes of soil and water must be treated to guarantee compliance; otherwise, pockets of contamination may be missed.

Special characterization and remediation technologies are necessary for decontamination and decommissioning of inactive facilities, underground storage tanks, and wastewater lagoons. These facilities often contain significant quantities of radioactive wastes, in certain cases mixed with heavy metals and/or hazardous organic compounds that make personnel entry unacceptable. Thus, the development of advanced robotic samplers, smart probes, mobile and in-situ fiber-optic devices, and nonintrusive characterization instrumentation (based on electromagnetic, thermographic, and acoustic

TABLE I

Summary of Major Problems at DOE Facilities Requiring Innovative Solutions

Kansas City Plant
VOCs (air emissions)
PCBs (soil-groundwater)

Los Alamos National Laboratory
USTs (replacement), Radioactive emissions (air/water), VOCs (air), PCBs (soil/groundwater)

Pantex and Pinellas Plants
USTs (replacement),
Volatile organics (soil/groundwater)

Sandia National Laboratory
Mixed waste landfill
(soil/groundwater contamination)

Argonne National Laboratory
Brookhaven National Labortory
Fermi National Laboratory
Soil/groundwater conamination

Princeton Plasma Physics Laboratory
USTs (replacement, soil/ grounwater contamination)

Idaho National Engineering Laboratory
Buried waste
USTs (replacement, soil/groundwater contamination)

Lawrence Berkeley Laboratory
USTs (soil/groundwater contamination - volatile organics)

Lawrence Livermore National Laboratory
Sewer system leakage
(soil/groundwater contamination)

Savannah River Site
Volatile organics in soil (humid sites demo)
Soil/groundwater contamination

Nevada Test Site
Cleanup of Pu contaminated soils,
Septic system soil cleanup

Oak Ridge National Laboratory
USTs (soil/groundwater contamination)

Fernald (FEMP)
U contaminated soils

Portsmouth Gaseous Diffusion Plant
PCBs (soil/groundwater contamination)

Paducah Gaseous Diffusion Plant
PCBs (soil/groundwater contamination)

Hanford
Volatile organics in soil (arid sites-demo)
USTs (replacements/cleanup)

Rocky Flats
Radioactive and hazardous mixed waste
(soil/groundwater contamination)

principles) is needed for sampling and chemically characterizing these sites. The development of such techniques will significantly reduce radiological exposure to workers and provide more assurance that the correct remedial technology has been selected.

Most DOE sites have some form of subsurface contamination, ranging from buried concentrated waste forms, such as tanks or trenches, to dispersed contaminants in soil or water. Soils, sludges, sediments, soils mixed with buried waste, and mill tailings at DOE sites are contaminated with radionuclides, toxic metals, and hazardous organic compounds. Contamination resulted from a variety of operations, including the use of soil columns, ponds, liquid waste storage tanks, and subsurface disposal of waste. The potential for migration of radionuclides and heavy metals from contaminated soils necessitates development of technologies to treat the contaminated volume in a manner that effectively protects public health, public safety, and the environment.

In some instances, contamination is contained largely in the surface soils. In other cases, there is subsurface contamination by hazardous organics, nitrates, metals, inorganic salts, and radionuclides resulting from disposal of wastes in lagoons, shallow-land burial, or leaks from cribs, tanks, and pipes. Soil treatment strategies can be classified as (1) in-situ treatment and (2) retrieval and treatment.

Technologies are sought that can satisfy one or more of the following requirements:

- isolation and containment of radioactive constituents or heavy metals;
- long-term immobilization without migration of radioactive constituents or heavy metals;
- removal of radioactive constituents or heavy metals for treatment;
- degradation of organics or organometallics to innocuous products such as carbon dioxide and water;
- elimination or reduction to acceptable limits of chemical toxicity; or
- removal of chemical constituents for treatment.

Radionuclide, heavy metal, and/or inorganic chemical contamination occurs in groundwater at many DOE sites. This contamination results from a variety of operations, including the use of liquid waste storage tanks and disposal of liquid wastes to cribs (engineered leach fields), trenches, and ponds. Many contaminants are dispersed in the soil column (unsaturated zone) and in the groundwater. Because of the migration potential of these contaminants, technologies are needed to treat the contaminated groundwater in a manner that effectively protects the environment and human population.

Both extraction and in-situ technologies for treating these contaminants are sought that meet the following requirements:

- removal or destruction of organics in the presence of other wastes;
- isolation of heavy metal, radioactive, and/or inorganic constituents;
- removal of heavy metal, radioactive, and/or inorganic constituents;
- reduction of concentrations to Maximum Contaminant Levels for drinking water; or
- elimination of impacts to surrounding environment.

The DOE's uranium enrichment and fabrication facilities, nuclear production reactors, and fuel reprocessing facilities all include massive structures that are contaminated with radionuclides and, in many cases, hazardous materials. These facilities present immense challenges for decontamination and decommissioning (D&D). Technologies are needed to ensure that the D&D processes used are cost-effective and meet all health, safety, and environmental regulations. Many of the presently available
decontamination processes are expensive, create too much waste, and require modification to satisfy current regulations.

To reduce worker exposure, and D&D time and to minimize wastes, technologies must be developed that meet the following requirements:

- remotely characterize contamination in real time;
- perform decontamination of concrete, piping/equipment;
- reduce waste volume and facilitate recovery of recyclable materials;
- can treat chemically contaminated as well as radioactively contaminated materials and waste.

Clearly, there are more technology development needs and more innovative ideas than resources to devote to these investigations. Priorities must be set and sufficient resources must be allocated to pursue those activities deemed most urgent.

RDDT&E PROGRAM STRUCTURE

The OTD has developed the RDDT&E Program to promote the resolution of major technical issues and the rapid advancement of the current technology beyond what is now available for environmental restoration and waste management operations. The RDDT&E Program has been designed to satisfy needs of the ultimate users: DOE installations, the Office of Environmental Restoration, the Office of Waste Operations, and the Defense Programs.

Applied R&D activities constitute a major portion of the RDDT&E Program. Critical tasks are planned and conducted to provide a technical, regulatory, and economic base for the decision-making process to transfer technologies from R&D to the DT&E phase. Most tasks focus on the collection of experimental data to support the development of engineering specifications for full-scale technology implementation. Other activities concentrate on the identification of critical engineering issues for full-scale testing.

The DT&E staff is chartered to identify technologies that are promising for transition to the demonstration arena. Tasks are designed to develop cost-effective, efficient programs for demonstration, testing, and evaluation of promising technologies and to advance those technologies to full-scale implementation on schedule to meet compliance requirements. Promising technologies are organized into Integrated Programs and Integrated Demonstrations that focus technical activities toward the solution of critical DOE environmental problems. Integrated Programs and Demonstrations provide a means to move technology products from universities, industries, governmental agencies, international agencies, and DOE laboratories to the user.

An Integrated Program (IP) is a group of research, development, and/or demonstration tasks that relate to a single

class of environmental restoration or waste management issues. These programs were phased into the RDDT&E Program to address cross-cutting technology issues and to sustain RDDT&E input into the Integrated Demonstration process.

An Integrated Demonstration (ID) is the cost-effective mechanism that assembles a group of related and synergistic technologies to evaluate their performance (individually or as a complete system) in correcting environmental restoration and waste management problems. Currently identified IPs and IDs (Table II) fall into three areas: groundwater and soils characterization and cleanup, waste retrieval and waste processing, and waste minimization and waste avoidance.

R&D INITIATIVES

At the national laboratories and DOE facilities, the waste management R&D activities include process modification, waste minimization, recycling of materials, waste form development and testing, and container development. Environmental restoration R&D activities stress DOE's unique problems with radionuclides but also acknowledge the need to improve hazardous and mixed waste technologies. These projects include site characterization methods; in-situ monitoring of chemical species; chemical analysis techniques; thermal destruction of organics; in-situ bioremediation; soil vitrification; chemical separation technologies; and application of robotics to characterization, excavation, handling, and treatment of hazardous materials. For FY 1991, the funds for activities in this regard are more than $50 million and for FY 1992, funding projections are approximately $140 million.

The private sector initiatives have included contracted R&D technology development. In FY 1990, on behalf of the OTD, the applied R&D Program Coordination Office (PCO) solicited proposals from the private sector for applied R&D in technologies in the following general areas: soil remediation; groundwater remediation; characterization and sensing of buried objects, contamination, and/or geological/hydrological features; and containment of contamination at sites (2). Based on the recommendations arising from proposal evaluation by an independent peer review, contract negotiations were authorized by DOE with 15 offerors for a total of $6 million in funding; all contracts were in place by September 1990. The 15 selected projects listed by the technical areas addressed are as follows:

- Groundwater cleanup
  - Biodegradation of trichloroethylene (TCE) and other chlorinated hydrocarbons in a vapor phase bioreactor
  - Removal of volatile organic compoundss (VOCs) with a combined air stripping/membrane vapor separation system
  - Removal of radionuclides, toxic metals, and organics from contaminated groundwater using chemical binding/filtration cold vaporization techniques
  - Removal of radionuclides, heavy metals, inorganic and/or organic ions from groundwater using the Alga SORB biosorbent
- Soil cleanup
  - Volume reduction and stabilization of soil contaminated with radionuclides, heavy metals, and inorganic/organic ions using a combined soil washing/in-furnace vitrification system

TABLE II

Proposed Integrated Demonstrations and Integrated Programs

Integrated Demos

Soil and Groundwater Remediation

ID-A1	VOC in Saturated Soils
ID-A2	Plutonium in Soils
ID-A3	Uranium in Soils
ID-A4	VOC in Unsaturated Soils
ID-A5	Non Pu/U Metals in Soils
ID-A6	Toxic Chemicals in Soils
ID-A7	Non-VOC Unsaturated Soils
ID-A8	Non-VOC Saturated Soils
ID-A9	Mixed Waste Landfill

Waste Retrieval and Waste Processing

ID-B1	Buried Waste
ID-B2	Underground Storage Tanks
ID-B3	Dry Storage
ID-B4	Newly Generated Mixed Waste
ID-B5	RCRA Waste
ID-B6	Combustible Waste
ID-B7	D&D/Concrete
ID-B8	D&D/Metal
ID-B9	In-Situ Vitrification
ID-B10	Advanced Processing

Waste Minimization and Avoidance

ID-C1	Depleted U Waste Minimization
ID-C2	Pu Waste Minimization
ID-C3	Envir. Conscious Manufacturing
ID-C4	DP/EM MOU
ID-C5	DOE/Air Force MOU
ID-C6	Non-Rad Components
ID-C7	General Waste Minimization

Integrated Programs

IP-1	In Situ Remediation Tech. Dev.
IP-2	Charact. and Sensor Tech. Dev.
IP-3	Radioisotope Separation and Proc.
IP-4	Mixed and Hazardous Wast Dest.
IP-5	Pollution Prevention

  - Investigation of electrokinetic effects in the treatment of contaminated soils, sludges and lagoon sediments.
  - Investigation of the effectiveness of composting to destroy explosives and other hazardous organic contaminants in soil, sediments, and sludges
- Site Characterization
  - Investigation of high-resolution, shear-wave seismic reflection profiling for hydrogeological surveying
  - Development and testing of hydraulically installed multisampling lysimeter for use in a vadose (unsaturated) zone
  - Development of a multisampling concept to deploy instrumentation and sampling systems down hole by pneumatically emplacing an eversible, impermeable membrane liner carrying many instruments
  - Development of a mobile fiber optic Raman spectrograph for in-situ characterization/monitoring
  - Development of surface-acoustic-wave (SAW) microsensor arrays for detecting VOCs
  - Development of a bulk soil assay system for most elements and radionuclides using a mobile sensor incorporating both capture-gamma ray (CGRS) and inelastic-gamma ray imaging and spectroscopy (IGRIS) techniques
  - Development of hardware and software for three-dimensional site characterization using three minimally invasive measurement techniques -- cone penetrometry, synergistic electromagnetic mapping technology (SEMT), and reflection seismology
- Containment

  Investigation of the fixation of heavy metals (e.g. chromium) through in-situ reduction followed by injection of a silica solution to immobilize the resulting metal hydroxides.

In companion solicitations, the Innovative Technology Development Program announced the selection of seven awardees for a total of $1.5 million in funding in March 1991. The selected projects include the following: extraction and separation of actinides and lanthanides from waste streams and soils, application of synthetic membranes to remove volatile organics from water, use of fiber-optic TLDs to monitor soil or waste storage, isolation of contaminated areas of aquifers through placement of subsurface barriers, using light as a catalyst to destroy organic contaminants, application of computer models to simulate flow of hazardous materials, and treatment of TCE in contaminated airstreams. The Field Demonstration Program is now reviewing proposals for remediation technologies received in June 1991 for possible pilot field testing and evaluation.

Other initiatives that have been undertaken involve DOE's participation through interagency agreements with the U.S. Environmental Protection Agency (EPA) in the Hazardous Substance Research Centers (HSRCs) Program (3), and the Superfund Innovative Technology Evaluation (SITE) Program. The five university-based HSRCs (each covering two EPA regions), which are geographically distributed across the country represent multi-university consortiums whose directors are located at the lead university or institute campus. The basic mission of the HSRCs is to study all aspects of the manufacture, use, transportation, disposal, and management of hazardous substances. The HSRC projects supported by DOE primarily focus on biotechnology. The projects supported in 1990 include the following:

- Contaminated groundwater treatment with bioreactors utilizing a white rot fungus
- Remediation of contaminated aquifers with surfactants: The effect of surfactant adsorption and desorption
- Phase equilibria and transport properties of surfactant systems of interest to soil remediation
- Biodetoxification of hazardous solid wastes by staged anaerobic fermentation conducted at separate redox and pH environments
- Optimal bioreactor design for biological removal of mercury
- Heavy metals removal from dilute aqueous solutions using biopolymers
- In-situ bioremediation of organic groundwater contaminants
- Innovative treatment of bank stabilization of metals contaminated, soils and tailings along Whitewood Creek, South Dakota
- Modeling of the use of plants in remediating soils and groundwater contaminated by hazardous organic substances
- Test-bed evaluation of in-situ bioremediation of chlorinated aliphatic compounds by toluene monooxygenase containing bacteria
- Dispersion modeling of volatile organic emission from ground-level treatment systems
- Dispersion modeling of volatile organic emissions from treatments of contaminated groundwater

For 1991, eight projects (both ongoing and new) have been selected for DOE support.

- Electrode emplacement geometries and electric field strengths for in-situ extraction of contaminants from hazardous waste sites by electroosmosis
- Use of pneumatic fracturing to enhance removal of VOCs from clay formations
- Remediation of contaminated aquifers with surfactants: The effect of surfactant adsorption and desorption
- Phase equilibria and transport properties of surfactant systems of interest to soil remediation
- Innovative treatment and bank stabilization of metals-contaminated soils and tailings along Whitewood Creek, South Dakota
- Modeling of the use of plants in remediating soils and groundwater
- Test-bed evaluation of in-situ bioremediation of chlorinated aliphatic compounds by toluene monooxygenase containing bacteria

- Dispersion modeling of volatile organic emissions from ground-level treatment systems

The purpose of the SITE program is to accelerate the development, demonstration, and use of alternative or innovative treatment technologies at superfund sites. One of the program components, the Emerging Technologies Program (ETP), fosters development of emerging technologies or approaches to ensure that a steady stream of appropriate technologies will be ready for demonstration. Since one of the OTD objectives is to tap the research expertise in the nation's academic institutions and private enterprise, it was recognized that DOE participation in the HSRC and SITE programs provides an excellent opportunity for DOE to leverage research funds to provide an even greater return on its investment.

OPPORTUNITIES FOR PARTICIPATION

In eliciting broad participation from qualified organizations who can contribute to its RDDT&E activities, the OTD is aware of the wealth of technological talent and innovative ideas in all sectors. It has initiated steps during the past two years to increase participation of the private sector (academia and industry) through competitive solicitations and through funding of unsolicited proposals. The DOE also worked to increase participation by academia through interagency agreements for cooperative funding of research and through the establishment of a DOE educational consortium. Many significant technology development activities are also being conducted at DOE sites, such as the national laboratories. The DOE is funding technology development and technology exchange activities beyond the United States through direct contracts, international agreements, and other mechanisms.

The DOE plans to continue this type of support for technology development in the coming years. Organizations interested in responding to Program Research and Development Announcements should contact Thomas Martin of the Morgantown Energy Technology Center (METC), P.O. Box 880, Morgantown, WV 26507-0880. Organizations wishing to submit unsolicited proposals or needing additional information should contact Stephen C.T. Lien, Director, Division of Research and Development (EM-54), Department of Energy, 12800 Middlebrook Road, Trevion II Building, Germantown, MD 20874, for information on submission format and procedures prior to preparation of a proposal.

SUMMARY

The TD programs and the supporting activities described here address some, but by no means all of the key needs for remediation technology developments. The technology development approach, which is designed to satisfy the regulatory requirements under which DOE's 30 year cleanup program must operate, has been discussed. The accelerated development of technologies can be facilitated by a variety of factors that include the integrated nature of the development process thereby enhancing the cross-fertilization of ideas and increasing the rate of transfer of technologies between DOE and the private sector and academia.

Better technologies will be developed through integrated programs and demonstrations. Implicit in the discussion of remediation needs is that once technologies are developed and evaluated, they must be implemented at DOE's facilities to yield benefit from the R&D investments. Success is implementation. Many technological challenges lie ahead in developing faster, better, safer, and cheaper remediation technologies with tremendous opportunities for innovative approaches.

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PROPOSED PLAN FOR VITRIFICATION DEMONSTRATION OF LOW-LEVEL RADIOACTIVE WASTES AT THE FERNALD ENVIRONMENTAL MANAGEMENT PROJECT

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Westinghouse Environmental Management Company of Ohio*

ABSTRACT

Glassware was made by the Romans several hundreds of years before Christ. Some of this glassware was discovered in ship wreckage at sea. The glassware has eroded less than ½ mm over 2500 years. The erosion rate of the crude Roman glass in corrosive salt water implies that low-level radioactive wastes dissolved in molten glass should remain entombed in the glass for extremely long periods of time (10 000 years plus). The extremely low leach rate for such a glass should keep concentrations in the environment below all regulatory limits and by that provide protection of the environment indefinitely.

Vitrification is considered, by many, as a most effective (if not the most effective) treatment method for disposal of radioactive and numerous inorganic hazardous wastes. However, vitrification of low-level radioactive wastes at large production/commercial rates has not been accomplished and needs to be demonstrated to justify selecting vitrification as a competitive alternative to other treatment methods.

This paper describes a proposed plan to demonstrate vitrification of low-level radioactive wastes at the Fernald Site (FS) located near Cincinnati, Ohio. Demonstrations will progress from laboratory to on-site bench-scale, to a pilot size, then to full-sized vitrifiers (glass melters). The bench sized unit will mainly prove the process and develop glass mixes using various waste forms and glass formers. The pilot scale unit will evaluate and develop operational requirements and processes.

FS DESCRIPTION AND BACKGROUND

The FS is located near the unincorporated town of Fernald, Ohio, approximately 32 km northwest of Cincinnati (Fig. 1). The FS production facilities cover approximately 0.55 km^2 in the center of a 4.25 km^2 site. Several rural communities and commercial operators lie within 1.0 km to 4.8 km of the plant.

Fernald produced high-purity uranium metal from the early 1950s until 1989 for the U.S. Department of Energy (DOE) defense nuclear fuel cycle. The metal was predominately fabricated into fuel cores and target elements. These were used in nuclear reactors at other DOE sites. Many chemical and manufacturing processes were used in the production of uranium metal. Process wastes and sludges containing low concentrations of uranium and thorium were disposed in large on-site waste pits. Table I lists the variety of materials in the waste pits. Typical commercial wastes were disposed in lime sludge ponds, fly ash piles, and sanitary landfills. Uranium contamination has been found in on-site soils and perched groundwater around process facilities and in a groundwater plume that extends approximately a kilometer off-site.

In November 1989, Fernald was placed on the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) National Priority List (NPL) to provide focus for ongoing cleanup initiatives. Although financing of remediation will not come from the Superfund, the Fernald site will be remediated according to CERCLA using DOE funds.

Fernald is the appropriate site conduct a demonstration of this technology. The integration of this demonstration with the remediation of the Fernald site provides a unique opportunity for a coordinated effort among the DOE sites and many commercial sites. The Fernald site remediation will involve a variety of materials such as process and pit wastes, soils, fly ash, drummed waste, etc., with a variety of contaminants such as heavy metals, organics, and radioactive chemicals. However, the wastes contain low levels of penetrating radiation and radioactive contamination that provide a demonstration bed of lower hazard level with results applicable by analogy to many other DOE and commercial sites. This demonstration, if successful, will be carried through full scale and provide valuable information to other sites planning remediation of large volumes of varied wastes.

NEED FOR VITRIFICATION DEMONSTRATION OF LOW-LEVEL RADIOACTIVE AND MIXED WASTES

Besides Fernald, many DOE sites have contaminated waste sludges, soils, and fly ashes that need remediation. The issue of how to best treat these wastes to protect human health and the environment is debated. Solidification (or cementation) processes, soil washing, and capping waste pits have been used with varying degrees of success. Vitrification has not significantly been used in the DOE complex largely because of the stigma that vitrification lends itself to treating low-volume, high-level radioactive wastes because of electrical power costs and technology concerns. Vitrification is a process that converts contaminated solids (and liquids containing contaminated solids) into glass. The glass is so insoluble, that technically, the environment is protected from the spread of contaminants by simply placing soil over the glass for radiation-shielding purposes. Politically, however, a more elaborate disposal scheme may be necessary, but it need not be as extensive as those required for other treatment methods.

Vitrification appears to rank higher than solidification in protecting the environment because of its very-low leachability and its presumed excellent stability. Unfortunately, it ranks lower in implementability because it remains a largely undemonstrated process for large-scale remediations.
Solidification may rank less in its protection of the environment because it normally has a higher leach rate and its stability may be less than vitrification. However, solidification

* Westinghouse Environmental Management Company of Ohio with the U.S. Department of Energy under Contract No. DE-AC-05-86OR21600

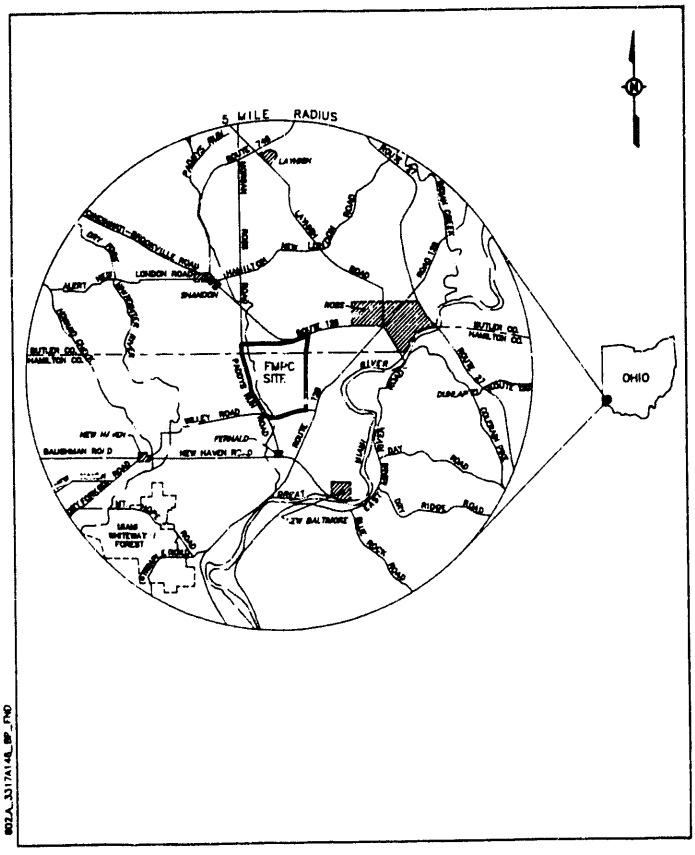


Fig. 1. Five-mile radius map, Fernald Environmental Managemen Project.

ranks higher in implementability because it has been proven successful in some large-scale remediations. Vitrification has to be proven feasible and economical for low-level radioactive and mixed wastes if it is to be considered as an alternative for solidification in the future.

ADAPTING COMMERCIAL VITRIFICATION

Electrical vitrifiers have commercially produced glass (for bottles, for example) since the 1920s. Some vitrifiers produce over 180 000 kg of glass a day. This glass production technology should be adaptable to treat low-level radioactive and mixed wastes with similar production rates. Power requirements for such a vitrifier approximately equate to the power needed to run a large hotel, which is not as excessive as generally perceived. Some advantages of vitrification over other treatment processes, such as solidification, are: (1) volume reduction that can lead to lower disposal costs, (2) significantly lower leachate rates, (3) no additional ingredients, such as cement or gravel, are frequently not needed (e.g., soils and fly ash contain their own glass formers), and (4) no curing or setting problems that can plague cement processes.

Wastes placed in a vitrifier are treated by physically making the wastes part of the glass. At elevated temperatures, glass becomes electrically conductive. Current passing between the electrodes in the vitrifier causes the conductive glass to heat and maintain the glass in the molten state. This is known as joule heating. Joule-heated vitrifiers normally need to be brought up to temperature by another heat source such as gas heating. Organics dropped into the molten glass between 1600 K and 1900 K will burn and oxidize to gases (mostly CO_2 and H_2O) that are collected and treated in the off-gas. Most inorganics will oxidize and dissolve in the molten glass. Molten glass at 1600 K behaves as a solvent that has a viscosity similar to 10-weight motor oil. Most oxides are soluble in glass.

The principal objective of the vitrification demonstration is to evaluate and demonstrate vitrification of low-level radioactive wastes as a competitive alternative to other treatment methods. Process versatility, efficiency, economics and cost optimization, waste reduction, and risk reduction are important elements of the demonstration. The project will consist of (1) evaluation of needs at other sites with similar type problems, (2) accumulation of data for vitrification, (3) characterization of the waste forms and potential glass formers, (4)

TABLE I

Operable Unit 1 Waste Materials Fernald Waste Pit Area

	Pit 1	Pit 2	Pit 3	Pit 4	Pit 5	Pit 6	Burn-pit	Clear Well	Total
Filter/sump cake	X	X				X			
Fly ash	X	X							
55-gal drums	X	X							
Slag and slag residues	X	X	X		X	X			
Raffinate	X	X	X						
Lime sludge	X		X						
Process Residues		X		X					
Noncombustible trash			X						
Asbestos		X		X					
Construction debris, concrete, etc.		X			X				
Green salt (uranium salts)				X					
Laboratory chemicals						X			
Waste oils, wooden pallets, etc.						X			
Stormwater runoff sediments							X		
Barium chloride, (kg x 1,000)				10.7					10.7
Thorium, (kg x 1,000)	<1	<1	<1	62	17	unkn	unkn	unkn	79
Uranium, (kg x 1,000)	54	1226	132	3042	50	863	unkn	unkn	5357

selection of the test areas and media, (5) preparation and issuance of proposals to procure and install demonstration size vitrifiers on-site, (6) completion of field demonstrations, (7) environmental safety, and (8) evaluation of the vitrification process for low-level radioactive wastes in terms of economics, efficiency, effectiveness (ability to treat waste at full-scale production rates), and versatility (applicability to numerous types of wastes). The demonstration is intended to be accomplished with participation from other DOE sites and commercial firms.

INTEGRATING THE DEMONSTRATION INTO FERNALD REMEDIAL ACTIVITIES

The demonstration will be integrated with the remedial activities at the Fernald Site, specifically the Environmental Remedial Action (ERA) project. The ERA project is a program for remediating the Fernald Site under CERCLA. Ex-situ vitrification is being considered as the preferred alternative for some of the five operable units in the ERA project. Operable Unit 1 (OU-1), which involves the remediation of waste pits at Fernald, contains the most materials being considered for vitrification. Approximately 350 000 m^3 of wastes and up to approximately 600 000 m^3 of soil in the waste pit caps, berms, and surrounding earth will need remediation. Tables I and II show the quantities and type of materials expected in OU-1. The many types of materials give a good representation of materials found at other DOE sites needing remediation.

Operable Unit 1 remdediation is a large project. For example, a 275 000 kg/24-day treatment facility will take ten years to remediate the pit wastes and 20% of the surrounding soils. This effort is estimated at approximately $1.2 billion. Solidification and vitrification are both being considered for the treatment methods. However, demonstrations are necessary to prove vitrification to be a feasible, reliable, and economically competitive process. Demonstrations will give the assurance necessary to accept vitrification as the preferred treatment method.

DEMONSTRATION DESCRIPTION

The large treatment processes needed for remediation of large amounts of waste at sites like Fernald make it reasonable to approach the development for vitrification in three phases:

Phase 1 -- Characterization and Laboratory Studies

Characterization of the waste forms and laboratory crucible studies to determine the possible glass formers will be a major portion in the initial stages of the development program. The wastes will be analyzed, and crucible melts of the wastes will be done to determine how well they produce glass. If the wastes themselves do not form good glass, various glass formers will be added to determine the most effective and economical formulas. Contaminated soils and/or fly ash on site will be investigated first for use as glass formers. Such an approach should result in a net volume reduction of wastes on site. Characterization and laboratory development will also provide information about any "bad actors" in the waste that would hinder the formation of glass, and thus, determine what pretreatment of the waste is necessary to form good glass.

Characterization and initial development activities will be done off site by a laboratory(ies) or university(ies) that specializes in developing glass formulas. However, later laboratories studies and work will be transferred to on-site (as facilities become available) for quick turn-around time to support operation of the vitrifiers. New on-site laboratory facilities are presently under construction. The facilities should provide the space needed to house the laboratory equipment necessary for supporting the demonstrations.

Phase 2 -- Bench-Scale Demonstration

After characterization of the wastes is complete and laboratory studies are well under way, demonstrations will start with a bench-scale, joule-heated vitrifier of approximately 450 to 3600 kg/day. This vitrifier will mainly be used to prove the process and develop glass mixes using various wastes and glass formers. The bench-scale vitrifier will be procured as a modular unit(s). This would allow the vitrifier to be relocated to another site if needed. Crucible studies may show corrosion problems or other concerns that may show it prudent to work with much smaller vitrifiers before going to the larger bench-scale vitrifier. If this were the case, laboratory-sized vitrifiers that could be easily and economically replaced would be used until the problems were resolved. Then the larger bench-scale demonstration would be done.

Phase 3 -- Pilot-Scale Demonstration

The next demonstration will be a pilot scale unit of approximately 18 000 kg/day. A unit of this size may be a full-size unit at other sites. The unit will be used to investigate and develop operational requirements and special processes that would be required of full-size units. For example, processing whole drums of waste (including the drum) in a vitrifier would be investigated. This would reduce drum handling and eliminate personnel exposure received while sorting drum contents. The metal drums are expected to melt and flow to the bottom of the glass melt where the resulting metal is drained and possibly recycled. The organic contents of the drum are incinerated and inorganic contents of the drum enter the glass melt. After, development is complete, the vitrifier is envisioned to continue operation as a demonstration unit and for other remedial needs. For example, the units could be used to treat Fernald Site mixed wastes.

SCHEDULE

Figures 2 and 3 show schedules for the demonstration phases and how these phases are integrated with the ERA project. The first wastes proposed for study are those from Pit 5 in OU-1. Several types of wastes are expected to be studied throughout the life of the demonstration. Pit 5 contains approximately 76 600 m^3 of low level uranium contaminated sludges. Vitrification may have more universal impact to the ERA project than just OU-1 (e.g., fly ash from OU-2 and soils from OU-3 would be investigated for use as glass formers for vitrification for the pit wastes in OU-1). Thus, using vitrification at Fernald would result in a net volume reduction of wastes needing disposal.

Various operational and permitting requirements are not shown in the schedules. However, these requirements will be accomplished in parallel with OU-1 design activities under the ERA project and Fernald Site CERCLA programs. Some permits or information packages that may be needed for the demonstration are:

- Removal Site Evaluation (RSE)
- National Environmental Policy Act (NEPA)
- National Emissions Standards for Hazardous Air Pollutants (NESHAP)
- Permit To Install (PTI)
- Permit To Operate (PTO)

TABLE II

Operable Unit 1 Quantities Fernald Waste Pit Area

	Average Depth m	Area m^2	Waste m^3	Cap m^3	Soil m^3	Total m^3
Pit 1	4.3	7432	25 749	2342	75 192	103 283
Pit 2	4.2	4478	14 128	947	41 614	56 689
Pit 3	8.2	21 878	163 049	54 682	25 398	243 129
Pit 4	7.3	7962	41 064	13 052	100 742	154 858
Pit 5	9.1	17 066	75 573	Open	184 028	259 601
Pit 6	7.3	3010	8836	Open	60 770	69 606
Clear Well	8.2	2369	7310	Open	28 326	35 636
Burnpit	6.1	1858	6938	616	12 180	19 734
Totals		66 053	342 647	71 639	528 250	942 536

INTERSITE INVOLVEMENT AND TECHNOLOGY INTEGRATION

Fernald (and probably any other DOE site) does not have all the expertise necessary to conduct the demonstrations and design the vitrification complex. Therefore, the demonstrations will involve representatives from other DOE sites. The involvement of multiple sites will provide the expertise needed. Involvement of other sites will present a broader picture of the needs and obstacles faced by DOE that can be addressed by the demonstration. A large realm of technical interaction will increase the interest at other sites and publicize the capability of vitrification as a treatment alternative.

The Risk Reduction Engineering Laboratory (RREL) of the U.S. Environmental Protection Agency (EPA) has expressed great interest in such a demonstration. The EPA is currently searching for a suitable location for their own Superfund Innovative Technology Evaluation "SITE" development/demonstration program for waste vitrification. Partnership with the U.S. EPA would give a better appreciation of both agencies' needs and problems in meeting regulations. The resulting direct technology transfer would provide a common basis for establishing acceptable performance criteria for disposition of vitrified waste forms.

Universities will be invited to help with Phase 1 (characterization and laboratory studies) and accelerated aging tests. Some universities are becoming actively involved with vitrification development for some DOE sites. Accelerated aging techniques and protocols are being developed to ascertain if a treated waste of concern will resist leaching and weathering for long periods of time.

Information on the demonstration will be made available to the U.S. EPA, DOE Office of Technology Development (OTD), and other interested DOE offices and contractors. Visits to the demonstration units on site will be encouraged to provide a broader understanding of the vitrification process. Security clearances are not mandatory for visiting the demonstrations.

CRITERIA FOR SUCCESS

The demonstration will be considered successful when the following criteria are met:

1. Bench-scale and pilot vitrifiers are installed and operational according to an approved demonstration work plan.
2. Technical evaluation and determinations are made that show how effectively the vitrified wastes will protect the environment.
3. The vitrification process is qualified against the following parameters:
   a. Versatility
   b. Effectiveness
   c. Economics
   d. Potential for waste reduction
   e. Process safety
4. Demonstration and data are verified in accordance with U.S. EPA Document No. EPA/540/2-89/058, "Guide for Conducting Treatability Studies Under CERCLA," Interim Final dated 1989.

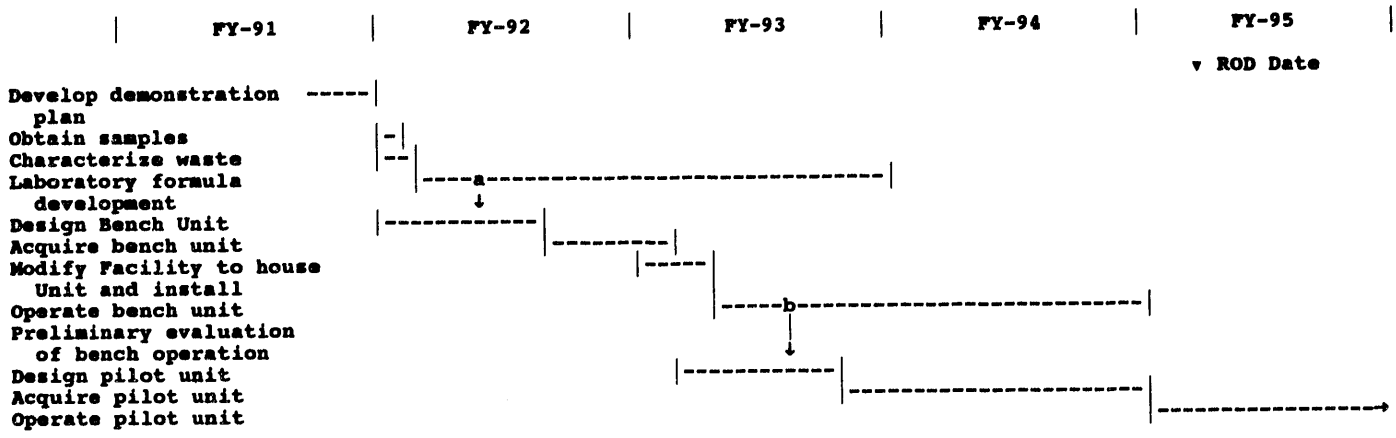
BUDGETS AND FUNDING

Plans are to do the vitrification demonstration at Fernald as part of the ERA Project using ER funds. Specifically, the demonstration will be handled under development activities for Operable Unit 1. Funds for the vitrification demonstration will compete with funds for solidification/cementation since this process is also being retained in the RI/FS effort as a possible treatment process. Both processes will be funded through the first phases of development. Most likely, however, only the process that proves more successful will be funded through completion.

DISCLAIMER

This paper was prepared as an account of work sponsored by an agency of the United States Government. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

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Key Decisions:

a. **Evaluate the laboratory crucible studies and decide whether to acquire the bench unit.**

b. **Evaluate the success of the bench unit and decide whether to construct the pilot unit.**

Fig. 2. Vitrification demonstration schedule.

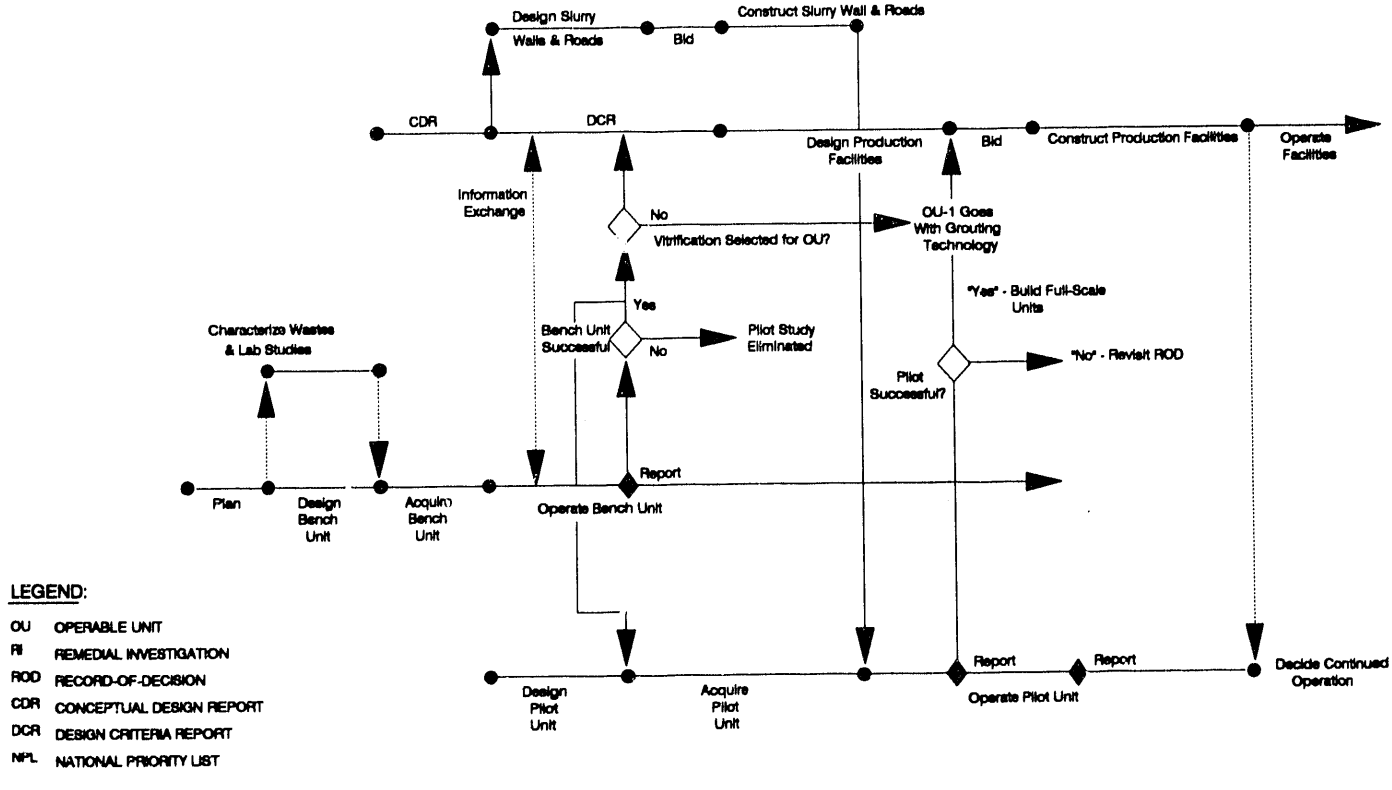


Fig. 3. Vitrification development & OU-1 integration.

SELECTION OF INNOVATIVE TECHNOLOGIES FOR THE REMEDIATION OF SOILS CONTAMINATED WITH RADIOACTIVE AND MIXED WASTES

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ABSTRACT

The remediation of sites containing radioactive and mixed wastes is in a period of rapid growth. The state of the art of remediation is progressing to handle the shortcomings of conventional pump and treat or disposal technologies. The objective of this paper is to review the status of selected innovative technologies which treat soils contaminated with radioactive and mixed waste. Technologies are generally classified as innovative if they are fully developed, but lack sufficient cost or performance data for comparison with conventional technologies. The Environmental Protection Agency recommends inclusion of innovative technologies in the RI/FS screening process if there is reason to believe that they would offer advantages in performance, implementability, cost, etc. This paper serves as a compilation of the pertinent information necessary to gain an overview of the selected innovative technologies to aid in the RI/FS screening process.

The innovative technologies selected for evaluation are listed below. Bioremediation, although innovative, was not included due to the combination of the vast amount of literature on this subject and the limited scope of this project.

1) Soil washing and flushing
2) Electrokinetics
3) Ultrasound
4) Soil vapor extraction
5) In situ hot air/steam extraction
6) In situ radio frequency
7) In situ soil heating
8) Low temperature thermal treatment
9) Infrared incineration
10) In situ vitrification
11) Plasma torch slagging
12) Cyclone reactor treatment
13) Vegetative radionuclide uptake

The information provided on each technology includes a technical description, status, summary of results including types of contaminants and soils treated, technical effectiveness, feasibility and estimated cost.

INTRODUCTION

The remediation industry for sites contaminated with radioactive and mixed wastes is currently in stage of rapid development. The methods most often used, such as excavation followed by disposal or pumping and treating the porewater of saturated soils, have become less desirable as their long-term effectiveness is suspect. Excavation and disposal merely move large volumes of contaminated soil to a different location. Pumping and treating porewater often only postpones contaminant migration. When the process is shut down, contaminant migration resumes because the source of the contamination, the contaminated soil, is largely unaffected by this temporary treatment process. To overcome the limitations of these types of conventional methods, the development of innovative technologies has been rapidly accelerating. Many innovative technologies showing promising results may be more effective than conventional methods.

Technologies are generally classified as innovative if they are fully developed, but lack sufficient cost or performance data for comparison with conventional technologies. According to the Environmental Protection Agency, innovative technologies should be carried through the remedial investigation / feasibility study (RI/FS) screening process if there is reason to believe that the innovative technology would offer significant advantages (i.e., treatment performance, implementability, lower costs, etc.). It is imperative that innovative technologies be identified early in the RI/FS process so that appropriate site characterization can proceed without delay. Unfortunately, innovative technologies are rarely selected for consideration as possible alternatives in the RI/FS process. This is likely due to the vast number of symposia proceedings, government reports, and journal articles that must be reviewed to keep up to date with the latest results.

The purpose of this paper is to present the findings of extensive literature research and personal contacts with developers of innovative technologies. It will identify and evaluate those technologies that are most applicable to soils contaminated with radioactive and mixed wastes. A basic assumption is that technologies that are applicable to the treatment of heavy metal contaminants are applicable to the majority of radioactive contaminants which are also metals (e.g., uranium, plutonium, strontium, and cesium). Emphasis was placed on methods that: 1) separate the hazardous and radioactive contaminants, 2) destroy the organic contaminants, or 3) reduce the volume of radioactively contaminated soils that may ultimately need to be placed in an appropriate disposal site.

The innovative technologies selected for evaluation are listed below.

1. Soil washing and flushing
2. Electrokinetics
3. Ultrasound
4. Soil vapor extraction

5. In situ hot air/steam extraction
6. In situ radio frequency
7. In situ soil heating
8. Low temperature thermal treatment
9. Infrared incineration
10. In situ vitrification
11. Plasma torch slagging
12. Cyclone reactor treatment
13. Vegetative radio-nuclide uptake

The results of the literature search serve as a compilation of the pertinent information necessary to gain an overview of the selected innovative technologies. The information provided on each technology includes: 1) a technical description; 2) a summary of the results of previous applications during bench-, pilot-, and full-scale testing; 3) the types of contaminants and soils treated; 4) the potential advantages and disadvantages of the technology in terms of effectiveness, feasibility, and projected costs within the limitations of published information; and 5) references for additional details and review.

SOIL WASHING - PHYSICAL SEPARATION PROCESSES

A large fraction of the contamination in soils is often found on the fine grained particles, which occupy a small percentage of the soil volume. Therefore, by separating the fine grained particles (i.e., those <250um) from the larger particles the volume of contaminated soil that must be treated and/or disposed is substantially reduced. Physical separation processes are the most direct method for accomplishing volume reduction. There are five general catagories of physical separation processes. These are: 1) wet and dry screening, 2) classification, 3) flotation, 4) gravity separation and 5) magnetic separation. The first four are based on the mechanical separation of soil grain sizes. The fifth is based on differences in magnetic susceptibilities of materials.

The status of the mechanical technologies has been evaluated by the EPA (1). Each technology has been used to separate the highly contaminated smaller particles as described below. However, not one of the four has yet been used for the remediation of a radiologically contaminated site. The EPA (2) points out that pilot plant testing will be necessary to determine their capabilities for site remediation. Magnetic separation has been evaluated for many DOE sites, but has only shown promise for one site to date.

The following sections provide brief descriptions of the physical separation technologies. Results for mechanical separation techniques are listed in Table I. Preliminary results for magnetic separation experiments are described in the text.

Screening

Screening is the separation of soils by passing them through uniformly perforated surfaces (screens). Generally, a series of different sized screens is used. Smaller screens are placed below larger screens. As the soil passes through the screens, the grains that are smaller than the screen perforations pass through to the next smaller screen while larger diameter grains become trapped on a particular screen. In this manner, soils can be separated into various grain sizes.

Soils are usually screened when they are dry (dry screening), but may be flushed through the screens with water or some other fluid (wet screening). It is not practical to try to pass damp soils through screens due to their tendency to clump together.

Advantages	Disadvantages
inexpensive method for separating coarse and fine particles	screens can plug
	fine screens are fragile
	dry screening can produce contaminated dust
	wet screening produces large volumes of contaminated water

Classification

The separation of soil grains according to their settling rate in fluids is known as classification. Classification is usually done with water as the settling fluid. Faster settling grains, such as sands, and slower settling grains, such as silts and clays, are separated into two streams. The latter are called slimes or overflow.

There are three basic types of classifiers: 1) mechanical, 2) nonmechanical, and 3) hydraulic. Mechanical and nonmechanical classifiers are the same except for the way sand is removed. The hydraulic classifiers are different because of the reduced settling rate caused by the hydraulic fluid, usually water.

Mechanical classifiers carry the slow settling grains away in a liquid overflow. Faster settling grains are deposited on the bottom of the device and then dragged upwards against the flow of liquid by mechanical means. The amount of separation depends on feed rate, degree of agitation, height of the overflow weir, and the speed of removal. Mechanical classifiers are widely used in ore-washing facilities.

Advantages	Disadvantages
high continuous processing capabilities	clayey soils are difficult to process
extensive industrial track record	sandy soils with humus are difficult to process
inexpensive and reliable method	

Flotation

Flotation is commonly used to separate minerals such as uranium from ores. The process usually begins with a grinding operation to transform a soil or an ore into a desired grain size. The fineness of the grind is determined by the grain size at which the desired minerals are separated from the waste particles. The grains that have been ground are then put in flotation machines where they are suspended by mechanical means, usually air agitation, to a density of generally 15 to 35 percent solids. The surfaces of the suspended grains are treated with chemicals known as promoters or collectors. The chemicals cause the grains to become air-avid and water-repellent. With modifying agents, undesired minerals are depressed or rendered non-floatable. Next, a chemical known as a frother is added to create bubbles when subjected to

TABLE I

Summary of Soil Washing Results

Technology	Status	Summary of Results	Ref.
SOIL WASHING Supercritical Fluid Extraction (SFE)	All Bench Scale	73-87% spike recovery for PCDDs and PCDFs; 30-50% recovery for PCDDs and PCDFs from actual soil samples (relative to EPA Method 8290) both using SF-CO_2.	(10)
		>95% of 1000 ppm DDT and heavily contaminated PCBs on top-soil removed in 10-15 minutes with SF-CO_2/5% CH_3OH.	(11)
		92% PAH removed (original concentration, 0.1% total PAH (w/w)) from coal tar contaminated sandy loam soil - 7 hours extraction time with SF-CO_2/5% CH_3OH, 350 atmospheres CO_2 pressure.	(12)
SOIL WASHING Extraction with Surfactants	All Bench Scale	>80% of transmission fluid removed by stirring sandy soil, 4.8%(w/w) automatic transmission fluid (ATF), with 0.5% ethoxylated alcohol (1:21 solid to solution) for 30 minutes	(13)
		99.7% of PCBs, 1150 ppm (w/w) average, removed by mixing clay-like soil in 50mM SDS for 2 weeks (1:8 solid to solution)	(14)
		Surco 233 anionic surfactant - performed well with variety of soils including clays; Triton X100 performed poorly with clays due to adsorption; 96% and 82% of Arochlor 1260 removed with 1% SDBS from test soil and actual site soil, respectively (1:4 solid to solution, 20 minutes mixing time).	(15)
SOIL WASHING Extraction with Base	Pilot Plant Scale	95-99% of cyanides, PNAs, certain chlorinated HCs, and crude oil and about 70% of Zn and Pb recovered using 0.2% NaOH from sandy soil (solid to solution 1:3, mixing time not given)	(16)
SOIL WASHING Extraction with Organic Solvents	All Pilot Scale	PCB levels reduced to 2 and 8% of the original concentration of 300 to 2500 ppm on harbor sediments for 9 and 6 solvent passes, respectively with a liquefied propane-butane mixture	(17)
		PCB levels reduced to < 2ppm in soil after 1 hour extraction with patented solvent blend	(18)
		Authors claim successfully tested in a number of pilot projects on PCBs, PCP, PAH, pesticides, oils, etc. using a nonchlorinated, non-persistent organic solvent blend, Extraksol	(19)
SOIL WASHING Physical Separation	All Field Tested	PAC and CN^- content of sludge reduced 96% and 90%, respectively. (original concentrations were up to 2% PAC and .06% CN^-(w/w)) using high pressure water injection, particle separation, and water treatment in clay, silt, and sand	(20)
		About 100% reduction for PAH, phenol aromatics, PCBs and total cyanide in heavily polluted Berlin soil	(21)
		Reductions of 99-100% (1350 ppm) for PAHs, 80% (77 ppm) for CN^- and 90-100% for As (410 ppm), Cr (1270 ppm), and Hg (680 ppm) in soil near old coking plant in Ruhr area using an attritioner, screening, and pneumatic flotation; $80-90/ton plus disposal	(22)
		94% of PCP, 92-96% of PAH, 94-95% of petroleum HCs, and 45-84% of metals removed for both high and low level samples using scrubbing, screening, and flotation	(23)

TABLE I (Continued)

Summary of Soil Washing Results

Technology	Status	Summary of Results	Ref.
SOIL WASHING Extraction with Acids	Bench scale	The Acid Extraction Treatment System (AETS), using HCl has successfully treated organics, but not fully developed for heavy metals. No results provided.	(24)
	Bench scale	2^{-3}M HCl most effective of those tested for leaching CrO_4^{2-} and Cr^{3+} from soils	(25)
	Pilot scale	2 stage process: 14 VOCs present at concentrations between 1 and 18 ppm and 5 metals present at concentrations between 15 and 2000 ppm in 30 pounds each of 3 silty clay loams (1:3 weight soil: weight water) were reduced to less than 25 ppb (for the VOCs) using batch steam distillation after 10% of condensate was collected and by 53-91% (metals) after mixing for 20 minutes in 2N HCl and washing twice with city water	(26)
SOIL WASHING Extraction with Complexants	Field Tested	BEST process, a mobile solvent extraction system uses one or more secondary or tertiary amines (usually triethylamine (TEA)) to separate organics from soils and sludges; no results provided, but the process has been used at one site and selected for use at 2 others.	(27)
	Bench Scale	Soil is scrubbed with a variety of complexants & emulsifiers; 5 compounds were tested; aniline and benzidine -not detected in the post-treatment sample ; benzene and azobenzene - present at the $< 10^{-4}$ and 10^{-6} cleanup standard before treatment; 3,3' dichlorobenzidine (DCB) - post treatment, 10^{-4} cleanup standard $>$[DCB] $> 10^{-6}$ cleanup standard.	(28)

agitation and aeration. This creates a froth or foam at the top of the flotation machine. The air-avid, water-repellent minerals adhere to the bubbles and rise to the surface where they are collected in the froth and skimmed off.

Advantages	Disadvantages
success depends upon the contaminant being isolated in a particular grain size range that is a small fraction of the total volume	success depends on additives which may not exist for all radiologically contaminated soils

Gravity Separation

Gravity separation techniques make use of the differences in densities of minerals. The techniques are also dependent upon grain size, shape of the grains, and weight of the grains. Gravity separation techniques maintain a slight distance between the grains so that they are able to move relative to each other and thus be separated into light and heavy fractions. The gravity separator devices are classified according to the way they accomplish the spacing between grains.

The type that uses jigs applies a vertical oscillating motion to the solids-fluid stream. Another major type uses shaking tables to separate grains. The tables apply a horizontal shaking motion to the solids-fluid stream by vibration. A third type uses troughs or sluices to maintain intergranular spacing. With these devices, a slurry flowing down an inclined surface is used to maintain the spacing between grains.

Advantages	Disadvantages
economical and simple to implement	ineffective for fine particles
long track record	

Magnetic Separation

Magnetic separation is a technology that has been developed for the separation of contaminated materials on the basis of inherent differences in the magnetic susceptibilities of each material. Magnetic separation has been described by Hoegler (3):

"Magnetic separation is a technique being evaluated for the separation and classification of contaminated materials on the basis of differences in the magnetic susceptibility of the materials' constituents. The technique requires that materials to be separated be reduced to discrete particles of differing magnetic susceptibility, which is a characteristic property of all materials. The magnetic susceptibility of a particle is determined by the susceptibilities of the elements and/or compounds that compose that particle. Two approaches to magnetic separation were used in this study to examine its application to the separation of paramagnetic contaminants from Department of Energy (DOE) waste materials. Particles having an overall positive magnetic susceptibility can be entrapped and retained on a magnetized matrix, while the balance of the material is repelled from the matrix or is unaffected. This will be referred to as "matrix-induced gradient magnetic separation " (MGMS). "Dynamic" or "deflecting

magnetic separation" (DMS) is based on the deflecting of particles by a magnetic gradient, according to their magnetic susceptibility. The sign of the susceptibility determines the direction of the deflection. Particles with a positive susceptibility (paramagnetic) are deflected upgradient toward the region of highest field strength; those with a negative value (diamagnetic) are repelled downgradient from the highest field strength; and those with a near zero value are essentially unaffected. Hence, a stream of materials to be separated by DMS is spread into a continuous spectrum that reflects the range of susceptibilities present in the materials."

Results of bench-scale testing of magnetic separation of uranium from solid MgF_2 samples have been reported by Hoegler (3). These results demonstrate that there is potential to significantly reduce the volume load on the chemical uranium recovery process currently being used on one DOE site. An optimization of the magnetic separation process is being pursued so that a significant fraction of the waste stream can be reduced in uranium content to levels which will comply with state and federal regulations for on-site burial. To date, the DMS method has been demonstrated to be more successful than the MGMS method.

At the Feed Materials Production Center (FMPC) in Fernald, Ohio, magnetic separation has been demonstrated to be a possible solution for the significant problem of separating uranium from MgF_2. However, every site will be unique and should be investigated on a site by site basis. Hoegler (3) lists the sites that have been examined for potential use of magnetic separation technology. Of the 19 sites investigated only the FMPC site showed promise for further study.

Advantages	Disadvantages
separates uranium from MgF2	not considered effective on most of the soils

SOIL WASHING - CHEMICAL EXTRACTION PROCESSES

Chemical extraction processes are used to concentrate mixed waste contaminants so that the volume of soils which must be disposed in a controlled facility is reduced. The cleaned soils may be returned to the site from which they were obtained. A great deal of care must be taken to determine how much unextractable mixed waste contaminants are present. Universal regulatory standards for returning the "cleaned" soil to the excavation site do not presently exist.

There have been eight types of chemical extraction techniques proposed for remediation of contaminated sites: 1) extraction with water has been bench scale tested; 2) extraction with inorganic salts has been bench scale tested; 3) extraction with mineral acid has been field demonstrated, 4) extraction with complexing agents has been field demonstrated, 5) supercritical fluid extraction (SFE) has been commercially tested, 6) extraction with surfactants has been bench scale tested, 7) extraction with base has been field tested, and 8) extraction with organic solvents has been pilot scale tested. None of the chemical extraction techniques have yet to be used to remediate a radiologically contaminated site.

Extraction with Water

Chemical extraction with water can be used to separate contaminants from soil by "scrubbing" and rinsing the particles using high pressure water injection (HPI), attrition drums, and ultrasonic devices. The mixed waste can then be extracted from the water by coprecipitation, solvent extraction, or by ion exchange. Physical separation, mentioned earlier, can also be utilized to concentrate the hazardous material. Vibratory sieves, oscillators, hydrocyclones, and flocculation/skimmer tanks are often used. The extracted material must then be disposed of permanently.

The many studies conducted to determine the feasibility of water extraction of contaminants from soils have found the liquid to solid ratio (L/S) to be the dominant factor. Decontamination effectiveness normally increases with increasing L/S ratios. For example, with the radium cation in mill tailings, a L/S of 10/1 was necessary for 0.04 percent removal efficiency, 100/1 for 1.24 percent, 1,000/1 for 23.2 percent, and 10,000/1 for 40 percent, according to Shearer and Lee (4). These results were attributed to the relatively insoluble nature of barium-radium sulfate ($Ba(Ra)SO_4$), the most common form of radium in mill tailings.

Additional results for this technology are presented in Table I under extraction with water.

Advantages	Disadvantages
very inexpensive	requires large quantities of water
completely nontoxic	ineffective for common radionuclides
uses ambient temperatures	
uses simple extraction vessels	
dissolves some radionuclide salts	
removes organics from larger particles	
can be used as a pretreatment	

Extraction with Inorganic Salts

Laboratory experiments have been done to demonstrate the feasibility of extracting contaminants from soils and uranium ore tailings with inorganic salts. The process involves the thorough mixing of the salt solution and the solids followed by filtering of the solids to remove the solution. The contaminants are removed from the solution by ion exchange, coprecipitation, or membrane filtration.

There have been variable results reported in the literature regarding the effectiveness of this process. In general, the process appears to be affected by the nature of the tailings or soil, the concentration of the salt solution, temperature, pH, liquid to solid ratio, time, and temperature. Increasing the ratio of the salt solution to solid has a positive effect in removing radionuclides from ore tailings and soils. Use of multistage extraction has also been beneficial.

In uranium mill tailings for example, since radium sulfate is insoluble, the presence of sulfate reduces the effectiveness of the technique for radium. Hydroxide is the analagous anion in thorium chemistry because thorium hydroxide is the least soluble thorium compound. Essentially, the ability of a salt solution to extract radium or thorium is primarily reflected in the solubility of the compound or complex that it forms with radium or thorium. According to Silver and Anderson (5) the

radium extraction power of several anions decreases as follows: $Cl^- > NO_3^- > HCO_3^- > HO_4^- > PO_4^{-3}$. Nirdosh, et al. (6) reported that the ability of cations of various salts in releasing radium decreases as follows: $Cs^+ \sim Ca^{+2} > Mn^{+2} > NH_4^+ > K^+ > Na^+ > Li^+$.

Advantages	Disadvantages
high percentage of radium and thorium can be removed from tailings	large amounts of salts may be required for high L/S ratios
most salts are innocuous	some salts may be toxic
simple extraction vessels can be used	
recycling of salts may be possible	

Extraction with Mineral Acids

Extraction with mineral acids has been used extensively in the mining industry to extract metals from ores. As an example, the primary acids for extracting radium from carnotite are sulfuric acid, hydrochloric acid, or nitric acid. Increased concentrations of nitric acid or hydrochloric acid will promote the dissolution of barium-radium sulfate. Thorium has generally been extracted from ores with fuming sulfuric acid or nitric acid. Hydrochloric acid is also effective in removing nonradioactive toxic metals. Heating the acids before soil treatment has been shown to be beneficial. The combination of dilute acids and inorganic salts has been demonstrated to work better than concentrated acids alone. Results for this technology are presented in Table I.

Advantages	Disadvantages
high percentage of radium and thorium can be removed	expensive reagents required
uranium and other metals may be removed	high temperatures may be required
low L/S ratios may be used	stainless steel reaction vessels may be required
some acids may be recycled	multi-stage processes are likely to be required
NO_3^- or Cl^- may be introduced to the environment	

Extraction with Complexing Agents

The effectiveness of extraction with complexing agents depends upon the solution pH, temperature, concentration of the wash solution, and reaction time. The most common complexing agent used has been ethylenediaminetetraacetic acid (EDTA). Above a pH of 3, thorium forms an insoluble hydroxide which competes with the thorium EDTA complex. The leaching of radium with EDTA is generally conducted at a pH of 8 to 10. The optimum chelant concentration has been shown to be a 3:1 ratio of EDTA:total contaminants on a molar basis, according to Esposito, et al. (7). This combination will remove 90-99% of volatiles in all size fractions and semivolatiles in the >2mm size fraction. This drops considerably to 47-67% for semivolatiles (or less for certain soils) in the 250 um-2 mm size fraction. Other complexing agents of interest are citric acid, hydroxyethylenediaminetetraacetic acid (HEDTA), and oxalic acid. A summary of additional results for this technology is provided in Table I.

Advantages	Disadvantages
high percentage of radium removed	reagent (EDTA) is expensive
low concentration of reagent may be used	multi-stage is likely required
ambient temperatures are used	thorium is not removed from tailings
reagent is relatively innocuous	
reagent may be recycled	
expensive reaction vessel is not required	

Extraction with Surfactants

This technique has been widely used due to the ability of the surfactant to solubilize hydrophobic organic contaminants, such as PCBs, insecticides, and other volatile and nonvolatile organics. Surfactants are primarily organic molecules with charges on either end or a high percentage of polar groups. This duality allows the surfactant to solubilize organic and aqueous liquids. Typical anionic surfactants are sodium dodecyl sulfonate (SDS) and sodium dodecyl benzene sulfonate (SDBS). Nonionic surfactants are ethoxylated alcohol or nonylphenol. Variables which can be adjusted prior to extraction are the soil particle size fraction, pH, temperature, concentration of wash solution, and reaction time. Surfactant selection is based on its solubility in oil and water, critical micelle concentration (CMC), detergency, oil dispersion, particle dispersion, emulsification, foaming, wetting, and other properties. Solubilization of organics increases dramatically in the presence of a surfactant whose concentration is at or above the CMC, since it is the micelles which "dissolve" the organic material. Dispersion of colloidal size particles caused by addition of certain surfactants is unfavorable since they can clog soil pores and reduce flow. The surfactant can be regenerated using countercurrent extraction with hexane to remove nonvolatile contaminants. Results of extraction with surfactants is provided in Table I.

Advantages	Diasadvantages
contaminants can be solubilized into aqueous solution	extra cost if surfactant is not recycled
can be used for variety of hydrocarbon types	extra step required to recycle or destroy surfactant
	some surfactants are contaminants

Extraction with Supercritical Fluids

Supercritical fluid extraction (SFE) takes advantage of the fact that gases take on favorable solvating properties above their critical point because of their low viscosity and high solute diffusivity. Two such gases are CO_2 and N_2O. Several studies show that use of a polar modifier such as methanol greatly improves extraction efficiency. These studies tested

PAH, DDT, PCDDs and PCDFs. Matrix effects, such as adsorption by active sites and physical entrapment, will reduce the percentage of contaminants extracted. The cost of SFE is estimated by Knopf, et al. (8) to be approximately $100 per cubic meter. Results of soil remediation with SFEs are summarized in Table I.

Advantages	Disadvantages
extracting fluid is easily removed or regenerated	SFE efficiencies are too low for some compounds
does not use any toxic organic solvents	

Extraction with Base

Soil cleaning using counter-current flow and 0.2% NaOH has been identified by the EPA (9). Organic bromine, cyanide, PNAs, and some chlorinated hydrocarbons were removed from soil. The process also includes separation of coarse materials, separation of finer particles using hydrocyclones, and dewatering. The cost of the process is estimated to be $45 to $75 per ton. Removal of organics including PCBs using tertiary amines like triethanolamine (TEA) shows great promise. TEA is completely soluble in water below 20°C. Results for this method of soil washing are presented in Table I.

Advantages	Disadvantages
can remove large fractions of metals and organics	has not been used enough to gain wide acceptance

Extraction with Organic Solvents

This process typically uses an organic solvent, solvent blend, or liquefied gas solvent to remove organics from sludges and soils. Residual solvent is removed by heating with steam or hot air and collected by condensers for reuse. The contaminants are thus concentrated from a high volume solid waste stream to a low volume liquid waste stream. The residual solvent remaining on the soil is usually removed by steam stripping. This method has been successfully used on debris such as metal foil and paper as well as sand, clay, and sludges to remove a variety of organics: PCBs, PAHs, PCPs, solvents (chlorinated, aliphatic and aromatic HCs and alcohols), organic acids, oil, and grease. Results of studies utilizing organic solvents in washing soils are given in Table I.

Advantages	Disadvantages
effectively concentrates contaminants into a small volume	solvent vapors can pose a health risk
can remove a wide variety of organics	some solvents are contaminants
can be used on a wide variety of soils	solvents are expensive

SOIL WASHING - WET OXIDATION

Extraction and destruction of organics with hydrogen peroxide, known as wet oxidation, has recently been developed on a laboratory and pilot scale. Wilks and Holt (29) report that a research program was initiated in 1987 to examine various means of organic waste destruction. The program quickly developed by showing promising results with a number of materials of interest to the nuclear industry, in particular, ion exchange resins and organic decontamination liquors in waste sludge from the Steam Generating Heavy Water Reactor (SGHWR) in Dorset, England. The program developed from laboratory active and inactive trials to the operation of a 10 kg scale pilot plant to the construction of a 200 kg scale demonstration plant.

The wet oxidation process consists of oxidizing the organic material with hydrogen peroxide in the presence of a suitable catalyst. The process then proceeds by breakdown of the hydrogen peroxide and subsequent reaction of the free radicals which are formed with the organic materials. The primary products are carbon dioxide, water, and inorganic salts or acids generated from the functional groups present.

The primary by-product of the reaction is oxygen, which is generated by the competing self-decomposition reaction of the hydrogen peroxide. The efficiency of the reaction can be measured by the proportion of carbon dioxide to oxygen in the off-gas.

The process is analogous to incineration except that oxygen is supplied by the hydrogen peroxide instead of in molecular form. The process differs from incineration in many important ways: 1) the reaction conditions are relatively mild (100°C temperature and atmospheric pressure), 2) formation of corrosive products from functional groups occurs under less severe conditions, 3) minimum requirements for off-gas treatment, 4) applicability to materials and mixtures of low calorific values, and 5) materials such as plastics and oils, which are readily incinerated, are difficult to treat with wet oxidation.

Initial results of the wet oxidation process reported by Wilks and Holt (29) showed a volume reduction factor of 2.5 for the SGHWR sludge. This factor should vary with the amount of organic content in the waste stream. A 99% carbon removal was also achieved. Results for other waste forms should be available after a 1/15th full scale of the proposed active facility has been completed.

The wet oxidation technology will likely be applicable to mixed wastes with high organic contents and low calorific contents.

Advantages	Disadvantages
volume reduction factor of about 2.5	not applicable for oils and plastics
reduced organics for final disposal	requires excavation
potentially economical treatment	
relatively less severe operating conditions than incineration	

SOIL FLUSHING

Soil flushing relies on the same principles as the chemical extraction processes described for soil washing, except that soil flushing is conducted in situ. Extractants are injected into the ground through wells and conventional extraction wells are used to retrieve the mobilized contaminants. The wastewater is then treated and the resultant clean water reinjected upgradient of the contaminated area. Soil flushing

is not a good choice for soils with high organic content or too low or too high a permeability (high clay and silt or high sand). The best soil is one with about 20 to 25% clay in sand. Surfactants are frequently employed, however one of the main challenges in using them is to prevent the surfactant micelles and dispersed soil colloids from clogging soil pores. Use of an alcohol ethoxylate surfactant is a good way to avoid this. Also, the surfactant must be removed and preferably recycled from the resultant wastewater. This can be achieved by gentle extraction with a nonpolar solvent such as hexane. Soil flushing has the greatest potential on soils contaminated with only a few chemicals since it is contaminant specific. One cost estimate was provided by Wessling (30) for a study in which a gas stream enriched with ozone was injected into soil and the volatile hydrocarbon-ozone mixture was pumped through a carbon filter. The cost is $30 to $175 per ton depending on the pollutant concentration. A summary of soil flushing studies results is provided in Table II.

Advantages	Disadvantages
contaminant removal in situ, no soil excavation required	hydraulic control required
	only applicable to certain kinds of soil
	soil/solvent interactions may reduce contaminant mobility
	highly toxic or volatile solvents present health risks

ULTRASONIC DETOXIFICATION

Transformation of toxic compounds takes place at the gas-liquid interface of bubbles formed by the ultrasonic signal. It is actually the collapsing or cavitation of these bubbles and the resultant localized high pressure and temperature generated which gives rise to this phenomenon. Usually piezoelectric transducers positioned at the bottom of a reaction vessel provide an acoustical signal (typ. 40 kHz, 2 watts/cm^2 delivered). In one study, Trinity Environmental Technologies, Inc. (33) state that they were able to dehalogenate PCBs in mineral oil on a variety of solids at a cost of $150 to $200 per cubic yard. The PCBs were first extracted from the solid using multi-stage countercurrent extraction. Subsequent sonication reduced the PCB level from 100 ppm to 25 ppm in 5 minutes. Trinity claims this process will work on virtually any chlorinated hydrocarbons, including pesticides, herbicides, PCP, PCDDs and PCDFs. A pilot study is planned by the end of 1991 with the capacity to treat 1 to 10 tons of contaminated soil/hour.

A second study by Sadeghi, et al. (34) used a dilute alkali solution plus a small quantity of hydrogen peroxide to sonicate and remove bitumen from coal tar sands. A secondary benefit of this process was the generation of surfactants, which in turn could be used to remove organic material from coal tar sand. A dilute alkali/surfactant - tar sand (approx. 4:1 by wgt.) solution to which 5 drops of 30% H_2O_2 was added was sonicated from 10 minutes to 6 hours, depending on the soil type and level of contamination. Four out of six tar sands had >92% recoveries of organic material. These included hydrocarbons floating on the surface or solubilized.

Advantages	Disadvantages
no toxic or hazardous byproducts	one study used organic solvents to extract PCBs; potential health risk
cheaper than incineration	

ELECTROKINETICS

Electrokinetics is an effective method for processing soils and has been studied and utilized for the past fifty years for dewatering of soils and sludges, removing salts from agricultural soils, increasing petroleum production, etc. Although it has not yet been used for the remediation of radioactive sites, electrokinetics has been used for decontaminating hazardous waste sites in the Netherlands and various laboratory and field experiments in the U.S. have demonstrated positive results for removing contaminants from soils. It has been proposed that

TABLE II

Summary of Soil Flushing Results

Technology	Status	Summary of Results	Ref.
Soil Flushing	Pilot Plant	98% reduction in PAH and mineral oil concentration over 20 days	(30)
Soil Flushing	Bench Scale	Rate of equilibration of contaminant between surfactant and soil surface was a limiting factor; i.e., residence time is the key; 20-25% clay in sandy soil allows surfactant to move through slowly enough; solubility enhancements of 20-100 over water alone were achieved using 100 mM sodium dodecyl sulfate (SDS)	(31)
Soil Flushing	Field tested	Sandy soil polluted with 20 ppm cadmium (Cd) was cleaned by percolating water acidified to pH 3.5 with HCl to a depth of 25-30 meters. The percolate was pumped into a cleaning installation where the Cd was removed with GT-73 resin. The acidic water is then recirculated until the Cd reaches a constant low level. Treatment is going well with the ion exchange resin showing good performance. Expected treatment time: 150-180 days. No results/status were provided.	(32)

electrokinetics be investigated for the purpose of remediation of radiologically contaminated soils by Coe and Steude (35). Since electrokinetics has been demonstrated to be most effective at removing heavy metals from soils, it will likely be effective on certain radionuclides which also have metallic properties.

Electrokinetics is performed by passing a low DC current through a soil mass between positive (anodes) and negative (cathodes) electrodes. This induces an electrical potential and associated matrix potential (pressure head). When soil is subjected to a direct current voltage, it has been observed that the groundwater near the anode becomes acidic and the groundwater near the cathode becomes basic due to oxidation and reduction, respectively. Acar (36) has postulated that this pH gradient is the driving mechanism for the electrokinetic process. As the acidic groundwater passes through the soil pores toward the cathode, cations are desorbed from the soil surfaces and transported along with the groundwater. Contaminants can be removed from the soil by pumping the groundwater near the cathode. Some contaminants will electroplate onto the cathode and are removed when the cathode is removed. Water or proprietary fluids are injected at the anode to maintain saturation of the soil and control the pH of the groundwater.

The groundwater flow has also been postulated to be due to a momentum transfer imparted by ions onto the water according to Gray and Mitchell (37) and Mitchell (38). This flow is known as electro-osmotic transport. Electrolysis, or movement of ions within the groundwater, also contributes to the migration of the ions.

Sites that are candidates for remediation with electrokinetics can be composed of fine-grained or coarse grained soils. The electrokinetics method is particularly useful for sites with fine grained soils. The soils to be treated should be saturated. There is a loss of efficiency with decreasing partial saturation. Electrokinetics is particularly appropriate for soils that are saturated with groundwater or water from surficial sources such as rivers, lagoons, and bays. It is also feasible to artificially recharge sites with low groundwater tables.

Results from previous investigations indicate that electrokinetics shows potential for mobilizing heavy metals and polar organic contaminants. However, there has been relatively little done to investigate the effects on non-polar organics which may be mixed with the radiological contaminants. The most significant results have been that electrokinetics can desorb heavy metals. Since electrokinetics shows potential for decontaminating heavy metals from soils, it will likely be applicable for radiologically contaminated sites.

Lageman (39) of Geokinetics, Inc. in the Netherlands has reported promising results with electrokinetics. Laboratory experiments in clays showed that copper concentrations could be reduced from 1000 ppm to 100 ppm in 160 hours. Cadmium concentrations in clayer sand was reduced from 275 ppm to 40 ppm in 360 hours. During a field experiment beside a ditch at a former paint factory, concentrations of lead and copper were reduced in varying amounts from 50 to 94 percent. Beginning concentrations for lead were greater than 5000 ppm and beginning copper concentrations were as much as 1170 ppm. The duration of the experiment was 430 hours. In the first full-scale remediation project at a wood treatment facility, 25 to 30 kg of arsenic was removed and the average concentration was reduced from 110 ppm to below the required 30 ppm concentration.

Laboratory electrokinetic experiments with a mixture of sand, silt, and clay yielded a 97.4% reduction in cadmium concentration and a 92.3% reduction in zinc concentration, according to Muralidhara (40). The beginning concentrations averaged 1093 ppm and 920 ppm for zinc and cadmium, respectively.

The results of chemical analyses of composited samples from 60 dewatering tests in dredged soils were presented by Segall, et al. (41). The samples were taken from electrokinetic effluent water which had accumulated at the electrodes. A comparison between the electrokinetic effluent and the leachate from the dredged soils indicated that:

1. The electrokinetic effluent contained significantly more heavy metals (except cadmium and nickel) and organic compounds than was present in the original leachate.
2. The concentrations of mercury, lead, arsenic, and zinc were particularly higher in the electrokinetic effluent.
3. The total organic carbon content in the electrokinetic effluent was two orders of magnitude higher.
4. The chloride concentration decreased in the leachate by an order of magnitude.
5. Pesticides were directed toward the cathode.

Laboratory experiments were performed and reported by Khan, Pamukcu, and Kugelman (42) to determine the optimum operating voltage for electrokinetic flow experiments with Li_2CO_3 and NaCl. Their results showed that approximately 70 volts was optimal for their experiments. They also concluded that no change in pore structure occurred by reversal of the current.

Jacobs and Mortland (43) investigated ion transport in Wyoming bentonite with electro-osmosis. Their results showed that all Na^+, K^+, Mg^{++}, and Ca^{++} ions could be removed by electro-osmosis.

Laboratory experiments by Renaud and Probstein (44) demonstrated that acetic acid (CH_3COOH), a polar organic solution, is more efficiently mobilized than sodium chloride (NaCl), a dissociated salt. This is highly significant because the properties of acetic acid are representative of other toxic organic acids (formic, propionic, valeric, butyric, glutaric, glycolic, and benzoic) commonly found at hazardous waste sites. Acetic acid concentrations are especially high in municipal sewage.

The costs for in situ decontamination of soils with electro-osmosis can likely be much less than other techniques. Lageman (39) has estimated that the costs of electrokinetic treatment will range between $50 and $400 depending on the contaminant concentrations and the time allowed to complete the cleanup. Using more electricity can speed up the process but is less cost-efficient.

Advantages	Disadvantages
will be inexpensive to apply	chemistry and physics is not well understood

desorbs heavy metals from soils	applications will require extensive research is necessary training to validate effectiveness at sites
may be applied to many contaminants including both organic and inorganic	
electrokinetic fluid conductivity is much greater than hydraulic conductivity in clays	
electrokinetics is an in situ technology	

IN SITU SOIL VAPOR EXTRACTION

Soil vapor extraction (SVE) is an economical technology for removing volatile and semi-volatile organic contaminants from the vadose zone. It is also reported by Malot (45) that SVE is an effective method for removing liquid-phase hydrocarbons floating at the top of the water table. By applying a vacuum pressure to the subsurface through extraction wells, vapors flow through the unsaturated zone and are brought to the surface. Organic contaminants are volatilized from the soil and are carried along with the vapor flow. The factors affecting SVE have been documented by the EPA (46).

An SVE system can be coupled with other technologies such as steam stripping in order to expedite the cleanup process and reduce the unaffected residual contamination. Examples of steam stripping projects in progress have been reported by AWD Technologies, Inc. (47) and Lord, et al. (48). In situ radio frequency and in situ soil heating technologies can also be coupled with SVE. These technologies are described in the following sections.

A basic SVE system includes recovery wells connected to a vacuum source for pulling vapors from the vadose zone. The vacuum source can be positve displacement blowers or vacuum pumps. More complicated systems can incorporate trenches for shallow contamination, air injection wells, passive wells for inflow of air, and surface seals. The effluent vapors can be put through air/water separators and off-gas treatment systems that condense, adsorb, oxidize, or incinerate vapors. In some cases, the vapors are simply released to the atmosphere through diffuser stacks.

A full-scale SVE system with 23 vapor extraction wells connected to a carbon adsorption and catalytic oxidation off-gas treatment system was operated in the vicinity of a solvent distribution facility according to Danko, et al. (47). In 252 days of operation, approximately 43,000 pounds of chlorinated solvents and volatile organic contaminants were removed from the subsurface. A pilot-scale SVE system has been reported by McConachie (50) to have removed 5,000 gallons of gasoline from a spill site in 2360 hours of operation.

Many projects have been completed or are near completion using the Terra Vac SVE system, according to the EPA (51). At a Superfund site in Puerto Rico that was contaminated with carbon tetrachloride solvent, the process removed up to 800 lb/day of the solvent. More than 80% of the spill volume was recovered and groundwater concentrations were reduced by 95% to 99%. A Superfund site in Pennsylvania was remediated to standards set by the EPA Record of Decision. At this disposal area, 150 lb/day of benzene, toluene, xylenes, TCE, PCE, and trichloropropane were removed. The system was used to successfully cleanup a gasoline spill in Florida to a 1 ppb standard for benzene. At a Michigan site contaminated with PCE and TCE, the system was used to achieve a 5 ppb cleanup goal. A pilot test in South Carolina demonstrated removal of 250 lb/day of PCE and TCE in highly stratified sediments to a depth of 120 ft. At a leaking tank site in Puerto Rico, the system recovered 1400 gallons of gasoline and reduced the hydrocarbon concentrations in the surrounding soil from 600 ppm to nondetectable.

The costs for Terra Vac system have been estimated by the EPA (51) to average approximately $50/ton. Costs for a large remediation project (> 100,000 tons) can be as low as $10/ton, and for a small spill site project (≈ 10,000 yd^3), as high as $150/ton.

Advantages	Disadvantages
SVE system designs are not complicated	residual contamination may not be removed
necessary equipment is readily available	
inexpensive	
does not interfere with continued use of a site	

IN SITU HOT AIR/STEAM EXTRACTION

The in situ hot air/steam extraction technology removes volatile organic compounds, and to a limited degree, semi-volatile organic compounds (VOCs) from soil as reported by La Mori (52). The treatment is accomplished by injecting hot air and steam into the soil through two 5 ft diameter counter rotating blades that are attached to drill stems. The soil is cleaned as the drill stems and blades are advanced into and retracted from the ground. The vapors produced are trapped at the surface in a shroud covering and recovered by condensation and carbon absorption. The recovered contaminants can be either reprocessed or destroyed.

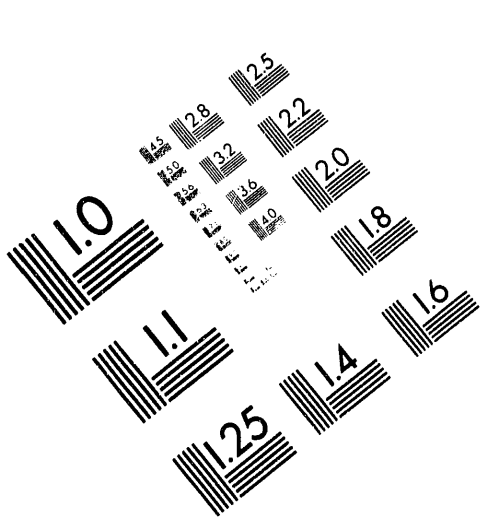
The initial use of the prototype rig demonstrate that 85% to 99% of chlorinatated VOCs were removed from clay soils. The goal of 100 ppm concentrations was achieved 80% of the time. The technology also removed 50% of the semi-volatile organic compounds present.

No projected cost information was found during the literature research.

Advantages	Disadvantages
does not require excavation	limited to shallow depths
amenable to solidification additives	limited success with semi-volatile compounds
amenable to nutrient additives for bioremediation	

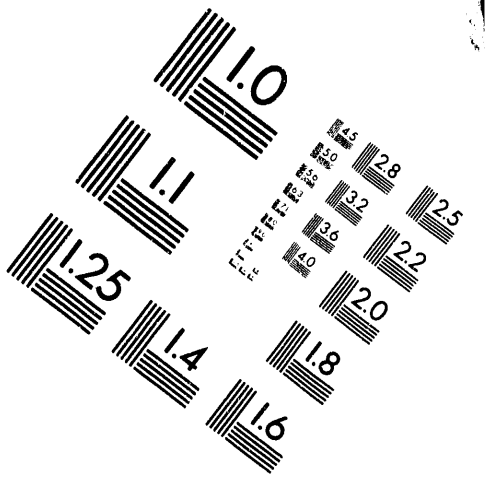
IN SITU RADIO-FREQUENCY

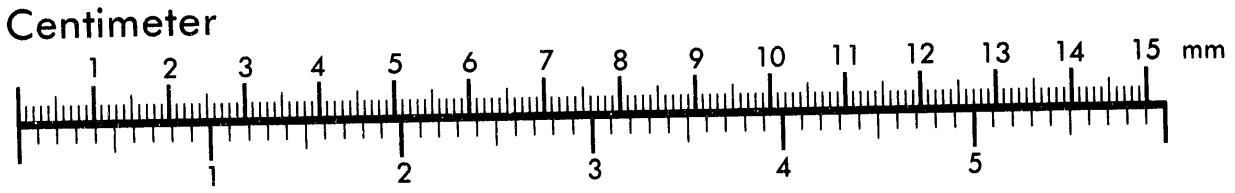
The in situ radio-frequency (IRF) process was developed by IIT Research Institute (IITRI) for treating hazardous waste contaminated soils and was subsequently licensed to Weston, Inc. for commercial applications. The original application for IRF was separating hydrocarbons from tar sands. Since the IRF process has demonstrated potential for treating

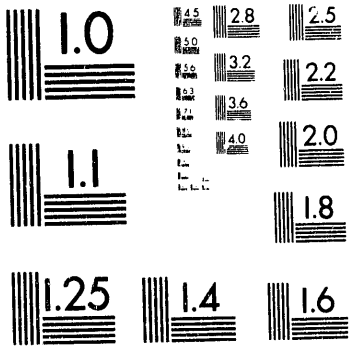


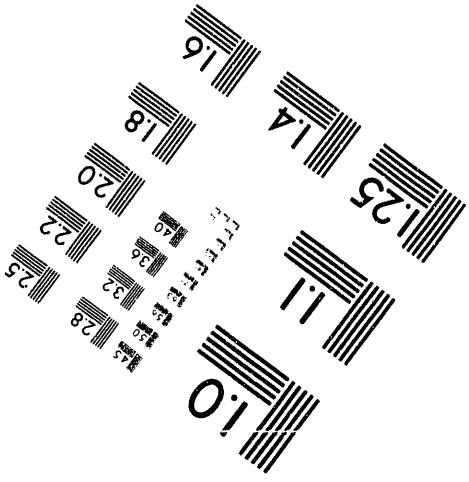


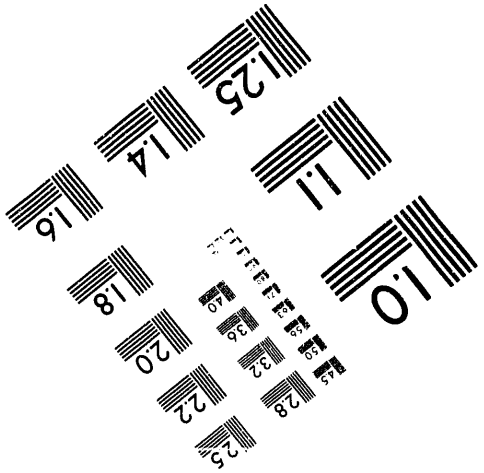
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6 of 10

soils with organic wastes, it is proposed here that IRF be used to reduce the character of the waste from mixed waste to radiological waste. The IRF process was originally designed by IITRI to extract useful fuels from oil shale and tar sand deposits.

The IRF decontamination process involves the insertion of tubular electrodes (hollow pipes) directly into contaminated soil. The electrodes are then excited with radio-frequency energy which can heat the soil and contaminants to temperatures ranging between 200°F and 1,000°F. This causes the volatile contaminants to vaporize. The vapors are then collected in the hollow electrode pipes under negative pressure. Finally, these vapors are transferred to a vapor treatment system.

In a field test conducted at Tyndall Air Force Base, Florida, the IRF processed was used to heat a 6 ft x 12 ft x 7 ft (approximately 500 cubic feet) block of soil to a temperature range of 150°C to 160°C. The site had been contaminated with jet fuel released during fire training exercises. Results of numerous pre-test and post-test soil analyses were reported by Dev and Downey (53). These results indicate that an average of 99.5% of the volatile aromatics and aliphatics were removed and an average of 99.2% of the semi-volatile aromatics and aliphatics were removed. The heating stage of the field test lasted 12.5 days while the cooling stage to a temperature of 50°C to 60°C took 17 days.

The IRF treatment process has been demonstrated to be applicable for sites containing jet fuel, gasoline, and other similar contaminants. Therefore, IRF treatment will likely have potential for radiologically contaminated sites containing similar types of mixed wastes.

The costs of IRF have been estimated to be very economical in comparison with other remediation techniques. It has been estimated that the costs of the IRF process will range from $50.00 to $90.00 per ton of treated soil.

Advantages	Disadvantages
economical	doesn't remove metals
in situ technique	volatiles may carry radionuclides from soil
appropriate for volatile mixed wastes	vapor treatment system may need to be redesigned to handle radionuclides

IN SITU HEATING

In Situ Heating (ISH) is a novel technology being developed by Battelle Pacific Northwest Laboratory for extracting and destroying organic contaminants in place. According to Heath, et al. (54), it is a two-fold process. First, an electrical soil-heating system is used to remove soil moisture and volatilize organic contaminants. Second, an air-ion system is used to generate free radicals that will attack and degrade the organic contaminant molecules. An off-gas system is used to control subsurface vapor flows and to provide secondary containment during soil processing.

The soil-heating system is a hexagonal array of electrodes that are inserted in a contaminated area to the lowest depth of the contamination. Multiple arrays are used to cover larger areas of contamination. The electrodes are connected to an electrical power supply. The electrodes are energized with high-voltage, low-amperage electrical current. The energized electrodes discharge electricity through the contaminated zone to an electrode in the center of the array that is electrically grounded. Over time, the electrical discharges heat the soil, remove the moisture, and volatilize the low-boiling point organics.

When most of the soil moisture is removed, the drier zone becomes more permeable to air flow. The electrodes are hollow and act as transport vents. A vacuum pressure is applied to the center electrode(s) to pull the volatilized species to the center of the heated mass and up to the surface. Ambient air is fed into the peripheral electrodes to provide a source of oxygen for generating destructive air ions which are distributed to the contaminated zone by the net flow of air toward the center electrode. In the presence of air and moisture, a direct current discharge has been shown to create superoxide radicals and ozone. The exposure of these air ions to the soil causes reactions and degradation of semi-volatile and non-volatile organics. The reactions serve to reduce the molecular weight of the contaminants and increase their volatility.

Laboratory results derived with an experimental air-ion apparatus indicate that a wide variety of organic compounds (e.g., acrylamide, styrene, chlorobenzene, benzene, benzoic acid, chloroform, citric acid, and phenol) in the liquid phase can be destroyed by the superoxide ion.

Bench-scale tests with a 1-kW soil-heating system have demonstrated the potential of ISH for removing organic contaminants from sands, clays, and loams with moisture contents ranging from 10 to 55 weight percent. Tests were conducted with trichloroethane, orthochloro-phenol, hexachlorobenzene, dodecane, butylbenzene, and chloronapthalene. In all cases, the process was shown to be capable of removing varying amounts of these organics in a period of hours. Greater than 99 % of volatile trichloroethane was removed from sand. Semi-volatile orthochlorophenol was removed from all three soil types with an efficiency of 99.5 %. Chloronapthalene, a solid at room temperature, was removed with only 25 % efficiency.

A pilot-scale system has been designed with a 50-kW soil-heating system. It includes an off-gas system consisting of a water-cooled shell-and-tube heat exchanger, a carbon adsorption bed, and a wet scrubber. A field test of ISH is expected to be conducted next year.

The cost of ISH estimated to range between $40 to $100 per ton of soil.

Advantages	Disadvantages
economical process for removing organics	does not affect metal contaminants
does not require excavation	
operates at low temperatures	

LOW TEMPERATURE THERMAL TREATMENT PROCESSES

Thermal Separation Plant

Mixed wastes can be rendered radiological waste by destroying the chemical contaminants of concern. For organic contaminated waste, the organics may be destroyed using thermal processes. The thermal separation plant utilizes

indirect heat transfer at low temperatures (100°C to 600°C) to volatilize organic materials such as solvents, petroleum products, or sludges to separate them from less volatile soil materials for subsequent treatment as separate waste streams. Since this method does not involve the direct contact of the mixed waste stream with a flame, off-gas and fine particulate matter produced from this thermal treatment are minimal. This reduces the amount of fine, radiologically contaminated particles which are a primary concern with incineration techniques. However, the off-gas stream will still need to be adsorbed onto carbon or incinerated in an afterburner.

A pilot plant owned by the IT Corporation has been constructed and demonstrated for the treatment of radiologically contaminated soils containing mixed wastes. Results have been presented by Troxler, et al. (55) for two pilot studies conducted in April and August of 1988, respectively. These results indicate that the thermal separation pilot plant can separate PCB and other organic wastes from a mixed waste allowing the treated soil to be handled as a low-level radioactive waste. Most of the metals, including uranium, were concentrated in the treated soil as the volatile components of the soil were driven off.

The thermal separation pilot plant is briefly described by Troxler, et al. (55) in the following excerpt:

"The thermal separator pilot-plant utilizes a 16 cm diameter by 3.3 meter long rotating alloy tube, with the middle 2 meters of the tube enclosed in a natural gas fired furnace. The initial and final sections of the tube are used for feeding and cooling solids, respectively. The flow rate and residence time of the solids traveling through the thermal separator can be controlled by varying the inclination of the tube and by controlling the rotational speed. The temperature of the solids inside the tube is measured by a series of thermocouples that extend within the tube. The system is continuously purged with nitrogen to maintain the concentration of oxygen below a level that will support combustion. Up to 70 kilograms per hour of solids are fed to the thermal separator using a hopper and screw conveyer. Treated material is collected in a sealed metal can."

"Organic materials (and volatile inorganics such as mercury) are vaporized from the feed material and are exhausted to a downstream treatment device. The off-gas treatment system can consist of either a secondary combustion chamber and conventional air pollution control devices or a series of physical/chemical treatment unit operations. The off-gas treatment system that is used with the pilot thermal separator consists of a cyclone, a wet scrubber, a demister, a HEPA filter, and carbon adsorption system."

The pilot studies reported by Troxler, et al. (55) provide the results of thermal separation treatment on radiologically contaminated soils from the University of Minnesota Rosemount Research site and from the DOE uranium enrichment facilities. This is the only citation available since this technology has only recently been developed. These soils initially contained high concentrations of PCBs. The conclusions of the pilot studies are: 1) thermal separation can separate PCB and other organic contaminants from soils in a mixed waste stream, 2) the treated soil contained less than 2 ppm of PCBs, 3) the PCB's were readily condensed in the scrubber system, 4) all identified volatile and semivolatile components in the waste stream were treated to levels below detectable limits, 5) mercury contamination was found to be 0.8 ppm before treatment and 0.1 ppm after treatment during one pilot test run, 6) most metals were found to be concentrated in the treated soil, and 7) the majority of the uranium and technetium contaminants remained in the treated soil.

Sites that contain soils contaminated with mixed wastes, especially soils with high organic content, are good candidates for thermal separation treatment. The soils treated in the pilot tests included fill material, organic soil, and a sandy soil. The technology was effective with these types of soil and it is likely to be effective for a wider range of soil types. In addition, this technology could be used with solid mixed waste, such as glassware, to volatilize the hazardous components rendering a small volume for disposal.

The technology can be designed into a mobile unit according to Troxler (55). A mobile unit could be used for smaller sites or a permanent unit could be constructed near a large site or many small sites. Otherwise, transportation costs for a large quantity of soil over a long distance to the treatment site could be a disadvantage of the thermal separation plant.

Advantages	Disadvantages
can use low temperatures in comparison with incineration	transportation costs to plant may be prohibitive
can separate mixed waste streams	

Low Temperature Thermal Treatment Unit

A low temperature thermal treatment (LT^3) has been developed by Weston Services Inc. The LT^3 unit is similar to the thermal separation plant in that it uses low temperatures (400°F to 600°F) to volatilize organic compounds from soils. The organics are then treated separately from the soils. The LT^3 unit has the advantage that it been designed as a mobile unit. Another major advantage of the LT^3 is that the temperatures used are well below the temperatures which might alter components of contaminated soils into possibly more toxic substances.

The heart of the LT^3 unit is the thermal processor which is an indirect heat exchanger. The thermal processor passes hot oil through the hollow shafts of screw conveyers resembling soil augers. The contaminated soil is heated by contact with the conveyers so that the organic matter is volatilized and driven off. The organic vapors are treated separately in an afterburner. The LT^3 system is subdivided into four subsystems: 1) soil treatment, 2) hot oil system, 3) emissions control, and 4) water treatment. The equipment is mounted on four tractor trailer beds for transportation.

A pilot-scale system of the LT^3 unit was demonstrated at Letterkenny Army Depot in 1985 and a full-scale demonstration is currently in progress at Tinker Air Force Base. The LT^3 unit is reported by Nielson, Cohen, and Sisk (56) to have removed 99.9% of the VOC contaminants from soil in the pilot-scale demonstration. Previous bench-scale studies demonstrated a removal of 96.7% of the benzene, toluene, ethyl benzene, and methyl chloride compounds and 99.8% of the oil and grease from soils. The soils to be treated in the full-scale demonstration are located in a sludge dump reported to contain waste oils and liquids from industrial operations and sludge from petroleum lubricants.

The LT^3 has undergone extensive bench-, pilot-, and full-scale investigations that have shown the feasibility of

treating soils which are contaminated with volatile organic compounds (VOCs), semi-volatile organic compounds, and polynuclear aromatics (PNAs). Generic waste contaminants treated include: coal tar, jet fuel, oil-based drill cuttings, petroleum hydrocarbons, diesel fuel, solvents, gasoline, and halogenated solvents. Most of the results of preliminary tests indicate a removal efficiency of approximately 99%. However, the operating conditions will have to be optimized to attain the required 99.99% removal efficiency.

Before the LT^3 unit can be used at any radiologically contaminated site it will need to be upgraded to handle radioactive waste. Bench-scale studies will be necessary beforehand to demonstrate feasibility. Since the LT^3 technology has demonstrated the ability to separate organic contaminants from soil, it shows merit for reducing the volume of radiologically contaminated soils that contain organic wastes. The mobile aspect of the LT^3 unit allows it to be near to a contaminated site. Hence, many transportation problems and associated costs may be avoided.

The cost of soil treatment with the LT^3 has been estimated to be approximately $100 to $125 per cubic yard.

Advantages	Disadvantages
low temperatures utilized	may require redesign of the off-gas system to handle radioactive wastes
can separate mixed waste streams	
transportable	
economical	

X*TRAX Transportable Thermal Separator

The X*TRAX is a mobile unit developed by Chemical Waste Management, Inc. for low temperature thermal treatment of soils contaminated with volatile or semi-volatile compounds. The contaminated soils are indirectly heated in a rotary kiln dryer to volatilize the organic contaminants. It is designed to operate at temperatures between 500°F and 800°F. Because the dryer is externally fired, the combustion products of the heat source do not contact the contaminated soils being treated. A major advantage of this system is that the combustion gases do not pass through the air pollution control (APC) devices. This allows the APC devices to be one tenth to one hundredth the size of what would be required for an equivalent capacity incinerator.

The vapors that are produced from the soils are carried by an inert gas to an off-gas system where they are scrubbed for particulate solids and cooled to condense organics. The carrier gas is then reheated and recycled to the dryer. The treated soils are discharged from the dryer as a powdered or granular dry material. Water may be added to the soils to prevent fugitive dust emissions. Reagents may be added to stabilize metal wastes in the treated soils.

A laboratory scale system is operated in Barnwell, South Carolina for treatability studies on mixed wastes and another is operated in Geneva, Illinois for hazardous wastes. Results of treatability studies with a laboratory system have demonstrated that better than 99% removal was achieved for various volatile compounds (i.e., acetone, xylene, ethylbensene, styrene, tetrachloroethylene, chlorobenzene, and 1,2-dichloroethane) and semi-volatile compounds (i.e., anthracene, bis(2-ethylhexyl) phthalate). Laboratory removal of 99.3%, 97.8%, and 98.4% of PCB contaminants were removed from sandy soil, silty clay, and topsoil, respectively. Additional laboratory results for clay soils and sludges indicate that greater than 99% of the organic contaminants were removed.

Pilot-scale results, as reported by Swanstrom and Palmer (57), have demonstrated that greater than 99.9% removal of organic contaminants (i.e., xylene, methyl ethyl ketone, tetrachloroethylene, and various benzene compounds) from surrogate feed materials were achieved. PCBs were removed from sandy and clayey soils with greater than 99% removal efficiency. Starting with PCB concentration of 600 to 5000 ppm, treated soils contained residual PCB concentrations in the range of 5 to 25 ppm. Other organic contaminants typically have residual concentration in the ppb range after treatment.

A full-scale X*TRAX system was completed in early 1990. It is expected to be applicable for soils, pond or process sludges, filter cakes and other similar waste forms. It is applicable for volatile and semi-volatile organic contaminants as well as PCBs. The organic contents of the wastes should be approximately 10% or less.

The costs of the X*TRAX system are estimated to range between $150 and $250 per ton of waste. Costs will vary depending on waste type, specific contaminants, disposal requirements, and the amount of soils to be processed. At least 5,000 cubic yards of soils need to be processed for economic feasibility.

Advantages	Disadvantages
mobile treatment system for on-site use	tars and heavy pitches create material handling problems
uses low temperatures	
can separate mixed waste streams	does not handle heavy metals with the exception of mercury

INFRARED INCINERATION

Incineration is the principal thermal treatment used in wide applications for treating hazardous wastes for volume reduction. A major advantage of incineration is that the volume of a waste stream can be greatly reduced depending on the amount of volatiles present. This makes incineration a good candidate for mixed wastes and/or highly organic soils which are radiologically contaminated. A major disadvantage of incineration is that high enough temperatures are used to alter the physio-chemical properties of the waste stream into possibly more toxic compounds than originally went into the incinerator.

Production of toxic vapors is a common problem with all incinerators. This problem can be handled with the use of scrubbers and afterburners. One aspect of this problem is the fate of metals contained in the wastes. Most of the metals are contained in the inorganic materials. The majority of inorganic materials remain inert during the incineration process and form ash particles. However, some metals are relatively volatile and vaporize during incineration. The vapors are carried away by the exhaust gas and condense as the gas cools. These metal species are also subject to secondary chemical reactions which may form more volatile components than were in the original waste. To ensure that incineration does not cause additional toxic releases, every incineration process

has to undergo extensive pretesting, known as a trial burn, before it can be permitted for operation.

Trial burn plans require a 99.99 % destruction and removal efficiency (DRE). If polychlorinated biphenols (PCBs) or dioxins are present in the waste stream, then a DRE of 99.9999% or greater is required. Operating conditions such as temperature, turbulence, and residence time must be optimized to minimize hazardous emissions. Current EPA proposed regulations will replace DRE requirements with concentration based standards.

There are four general types of incinerators: 1) rotary kiln, 2) fluidized bed, 3) fixed and multiple hearth, and 4) infrared. Rotary kiln incinerators are the most common type used for treatment of radiologically contaminated soils. Infrared incinerators have only recently been developed to treat hazardous and mixed wastes. Only infrared incineration is addressed in this paper because the other types are well-established and, therefore, do not meet the criteria to be innovative.

Infrared incineration has great potential for wide applications due to the high temperatures it can produce with minimal production of hazardous emissions. It is proposed here that infrared incineration be used to treat radiologically contaminated soils for volume reduction of mixed wastes. By removing the volatiles and semi-volatiles, the volume of the wastes can be reduced.

The Shirco infrared incineration system was demonstrated at the Peak Oil Superfund site in Brandon, Florida from July 31, 1987 to August 4, 1987 as part of the EPA (58) Superfund Innovative Technology Evaluation (SITE) program. This infrared incinerator was described briefly in the previous section. The Shirco unit achieved a DRE for PCBs above 99.99%. However, it was not possible to calculate the DRE to four decimal places due to the analytical procedures that were used. The PCBs residing in the ash were less than the 1 ppm operating standard.

The advanced electrical reactor (AER) is manufactured by the Huber Corporation of Borger, Texas. The AER is a mobile unit which uses infrared radiation to pyrolytically treat waste streams. The reactor includes a tubular core surrounded by an annular radiant zone. The core and radiant zone are separated by a porous sleeve. Electrodes are housed in the outer annular space to heat the wastes. A radiation transparent gas (nitrogen) flows through the sleeve of the core preventing the deposition of treated wastes on the hot surfaces. The nitrogen flow is known as a fluid wall.

The AER unit will accept liquids, solids, and sludges. However, the nonliquid wastes must be reduced to 100 mesh size. An AER unit has been demonstrated for the treatment of radioactive wastes. The wastes were heated to 4,000°F. The waste stream was transformed into nonleachable glass granules. Additives are used to help form the glass substance: iron oxide added to wastes containing hexavalent chromium forms inert, nonleachable ferrochrome beads; limestone added to wastes with reactive components such as chlorine forms nonleachable salts, etc.

The AER manufacturer operates a 12-inch pilot plant in Texas and has developed an 18-inch unit which will process approximately 4 tons of contaminated soil or oil per day. The costs for the AER are approximately $300 to $400 per ton of waste.

Infrared incineration is an effective method for volume reduction. It is especially useful for mixed waste streams containing a great deal of organic or other volatile substances. Dedicated incinerators can be constructed near large contaminated sites or mobile incinerators can be temporarily set up on smaller sites. High temperature incineration can be used to form nonleachable glassy forms of treated wastes which can be redeposited on-site.

Advantages	Disadvantages
applicable for mixed wastes	may alter wastes into a more toxic form
great potential for volume reduction	trial burn tests are difficult to pass for permitting
	high initial capital investment
	incinerators encounter many difficulties in initial operations

IN SITU VITRIFICATION

In situ vitrification (ISV) is a high temperature thermal treatment process that converts soil into a glass and crystalline matrix that is resistant to leaching and contaminant migration. Electrical energy is applied to the soil via a conductive starter path between electrodes. The resultant heat melts the starter path and the surrounding soil at temperatures near 1600°C. As more electrical energy is applied, the molten mass grows downward and outward capturing more radionuclides and hazardous metals. Any buried metal objects are melted and form a pool at the bottom the of the molten mass since they have a greater specific gravity than the components of soil. Gases and vapors are contained within a hood placed over the vitrification zone and transferred to an off-gas treatment system where they are scrubbed and filtered. The high temperatures destroy most of the organic components by pyrolysis. When the process is completed, the molten mass cools leaving a block of glass and various crystalline phases.

The performance of ISV has been demonstrated with bench-, pilot-, and full-scale tests on actual and simulated hazardous and mixed wastes. Kindle and Barich (59) report that there have been 75 tests with electrode spacing ranging from 0.23 to 5.0 m, power utilization ranging from 15 to 3750 kW, and resultant block masses ranging from 1 to 700 tons. The latest full-scale field test was conducted on the Hanford Site in 1990. The site was a 12 ft x 12 ft x 8 ft disposal crib that contained mixed wastes including ^{90}Sr, ^{137}Cs, ^{60}Co, and ^{239}Pu, chromium, and lead. The molten mass achieved with ISV was 14 ft deep with a 35 ft diameter. Drilling cores from the cooled mass will be analyzed with the Toxicity Characteristic Leach Procedure (TCLP). Recent tests performed on buried waste materials simulating materials at the Idaho National Engineering Laboratory Subsurface Disposal Area passed the EPA requirements of leach tests by several orders of magnitude, according to Shade, et al. (60).

Observed destruction and removal efficiencies (DRE) for organic contaminants exceed the required values. For various pesticides, volatile and semi-volatile organic compounds, the DREs are greater than 99.99 %. For non-volatile PCBs, dioxins, and furans, the DREs are greater than 99.9999 %.

Advantages	Disadvantages
excavation and disposal is not required	regulatory permitting may be difficult
applicable to soils with mixed wastes	treated sites may require long-term security measures since radioactive wastes remain in place
uses 40% of the energy of incineration	
immobilizes metals and inorganic contaminants	
removes and/or destroys organic contaminants	

TRANSFERRED-ARC PLASMA

Over the past few years a Plasma Centrifugal Reactor (PCR) has been developed by Retech, Inc. in Ukiah, California. The PCR furnace uses high temperatures from an electric arc to melt and vitrify soil solids while decomposing toxic hydrocarbons into simple, less toxic, molecules. This reactor operates at about 1600°C which is sufficient to produce molten glass. In general, plasmas are capable of producing temperatures in excess of 10,000°C. In the treatment of radiologically contaminated soils, the PCR furnace will produce a molten slag that is reduced in volume and can be handled without the complications due to the presence of organic compounds. An additional advantage is that it is not necessary to supply excess air for the process so that the generation of gases and fine particulate matter is minimized.

The reactor section includes the feeder, the primary chamber, the secondary combustion chamber, and the glass collection chamber. The gas treatment section includes a quench tank, a venturi scrubber, a packed bed scrubber, a demister, an activated charcoal adsorber, and a stack blower. The furnace is expected to handle single 55-gallon drums of waste loaded one at a time.

The PCR was developed in three phases: Phase I (1985-1986) - initial studies to demonstrate feasibility of reducing the volume of radiologically contaminated materials (metals, glass, rubber, plastics, filter elements, etc.); Phase II (1986-1988) - a quarter-scale furnace to treat waste streams of water, methanol, fuel oil, soil, and soil plus polymers and/or other chemicals; Phase III (1988-1989) - a full-scale furnace is to treat spiked samples known as Synthetic Soil Matrix (SSM) to be provided by the EPA. Eschenbach et. al. (61) reported a volume reduction by a factor of 20 with the materials treated during Phase I. Phase II results were favorable enough for the PCR to be selected by the EPA for the second round of the Superfund Innovatice Technology Evaluation (SITE) program. Results from Phase III are expected to be available in a report by the end of 1989.

The PCR furnace is capable of handling mixed wastes and reducing the volume of radiologically contaminated soils. Since the PCR furnace can use very high temperatures, it would be well suited for sites containing assorted materials (metals, plastics, etc.) in addition to contaminated soils. Costs for this technology were not estimated in the literature.

Advantages	Disadvantages
vitrifies waste into nonleachable form	high energy consumption
can handle mixed wastes	no standards for testing suitability of the treated waste form for disposal
fewer particulates are distributed	requires excavation
not yet designed to be mobile	

CYCLONE REACTOR TREATMENT

A cyclone furnace for vitrifying contaminated soils is being developed by Babcock & Wilcox Co. Czuczwa (62) reports that the cyclone furnace is a well-established technology used for the combustion of high inorganic (ash) coal. The technology has been used to form a vitrified slag from municipal solid waste containing heavy metals. The resultant slag material passed EPA leachability limits for all eight of the RCRA listed metals. This R & D project lead to the development of a system specifically designed for the treatment of contaminated soils that also contain organic constituents.

A 6 million Btu/hr cyclone furnace has been used to conduct pilot-scale vitrification tests. The furnace is water-cooled and is designed as a single cyclone, front-wall-fired cyclone boiler. This cyclone test facility has demonstrated to similar characteristics as full-scale units with regards to furnace/convection gas temperature and residence times, NO_x levels, cyclone slagging potential, ash retention in the slag, unburned carbon, and flyash particle size. The cyclone furnace is a horizontal cylinder (barrel). Natural gas and preheated primary combustion air enter tangentially into the cyclone burner. Preheated secondary air, contaminated soil, and natural gas enter tangentially into the cyclone furnace barrel. The soil is captured and melted while the organics are destroyed in the molten slag layer that is formed. Soil is retained on the wall of the furnace barrel by centrifugal action. As the soil melts, it exits the furnace from a tap at the cyclone throat and is dropped into a water-filled slag tank where it solidifies. A small portion of the soil also exits as fly ash with the flue gas and is collected in a baghouse. A heat exhanger is used to cool the gases in the stack before they enter the baghouse. The facility is also equipped with an acid gas scrubber that can be used when necessary.

A pilot-scale test was conducted with a synthetic soil matrix (SSM) formulated by the EPA using 2.5 tons of SSM spiked with 7000 ppm lead, 1000 ppm cadmium, and 1500 ppm chromium. An additional 3 tons of unspiked SSM was used for preliminary testing. Results of the tests with heavy metals indicate the resultant slag was relatively enriched with chromium, but depleted with lead and cadmium. A mass balance study on the metals showed that the lead and cadmium that was not found in the slag could be found in the fly ash.

The average lead, cadmium, and chromium TCLP leachabilities of the cyclone-treated SSM were 0.19, 0.12, and 0.08 mg/L, respectively. The amount of metals present in the SSM that leached before the vitrification process was 84, 3.8, and 29 percent for cadmium, chromium, and lead, respectively. The amount of metals present in the slag that leached after the vitrification process was 2, 0.07, and 0.18 percent for cadmium, chromium, and lead, respectively. These TCLP

results indicate that the process can successfully produce a non-leachable slag.

Advantages	Disadvantages
long track record for basic process	fly ash has significant metals content
treats soils with low calorific content	requires excavation and disposal
can handle soils with mixed waste	transportation costs may be prohibitive

VEGETATIVE UPTAKE OF RADIONUCLIDES

Numerous studies have been conducted to determine the feasiblity of using plants to uptake radionuclides. A selective annotated bibliography entitled "Radionuclide Movement in Soils and Uptake by Plants" was presented by Francis et al. (63). The majority of the papers cited in this reference have to do with reducing the absorption of radionuclides by plants to prevent pathways into the food chain. For the purposes of decontamination with the use of plants, an opposite trend is sought. High absorption rates are favorable. Once a plant has absorbed the radionuclides of concern, the plant can be harvested and reduced to a small volume by incineration or some other treatment. The final volume of contaminated solids is significantly smaller than the original volume of contaminated soil. An extensive feasiblity study was conducted at the Idaho National Engineering Laboratory and the results of this study were presented by Chapin and Cooper (64) and Chapin (65).

The most significant finding of the feasibility study by Chapin and Cooper (64) is that aquatic plants can be used effectively for soil decontamination. The technique used appears to be feasible with the use of plants such as water hyacinth, alligator weed, water willow, or the common cattail. The best results were reported for the water hyacinth grown in a solution containing soil contaminated with ^{60}Co, ^{90}Sr, and ^{137}Cs. For one group of tests, Chapin (65) reported that the level of radionuclides per gram of ashed plant is equivalent to the level of radionuclides per gram of soil for ^{137}Cs and ^{60}Co. The quantity of ^{90}Sr uptake was approximately a factor of two greater than the amount in the soil. For a second group of tests, the results were significantly better. The uptake of ^{137}Cs was analyzed to be nearly an order of magnitude greater than that found in the soil. The uptakes of ^{60}Co and ^{90}Sr were factors of two greater than the levels found in the soil. Chapin (65) points out that the results could be improved if a companion technique could be developed to enhance the release of radionuclides from the soil into solution.

A study by Jayaraman and Prabjakar (66) also reported favorable results for uptake using water hyacinths. It is interesting to note that both this study and the one by Chapin and Cooper (64) reported that the majority of radionuclides were found in the roots of the plants, but relatively little was found in the leaves. Wolverton, et al., (67) have demonstrated that water hyacinth plants have the ability to concentrate cadmium, lead, and mercury to levels several hundred times those present in the aquatic medium. The percent of these heavy metals combined in solution was reduced by 81%, 87%, and 91%, respectively, over a 24 hour period. These results have important implications pertaining to the decontamination of surface impoundments that contain other heavy metals such as uranium, americium, etc.

The best candidates for using aquatic plants for decontaminating soils are ponds, lagoons, and other surface water impoundments.

Advantages	Disadvantages
inexpensive and simple	limited to sites with standing surface water
	introduced plants may adversely compete with native plants
	requires additional treatment such as incineration for maximum volume reduction

SUMMARY

Selected innovative technologies for the remediation of soils contaminated with radioactive and mixed wastes were identified and reviewed. The technologies are in various stages of development. The innovative technologies described have not yet been used to completely remediate a radioactively contaminated site.

Technologies with potential for extraction and/or destruction of organic contaminants included: 1) soil washing and flushing, 2) ultrasound detoxification, 3) soil vapor extraction, 4) in situ hot air/steam extraction, 5) in situ radio frequency, 6) in situ soil heating, 7) low temperature thermal treatment, and 8) infrared incineration.

Technologies with potential for extraction of metals and other inorganic contaminants included: 1) soil washing and flushing, 2) electrokinetics, and 3) vegetative radionuclide uptake.

Technologies with potential for containment of metals and other inorganic contaminants include: in situ vitrification plasma torch slagging, and 3) cyclone reactor treatment. These containment technologies have the added advantage of destroying organic contaminants during processing.

ACKNOWLEDGEMENTS

The authors would like to extend their gratitude to Diane Shigley and Brian Stahl of Stone & Webster Engineering Corporation for editing the paper. The efforts of Martina Iten of the Stone & Webster Engineering Corporation Library and Jane Cooper of the Washington State University Library were instrumental in obtaining current information on the technologies.

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SOIL WASHING RESULTS FOR MIXED WASTE POND SOILS AT HANFORD

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ABSTRACT

Soil washing technology was assessed as a means for remediating soil contaminated with mixed wastes primarily composed of heavy metals and radionuclides. The soils at the U. S. Department of Energy's Hanford Site are considered suitable for soil washing because of their relatively low quantities of silt and clay. However, in a limited number of soil washing experiments using soils from different locations in the north pond of the 300 Area, the degree of decontamination achieved for the coarse fraction of the soil varied considerably. Part of this variation appears to be due to the presence of a discrete layer of contaminated sediment found in some of the samples.

INTRODUCTION

Soil washing is being considered for remediating soils located at the U.S. Department of Energy's (DOE's) Hanford Site. The Hanford Site encompasses 560 square miles of semi-arid desert in South Central Washington and lies in a structural and topographic basin of eastern Washington within the Columbia Plateau. The site is bordered to the north and east by the Columbia River and is adjacent to the northern boundary of the city of Richland, Washington. Located on this site are a number of government facilities which were operated to produce plutonium for the Department of Defense and conduct nuclear research for the DOE. As a result of these operations, over 1000 inactive waste disposal and unplanned release sites were generated ranging in size from minor spills to burial grounds of 100 acres. The soils at these sites are primarily contaminated with both heavy metals and radionuclides. In support of cleanup efforts at Hanford, the effectiveness of soil washing in treating contaminated soils was assessed.(1) A limited number of soil washing tests were conducted using soils obtained from a waste disposal pond located in the 300 Area of the Hanford Site.

SOIL WASHING PRINCIPLES

Successful soil washing largely depends on matching the type of contamination and soil characteristics with specific operations that can perform well under those conditions. In general, there are three main types of soil contamination: contaminants dissolved in the water in the soil, contaminants chemically fixed as solid compounds, and contaminants adsorbed onto the surfaces of the various solids in the soil. The majority of the near-surface contamination in the north pond is expected to be in the form of sediments comprised of precipitates disposed with the wastes and chemically fixed solids resulting from interactions between dissolved solids in the waste and certain minerals present in the soil. Principal soil minerals of concern are carbonates, sulfides, phosphates, and hydrous metal oxides containing manganese or aluminum.(2)

Soil washing, as it is currently practiced for chemically fixed heavy metals and radionuclides, is accomplished primarily through attrition scrubbing and separation of soil fractions by size. In some instances, surfactants are added to facilitate separation of fine and coarse particles by neutralizing the charge associated with the particles. The soil is separated into two fractions. The coarse fraction of the soil has a much lower surface area per unit weight and a corresponding lower amount of contamination than a comparable mass of very fine particles. Ideally this fraction of the soil can be returned to the site. The fine soil fraction is composed of very fine sand, silt, and clay and has a much larger surface area for chemically fixing dissolved solids and precipitates. It also includes discrete particles of precipitate. After washing, this fraction of the soil, which is usually in the form of a sludge, is contaminated and requires further treatment or off-site disposal. As a general rule, soil containing less than 25% silt and clay can be washed economically.

In actual practice, the contaminants do not always partition sufficiently to the fine fraction of the soil. This is particularly true for radionuclides whose maximum allowable levels are very low. Some of the contaminants become solubilized or dispersed in the water phase and must eventually be removed. Also, depending on the method of separation, both the fine and coarse fractions contain a small portion of the other soil fraction. In addition, some of the contaminants remain on the coarse particles. In either case, residual contamination may preclude returning the coarse fraction to the site without further treatment, and it may be necessary to solubilize the contaminants by adjusting the pH or by using chelating or complexing agents.

SITE DESCRIPTION

The surface soil at Hanford is characterized by a layer of light brown, fine, slightly silty, wind-deposited sand typically varying from less than 0.3 m to over 4.5 m in depth. Surface soil samples from two separate locations near the 300 Area contained 69% to 97% sand, 1% to 26% silt, and 1% to 5% clay.(3)

Underlying the surface soil are poorly sorted, unconsolidated glaciofluvial sediments informally referred to as the Pasco gravels of the Hanford Formation. These sediments were deposited during catastrophic flooding episodes associated with failures of the Lake Missoula ice dam during the late Pleistocene epoch.(4) The last major flood occurred approximately 13,000 years ago.(5) The Pasco gravels of the Hanford

* Operated for the U.S. Department of Energy by Battelle Memorial Institute.

Formation consist of a variable mixture of boulders, cobbles, gravel, sand, and silt; however, most of the sediments can be classified as a silty sandy gravel consisting of 50% gravel, 40% sand, and 10% silt.(6) The uppermost aquifer beneath Hanford consists of an unconfined system ranging in depth from less than 0.3 m near the Columbia River to over 90 m.(7)

The bench-scale treatability tests reported in this paper were conducted using soil samples from the north process pond in the 300 Area located in the southeast corner of the Hanford site approximately 5 km north of Richland and approximately 90 m west of the Columbia River. In the vicinity of the pond, the surface soils are thin and the Pasco gravels are about 15 to 18 m thick.

The north pond area consists of six small settling basins and one large infiltration basin, as shown in Fig. 1, separated by 3.7-m-wide dikes. The entire 10 acre area is surrounded by a dike 4.5 m wide and approximately 3 m high.

From 1949 to 1974 the pond was one of two unlined surface impoundments that received low-level radionuclide liquid wastes and cooling water from facilities located in the 300 Area. The pond was dredged periodically to increase infiltration rate. Since closure, several of the dikes between basins were removed and uncontaminated material from the dikes was placed on the bottom of the basins. The pond has since dried out.

The estimated inventory of nonradiological chemicals known to be disposed in the pond is listed in Table I. Previous analyses (8) of soil samples taken from the site indicate low levels of both the sodium and nitrate ions, suggesting that they were fairly mobile species.

RESULTS OF BENCH-SCALE SOIL WASHING TESTS AT HANFORD

Bench-Scale Experimental System and Procedures

Figure 2 shows a procedure flow diagram for the bench-scale soil washing system. Soil samples ranging in size from about 100 g up to 500 g were used in each experiment. A portion of each sample was retained for comparison with the cleaned soil fractions. The soil samples were dried, weighed, and mixed with water in a 3.8-L polystyrene bottle. The water-to-soil weight ratio ranged from 1:1 to 10:1. The bottle was then placed on a reciprocating shaker for a period ranging from 30 min to 1 h and shaken at a stroke length and frequency of 4.57 cm and 4 Hz, respectively.

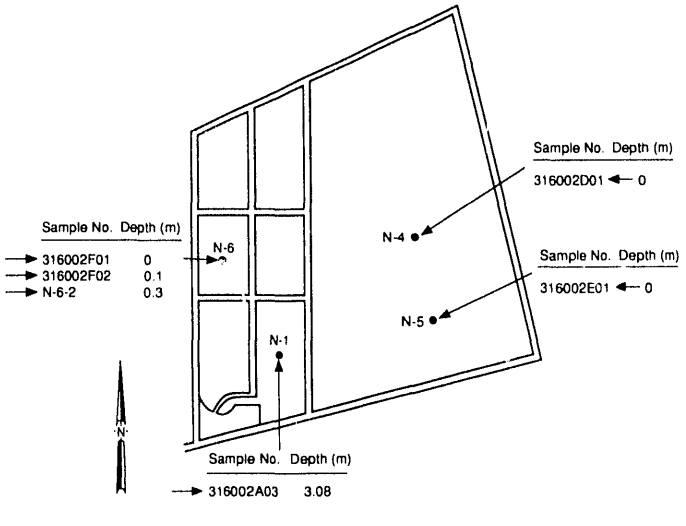


Fig. 1. Diagram of 300 area north pond.

TABLE I

Estimated Nonradiological Chemical Waste Inventory for the North Process Pond

Chemical	Quantity (kg)
Beryllium	30
Cadmium	60
Chromium	3,000
Copper	50,000
Fluoride	5,000
Lead	2,000
Mercury	40
Nickel	8,000
Nitrate	800,000
Nitrite	700,000
Nitric Acid	900,000
Silver	900
Sodium	1,000,000
Sodium Aluminate	2,000,000
Sodium Hydroxide	800,000
Sodium Silicate	90,000
Trichloroethylene	100,000
Uranium	30,000
Zinc	3,000

Total volume of Liquids Disposed:
10,000,000,000 L

The soil-water slurry was then poured into the top of a Gilson Wet-Vac Model WV-3. The Wet-Vac contains three screens and filter paper to collect the various soil fractions. After the wash solution was separated, rinse water was added to the Wet-Vac and recirculated. The solids retained on each screen were collected, dried, weighed, and submitted for analysis. The wash water and the recycle water were also submitted for analysis. Analysis of the original sample and each washed fraction was performed using U.S. EPA SW846 methods.

Samples Tested

The sample numbers shown in Fig. 1 correspond to the samples used in the tests. Soil samples taken from the ponds show that the soil is quite sandy with a lot of gravel and boulders. The particle size distribution for some of the samples is given in Table II. Rocks and gravel that could not pass a 1.27-cm screen were not included in the samples.

Experimental Results

Nine soil washing tests were performed to gain experience with the soil washing apparatus and to explore some of the parameters known to be important to the process.

Table III shows the concentrations of a number of constituents in the whole soil before washing and in the different fractions following soil washing for a soil sample obtained from location A03. This test used a wash water/soil ratio of 5:1 and a total washing time of 1 h. Also shown in Table III for comparison are the average concentrations of these elements

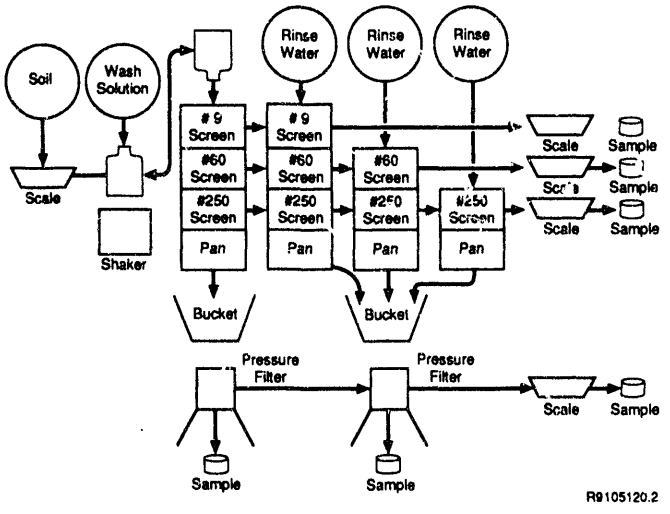


Fig. 2. Schematic of bench-scale soil washing system.

for soil samples obtained at depths ranging from 0 to 3.3 m from a location in the 300 Area which is believed to be representative of uncontaminated soil.(8) It can be seen from the data that there is a definite partitioning of the major contaminants to the smaller fractions. In addition, very little of the contamination partitioned to the wash water.

Both the elemental and overall material balances between the total soil and the sum of individual fractions and wash water recovered are shown in Table III. These balances are expressed as a percent of the soil sample values before washing. The amount of material accounted for in the balance is not very good for several of the elements. This trend was observed for all of the tests performed. The poor elemental balances can be attributed only partially to loss of material. The remaining discrepancies are attributed to analytical error including the method of selecting samples for analysis and the variability introduced by analyzing small (1-g) quantities of material. This is particularly important where single grains of soil account for a significant portion of the sample analyzed and individual grains of contaminants can account for a significant portion of the concentrations measured.

Table IV shows the degree to which contaminants were partitioned to the -2 mm/ + 250 μm fraction for four soil washing tests performed using a water/ soil ratio of 5:1 and 30 min of washing. There is considerable variation in the partitioning of individual contaminants for soil samples obtained from different locations. These results are significant because this fraction alone represents anywhere from approximately 50% to as much as 90% of the soil passing a 1.27-cm screen. Technical feasibility of soil washing will depend on adequate cleaning of this fraction.

The results obtained for tests using a soil sample collected from the N-6-2 location in the pond are particularly noteworthy. This sample was collected at a point close to where other samples were collected. However, inspection of the sample as it was washed and observations during collection at the site indicated that it contained a substantial quantity of a relatively hard, light green sediment. Earlier analysis of this sediment(8) showed that the green material in the sediment consisted mostly of copper. Preliminary analysis also indicated gross alpha levels about four times higher in the blue-green sediment than in the whole soil. Soil washing tests showed that the sediment was not readily attrited during washing. The poor partitioning results for this fraction suggest that a significant portion of the contamination is associated with the blue-green sediment and that simple washing does not partition the sediments to the smaller size fractions.

Three additional tests were performed with soil samples obtained from the N-6-2 site. Two tests were performed with HCl and H_2SO_4, respectively, added to the wash water to obtain an initial pH of 2. In both cases the acid caused foaming during washing and the final pH was increased to about 5.5, which is the same value obtained for all previous tests. In both cases partitioning improved only marginally for the -2 mm/ + 250 μm fraction. For example, HCL and H_2SO_4 achieved residual copper concentrations in the -2 mm/ + 250 μm fraction that were 109% and 69%, respectively, of the bulk soil concentrations. The third test was performed using a ball mill roller instead of the shaker in order to impart a tumbling action to the soil. Even though there was no obvious increase

TABLE II

North Pond Wet Sieving Results

Sieve Size U.S. STD.	Soil Type	Sample Number A03	F01	F02	N-6-2	F03	D01
-12.7 mm/ + 2 mm	coarse sand/ fine gravel	2.6	35.3	26.1	28.8	15.8	38.2
-2 mm/ + 250 μm	medium/fine sand	90.0	46.5	52.9	56.1	76.3	47.9
-250 μm/ + 63 μm	coarse silt/ very fine sand	3.8	7.5	13.4	7.8	3.2	4.6
-63 μm	clay/silt	3.7	10.3	7.8	6.1	4.6	9.4

TABLE III

Soil Washing Results for A03 Soil Sample Obtained from North Pond

	Analysis Values in g/gμ (μg/L for water) Soil Size Fraction							
	Background Soil	Bulk Soil (282 g)	2 mm to 12.5 mm (6.92 g)	250 μm to 2 mm (236.3 g)	63 μm to 250 μm (9.9 g)	Less Than 63 μm (9.7 g)	Wash Water (1.56 L)	Material Balance (%) [a]
Chromium	9.8	286	23	110	690	2,180	0.23	67
Copper	18.4	12,500	1,560	8,000	22,900	69,000	0.34	79
Lead	5.1	92	0.0	60	250	425	0.0	80
Nickel	7.6	191	40	140	1,430	820	0.0	103
Uranium	---	65	5	24	117	316	0.0	55

[a] The sum of the soil fraction quantities was 93% of the quantity of the bulk soil.

in the amount of fines due to attrition, the results did indicate that the -2 mm/+250 μm fraction was decontaminated moderately. For example, the residual concentration of copper was about 48% of that in the bulk soil.

CONCLUSIONS

Based on the limited number of experiments conducted to date, it is not possible to draw any firm conclusions regarding the feasibility of using soil washing to remediate contaminated soils at the Hanford Site. However, the following conclusions can be made about the character of the contaminated soil in the north pond of the 300 Area and its behavior during soil washing:

- The soil in the 300 Area ponds is, as expected, primarily sand or larger material. At least 80 to 90% of the soil has a particle size greater than 250 μm.
- The primary hazardous contaminant present is copper, and the primary radionuclide present is uranium.
- Initially, the contamination is distributed throughout the range of particle sizes, but after washing, the contamination is partitioned preferentially to the fine fraction (< 250 μm) of the soil.
- After washing, the coarse fraction still contains significant levels of contamination, which appears in the form of discrete particles and as a coating on the sand particles. The amount of decontamination achieved for this fraction also varies significantly between soils from different locations in the pond.
- Very little of the contamination is water soluble, indicating that high water recycle ratios can be used.
- Additional unit operations, such as attrition scrubbing, will be necessary to further reduce the contamination for the coarse fraction.

While some test results are encouraging, additional tests will be needed to fully assess the applicability of the technology and to resolve some of the issues identified in these preliminary tests.

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TABLE IV

Comparison of Soil Washing Results for Soils Obtained from Different Locations in the North Pond (analysis values in μg/g)

	A03			F01			N6-2-1			D01		
	Bulk Soil	Soil 2mm/ 250 μm	% Bulk Value	Bulk Soil	Soil 2mm/ 250μm	% Bulk Value	Bulk Soil	Soil 2mm/ 250μm	% Bulk Value	Bulk Soil	Soil 2mm/ 250μm	% Bulk Value
Weight (g)	263	236	89.8	128	59.6	46.5	324	193	59.4	288	137	47.8
Chromium	286	110	38.5	766	296	38.6	645	800	124	75	40	53.3
Copper	12,500	8,000	64.0	12,400	4,830	39.0	9,070	12,000	132	2,070	1,260	60.9
Lead	92.0	60.0	65.2	50.0	69.0	138	NA	NA	NA	NA	NA	NA
Nickel	191	140	73.3	369	156	42.3	325	405	125	150	150	100

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FACILITY DESIGN TO APPLY COVER MATERIAL OVER RADIOACTIVE RESIDUE IN STORAGE SILOS

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ABSTRACT

This paper discusses the BentoGrout application system designed by Parsons under contract to the U.S. Department of Energy (DOE) for the Environmental Remedial Action (ERA) Project, Fernald Environmental Management Project (FEMP) Fernald, Ohio, as defined by the K-65 removal action work plan prepared by Theta Technologies, Inc. and Westinghouse Environmental Management Company of Ohio (WEMCO) with the objectives to reduce radon emissions from the silos.

The paper discusses support activities undertaken to develop the design basis and design criteria for the K-65 Silos BentoGrout Covering System. The development and execution of an application demonstration program is described with presentation of the results. Also addressed is the design of the full-scale application system and the philosophy of operational control. The instrumentation and monitoring subsystems are illustrated on system schematics.

The paper concludes with an evaluation of the above activities in achieving the purpose and objectives set forth in the Removal Action Work Plan.

INTRODUCTION

System engineering packages were developed for the design of the application of a cover material (bentonite) over the radioactive residues in the K-65 waste storage silos (Silos 1 and 2) at the Fernald Environmental Management Project (FEMP) in Fernald, Ohio. Design basis was defined by the Silos 1 and 2 Removal Action Work Plan (1), which was approved by the United States Environmental Protection Agency (U.S. EPA). The purpose of installing a cover material over the radioactive residues is to reduce emissions of radon gas from the K-65 silos into the environment. This action constitutes a Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) removal action at the FEMP which is a National Priorities List (NPL) site. Support activities carried and presented in this paper are: 1) the development and execution of an application demonstration program; and 2) design of the bentonite covering system for the K-65 waste storage silos.

BACKGROUND

Two silos at the FEMP contain processed pitchblende (high grade uranium/radium ore) from the Belgian Congo. This ore was processed to remove uranium at the Mallinckrodt Chemical Works in St. Louis and later at the FEMP. The residue of this processing contained significant amounts of radium and thorium. The two silos were constructed in 1951 and 1952 for the purpose of storing this residue, which was called K-65 material. The silos contain approximately 9,600 tons of residue. The radioactive constituents of concern are uranium-238 and 234, radium-226, and thorium-230. The radium bearing residues emit radiation in the form of alpha, beta, and gamma rays; and they emit radon gas. Most of the radon that is generated in the K-65 residues is contained within the silos. Currently, approximately 12 curies of radon are released to the head space of each silo per day. Due to the age of the silos, the radon emissions from the silos exceed the U.S. EPA limits.

These silos are included in one of the CERCLA Remedial Investigation/Feasibility Study (RI/FS) identified operable units, Operable Unit 4, at the FEMP. While pursuing final remediation, it has been determined by the DOE, as the lead agency at the FEMP, that a non-time-critical removal action is necessary. The scope of this removal action can be broadly defined as reducing the chronic radon emissions and the control of potential releases of residues from Silos 1 and 2. This removal action is being conducted pursuant to the Consent Agreement under CERCLA 120 and 106(a) between the DOE and the U.S. EPA as the Silos 1 and 2 Removal Action. An Engineering Evaluation/Cost Analysis (EE/CA) (2) has been prepared to evaluate the removal action alternatives using the preliminary characterization data to support the selection of a preferred alternative. The preferred alternative consists of covering the K-65 residues with a gas barrier material that will retard the emanation of radon gas into the space between the residues and the silo domes. The cover material will be a bentonite base slurry due to bentonite's plasticity and the relative ease by which it can be placed into the silos. The characteristics of the bentonite product, BentoGrout, sold commercially by American Colloid Company, were used to determine the preferred alternative. Therefore, it was determined to utilize the commercially available product, BentoGrout, as the cover material for this removal action.

APPLICATION DEMONSTRATION PROGRAM

An Application Demonstration Program was developed and carried out to illustrate the physical applicability of the alternative selected by the EE/CA and to provide basis for the detailed design. Parsons developed a detailed demonstration program consisting of the demonstration test facility specification and specific testing objectives to determine the chemical and physical parameters of the optimum BentoGrout slurry mix. The American Colloid Company (ACC) was retained for the execution of this program. The test program was carried out in ACC Corporate Laboratory (Phase I) Arlington Heights, Illinois, and for the field demonstration at

the ACC Operations facility located in Sandy Ridge, Alabama (Phase II).

The demonstration program was conducted using equipment by ChemGrout of LaGrange, Illinois. The equipment was designed to produce a BentoGrout mix at a continuous controlled discharge rate of up to 40 gpm at 225 psi. The demonstration equipment consisted of two 20 gpm mixer/pumping units (CD-500GH-CHEMGROUT) operating in parallel and discharging the BentoGrout slurry onto a common hopper. The slurry was discharged from this hopper at a variable, preselected continuous rate to a 40 gpm capacity pumping unit (CG3L8GH-CHEMGROUT) rated for 225 psi. The discharge rate was adjustable by varying the speed of the hydraulic-driven pump. The slurry transfer pipe was a flexible hose equipped with a straight pipe attached to the hose and a replaceable nozzle gun at the end of the straight pipe. The nozzle gun was configured to accommodate 1-inch, 3/4-inch, 1/2-inch, 3/8-inch, or 1/4-inch diameter orifices.

The site plan at Sandy Ridge consisted of an excavated pit measuring 40 feet in length by 10 feet in width and 4 feet in depth. A "waste pile" was erected in the east end of the pit to simulate the irregular residue surfaces in the silos. A portable metal bridge was fabricated to aid in access around the pit. A prefabricated concrete section was vertically placed in the west end of the pit to simulate the silos sides. This concrete was used to simulate the interaction of the BentoGrout slurry with the silos sides.

The construction of the demonstration pit included placing soil and sand mixed at 50 percent ratio into the pit. The mixture was compacted using a gas-powered tamper to simulate the surface of the residues within the silos. The sand/soil mixture was installed as base material in the pit. A "waste pile" was built in the pit over the base using a mixture of 50 percent sand and 50 percent excavated soil. A compaction of 90 percent was provided for the pit base and the "waste pile." A field laboratory and nine concrete cylinders were utilized to perform adhesion tests. The ChemGrout mixing units were located about 50 feet from the pit.

Mixing formulas to produce mixes with 20 percent to 40 percent solids were demonstrated and slurry characteristics were determined. The BentoGrout slurry mix designs were tested for percent weight of solids, percent weight of water, solid (dry) particle size distribution, density, solid (dry) specific gravity, viscosity, and setting time. Each mix formula was tested (Phase I) prior to the field demonstration test (Phase II), and results are summarized in Table I. BentoGrout (dry) particle size distribution was determined by sieve analysis. A chemical analysis was run on the BentoGrout and the composition for major, minor, and trace elements, as well as moisture loss and Loss on Ignition (LOI), were obtained.

The optimum formula was determined based on a comparative analysis of flow, area coverage by flow, setting time, and adhesion characteristics. The slurry mix produced with 25 percent solids was determined as the optimum formula for the application.

Dehydration effect on the 25 percent solids optimum mix was verified after 30 days. Loss of free moisture content was negligible. The test cylinders were observed to have perimeter cracking due to moisture loss created by the porous concrete. The cylinders did not exhibit cracking, and no crust was observed. Test cylinders, where moisture-saturated air was maintained over the BentoGrout blanket, exhibited no deterioration. This strongly suggests that in the full-scale application, the air space in the silos over the BentoGrout blanket must be maintained at a saturated-moisture condition all of the time.

Reslurrying of the optimum mix exhibited no problem; it could be reslurried in a standard mixer. It has been demonstrated that operating with the optimum mix, the base surface of the test pit, representing the surface of the residues in the silos, could be covered with a 1-foot layer of the BentoGrout slurry. During this operation, the slurry was discharged at 40 gpm while a spray gun was maintained in the center of the test pit in vertical position with unrestricted discharge. The whole area (40 feet by 10 feet) was covered by free flow of the slurry placed into the pit. Table II summarizes the results of the demonstration in a sequential order. The demonstration confirmed that the full scale application to cover residues in Silos 1 and 2 could be carried out utilizing the center manhole only.

It was demonstrated that a slurry with a solids content of 35 to 40 percent by weight could be produced and would be suitable to cover irregular surfaces and the "waste piles" by pumping and placing the slurry around the pile by stacking layer upon layer.

It has been demonstrated that irregular surfaces, simulated by the "waste pile" in the test pit, could be demolished by hydraulic spraying with the slurry. The "waste pile" was completely knocked down with slurry discharged at the rate of 40 gpm through the gun equipped with 3/8-inch orifice. An intensive splashing occurred during testing: Bentogrout slurry spread in three directions within a 15-feet-diameter area. It was concluded that heavy splashing may transfer K-65 material from the residue surface to the inside dome surface resulting in an increased radiation dose on the outer surface. Consequently, this concept probably will not be considered for full-scale application.

It has been found that BentoGrout slurry forms a non-Newtonian fluid with properties of Bingham plastics. All mix designs were subjected to a rheology test to quantify the rheologic characteristics of the BentoGrout slurries at various solids concentration to develop basis for pump/pipeline design. The test was carried out in a rheometer. Air pressure was applied to the closed sample chamber containing the mix to initiate flow through a calibrated tube. Varying air pressure caused variation of the slurry flow rate. Rheometer data point were developed by observing flow rates at different pressures. Rheogram is prepared by plotting shear stress versus shear rate, then the slope of rheogram, (Eq.1) is defined as the slurry plastic viscosity. In Bingham plastics, the slurry exhibits a yield stress which must be exceeded to induce flow and a uniformly changing plastic viscosity. Results are summarized in Table III.

$$\left(\frac{Shear\ Stress}{Shear\ Rate}\right) \qquad \text{(Eq. 1)}$$

Test results confirmed that BentoGrout slurries thicken with time. They exhibit rheopectic behavior. This behavior increases for slurries with higher solids content. Efforts to quantify this effect with a rotational viscosimeter proved to be unsuccessful because of the rapid rate of change observed in the slurry viscosity immediately after mixing. The rate of change was observed to slow after 15 minutes, but viscosity did continue to increase. This experience suggests that process design requires a rapid mixing and placement of slurries. Due to the lengthy elapsed-time - over 43 minutes - from the start

TABLE I

Bentogrout Mix Characteristics

		ACC Lab Arlington Heights, IL	Plant Water Sandy Ridge, AL	Pond Water Sandy Ridge, AL
Conductance (umhos/cm)		300	720	180
pH		7.69	8.77	7.38
Free Swell (cc/2g bentogrout)		12	10	8
Setting time Cone Penetrometer, (mm Penetration)				
20% Solids	15 mins.	>100	>100	>100
	24 hrs.	>100	>100	>100
25% Solids	15 mins.	>100	>100	>100
	24 hrs.	76	80	77
30% Solids	15 mins.	71	68	63
	24 hrs.	44	46	46
35% Solids	15 mins.	44	41	41
	24 hrs.	31	34	32
40% Solids	15 mins.	30	30	31
	24 hrs.	23	24	23
Density/Sp. Gr.				
20% Solids		71.5/1.14	72.0/1.14	82.0/1.31
25% Solids		74.0/1.19	74.0/1.19	73.5/1.18
30% Solids		76.0/1.22	76.0/1.22	76.0/1.22
35% Solids		79.0/1.27	80.5/1.27	79.0/1.27
40% Solids		82.0/1.32	82.2/1.32	82.0/1.31
Solids (dry) Sp. Gr.		2.5	2.5	2.5

of mixing to the completion of the run, plasticity of the sample, in general, advanced to a degree such that the slurry became almost non-pumpable. Consequently, this specific viscosity data could not be used to calculate pressure drop. Experience confirmed that the total dynamic pumping head requirement must be obtained based on the actual pressure differential measured across the pump. This measurement must be made while pumping the slurry immediately after the grout has been produced. Total dynamic head (PSI), measured at different operating conditions, are presented in Table IV.

DESIGN OF THE K-65 SILOS BENTOGROUT COVERING SYSTEM

Arrangement of the system to apply the BentoGrout slurry over the radioactive residue in the storage silos at the FEMP is presented in Figs. 1 and 2. The BentoGrout material will be delivered by a pneumatic tanker to a receiving/unloading area near the K-65 silo area. The dry feed material will be pneumatically unloaded from the tanker and transferred into a two-hour capacity feed bin. BentoGrout will be reclaimed from the bin by a pair of screw feeders and then fed into the Bentogrout mixing unit. Air vented from the bin will be discharged into the atmosphere through a dust collector to control dust emissions. The mixing unit will consist of two 200-gallon capacity mixer tanks, each equipped with side mounted high shear type ribbon blender driven by an electric motor. Slurry will be discharged into a feed hopper equipped with an auger to feed the Moyno transfer pump rated for 600 psi. The entire mixing unit will be mounted on a movable skid.

From the mixing unit, the BentoGrout will be pumped into Silos 1 and 2 through a distributor/sprayhead assembly unit housed in a basket positioned over the manhole and suspended from a mobile crane boom. As illustrated in Figs. 2 and 3, the distributor/sprayhead was designed for injecting BentoGrout mix into K-65 Silos 1 and 2. Equipment will be lowered into the silos through the center manhole (20-inch ID). The sprayhead will be lifted, lowered, and rotated to direct the slurry discharge flow as needed. All movements will be remotely controlled with observations by means of a closed circuit television (CCTV) camera in the control room. Use of the crane will avoid imposing any load on the silo dome within the restricted capped center area (30-feet diameter). The

TABLE II

Bentogrout Slurry Application

Mix: Solids % Weight	Hose ID (in.)	Gun ID (in.)	Time min.	Flow GPM	Spread L (ft.) x W (ft.) x T (in.)
25[1]	1-1/4	1	4.5	40	14 x 2
25[1]	1-1/4	1/2	5	40	45
30	1-1/4	1	8.5	40	10 x 2
30[2]	1-1/4	1/2	5	40	42
25	1-1/2	1	26.5	40	40 x 12
25[2]	1-1/2	3/8	5	40	60
25[3]	1-1/2	3/8	15	40	8-ft. diam. cone waste pile

1. Vertical, unrestricted discharge into pit, to determine flow characteristics.
2. Horizontal spray to determine trajectory.
3. Knocking Down Waste Pile installed in the east end of pit.

TABLE III

Bentogrout Mix Viscosities

Slurry Solid wt %	Yield Stress dynes/sq cm	Plastic Viscosity Centipoise	Temperature degrees C
25	201.3	108.4	13
30	547.3	119.1	12
32	441.4	5842.0	14
35	767.4	4215.8	13
40	1788.3	4964.4	13

TABLE IV

Total Dynamic Head Pumping Bentogrout Slurries

Solids	Hose ID (in.) x L (ft)	Gun Disch. ID (in.)	Flow GPM	Total Dynamic Head PSI
25	1-1/4 x 100	1	40	50
25	1-1/4 x 100	1/2	40	60
25	1-1/4 x 100	3/8	40	65
25	1x 100	1	20	40
30	1x 100	1	20	120
30	1-1/4 x 100	1-1/4	20	120
30	1-1/4 x 100	1-1/4	40	170
30	1-1/4 x 100	1/2	40	270
32	1-1/4 x 100	1-1/4	40	220

live load will not exceed 700 pounds at any point on the dome surface outside of the capped area. The manways in use for the distributor/sprayhead, cameras and lighting will be covered by glove bags during installation and operations to avoid radon emissions to the atmosphere. In addition, the existing and upgraded Radon Treatment System (RTS) will be operated per FEMP Standard Operating Procedures prior to start of installation and operations. Air volume of the silo atmosphere displaced by the installation of the bentonite will be handled by an exhaust blower installed in the RTS Building.

The BentoGrout mix will be prepared by alternate batching to provide continuous slurry feed to the distribution/sprayhead assembly at a rate of 40 gpm for the optimum mix (25% solids) and 20 gpm for the heavy mix (35 to 40% solids). The optimum mix will be used to cover the entire surface area with the exception of the irregular surfaces (waste piles) where the heavy mix will be used. First the waste piles will be covered by stacking layer on layer to one 1-foot thickness, then the remaining surface area will be covered using optimum mix to a one 1-foot thick blanket. At completion, the waste piles will be sprayed with the optimum mix as well as the silo wall at the entire peripheral interface. The slurry composition and batch volumes for the optimum, intermediate and heavy mixes are presented in Table V.

At a 200-gallon batch and a five 5-minute batch mixing time, the slurry will be pumped continuously at an average rate of 40 gpm, while at 100-gallon batch and five 5-minute batch mix time, it will be pumped at an average continuous rate of 20 gpm. Continuous operation will be achieved by alternating between the two mixing tanks.

At the end of daily operations and job completion, the mixer tanks, slurry pump and piping, and distributor/sprayhead will be flushed with water, discharging the slurry into the silo. Then the flush water will be diverted and recycled into the flush water tank for reuse and/or disposal.

The instrumentation and controls for the bentonite covering system, for the most part, are conventional electronic products with a few special devices. Interlocks are used where needed. Figure 4 indicates the information/control flow and the layout of the Control Room. Figure 5 indicates the equipment arrangement at the facility.

The bentonite handling and mixing measurements and controls include level, flow, pressure, speed and power. For the bentonite distributor/sprayhead and the basket suspended from the crane, the following types of instruments will be used: flow, pressure, power, and limit switches. The closed circuit television (CCTV) system to monitor the depositing of bentonite consists of two cameras and two lighting bars of four lights each; these must be put into the silos through the 20-inch peripheral manways and the camera must be able to zoom, pan, and tilt. For the headspace within the domes of the silos, the dynamic measurements include temperature, differential pressure, relative humidity and radon gas concentration. This

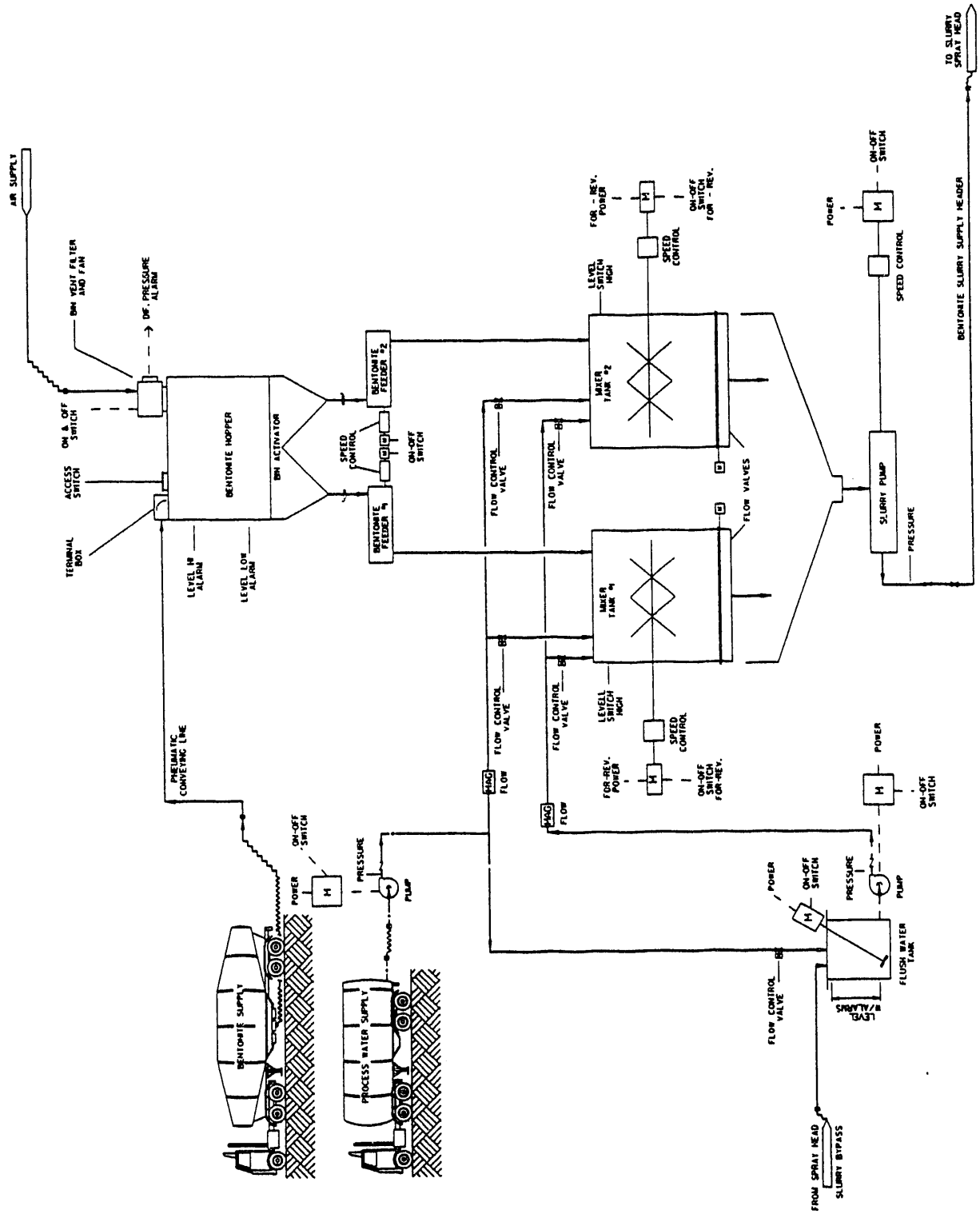


Fig. 1. K-65 Silos Bentogrout covering system mix and transfer operation.

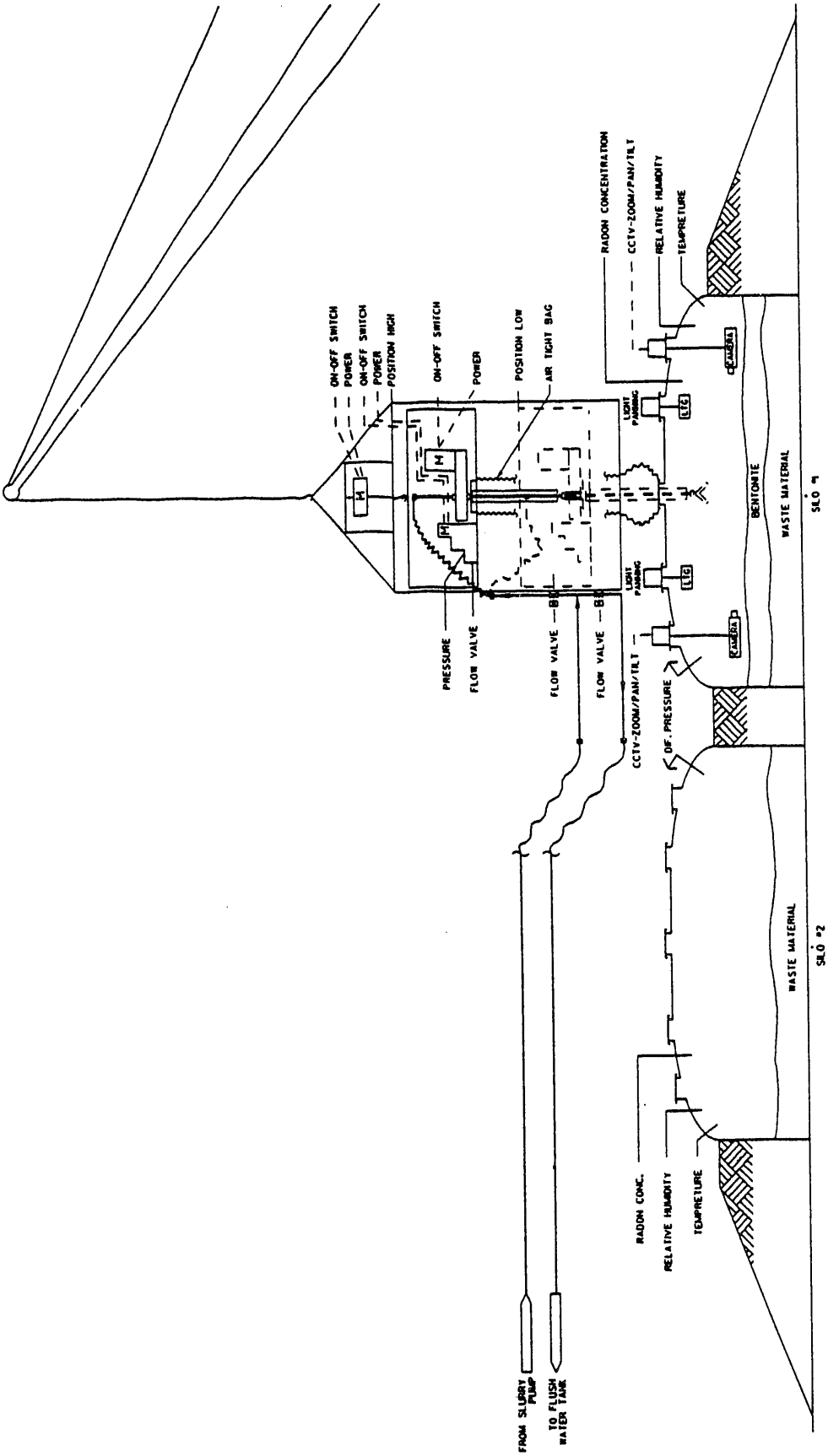


Fig. 2. K-65 Silos Bentogrout covering system distributor/spray head operation.

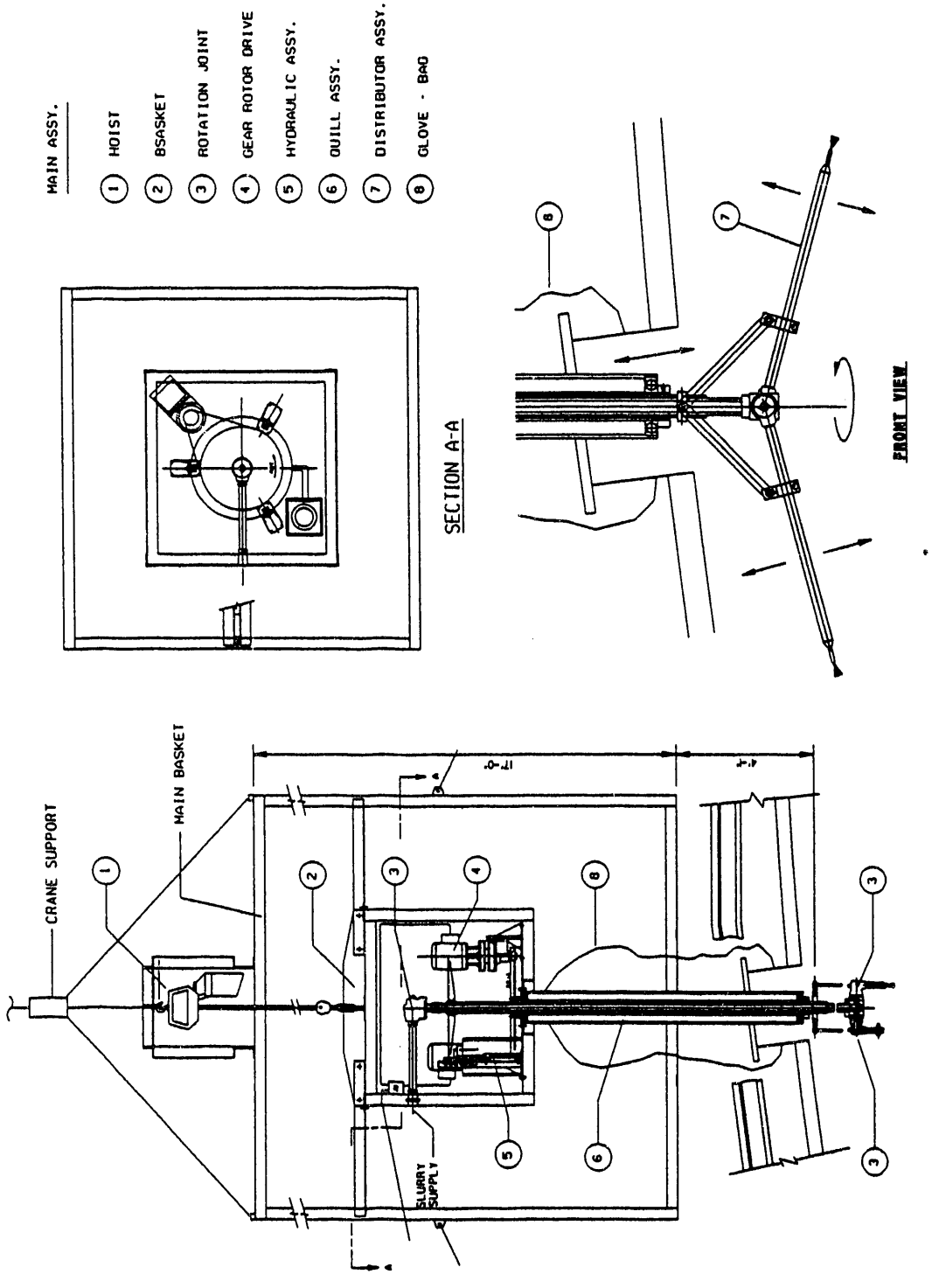


Fig. 3. K-65 Silos Bentogrout covering system distributor/spray head.

TABLE V

Mix Formulas

Description	Optimum	Intermediate	Heavy
% wt. BentoGrout	25	30	40
% wt. Water	18	14	9
Specific Gravity	1.18	1.22	1.31
Batch Volumes			
Water (gal)	176.4	170.8	79
BentoGrout (lbs)	490.0	610	434
Batch Volume (gal)	200.0	200	100
Mix Sequence			
Optimum and Intermediate Mixes	Time (Min.)	Time Sequence (Min.)	
Water Addition	3	(0 through 3)	
BentoGrout Addition	3	(1 through 4)	
Final Mixing	1	(4 through 5)	
Total Time (Min.)	5		
Heavy Mix	Time (Min.)	Time Sequence (Min.)	
Water Addition	1.5	(0 through 1.5)	
BentoGrout Addition	2.5	(1.5 through 4)	
Final Mixing	1.0	(4 through 5)	
Total Time (Min.)	5.0		

information will be logged into reports for a year with copies forwarded on a monthly basis to the U.S. EPA. The report may conclude that the purpose and objectives as set forth in the K-65 Silos 1 and 2 Removal Action have been met.

CONCLUSION

The following activities have been successfully achieved: 1) Process Technology identified by the Work Plan to reduce chronic radon emissions and to control potential releases of K-65 material from OU-4, Silos 1 and 2 by covering residue with bentonite base blanket has proved to be a workable and suitable concept for full-scale implementation, including determination of the optimum BentoGrout mix and demonstration of the various mix formulas; 2) Design packages of the full-scale application facility have been developed based on the demonstrated technology with specific consideration to facilitate injection, distribution through the center manhole, and covering the 80-feet-diameter irregular residue surface with a 1-foot uniform layer of cover material; and 3) Instructions were specified for equipment/system test and performance criteria, installation sequence and construction acceptance criteria, including requirements to practice utilizing the empty Silo 4 to handle and position the main basket structure over the center manhole. Completion of the above activities will ensure having a fully checked and proven system prior to implementation of applying the cover material over the radioactive residue in the waste storage silos at the FEMP.

ACKNOWLEDGEMENTS

The authors express their gratitude to the management of Westinghouse Environmental Management Company of Ohio for permission to publish this paper. We thank the management of Parsons ERA Project for their permission and help to enable us to present this paper. Thanks are given to all members of the design team for all their hard work and help to meet the technical challenges associated with this project.

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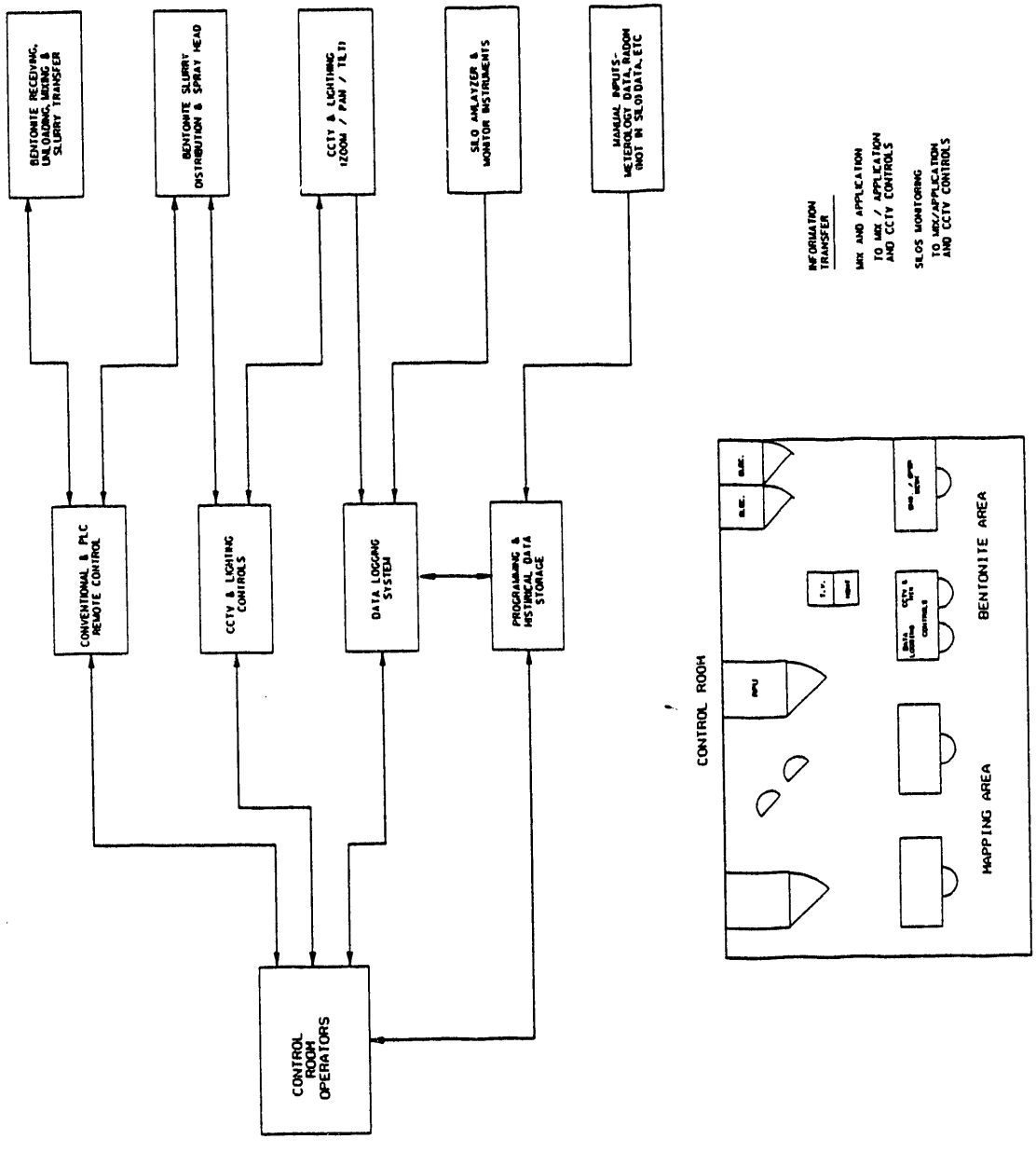


Fig. 4. K-65 Silos Bentogrout covering system overall control configuration.

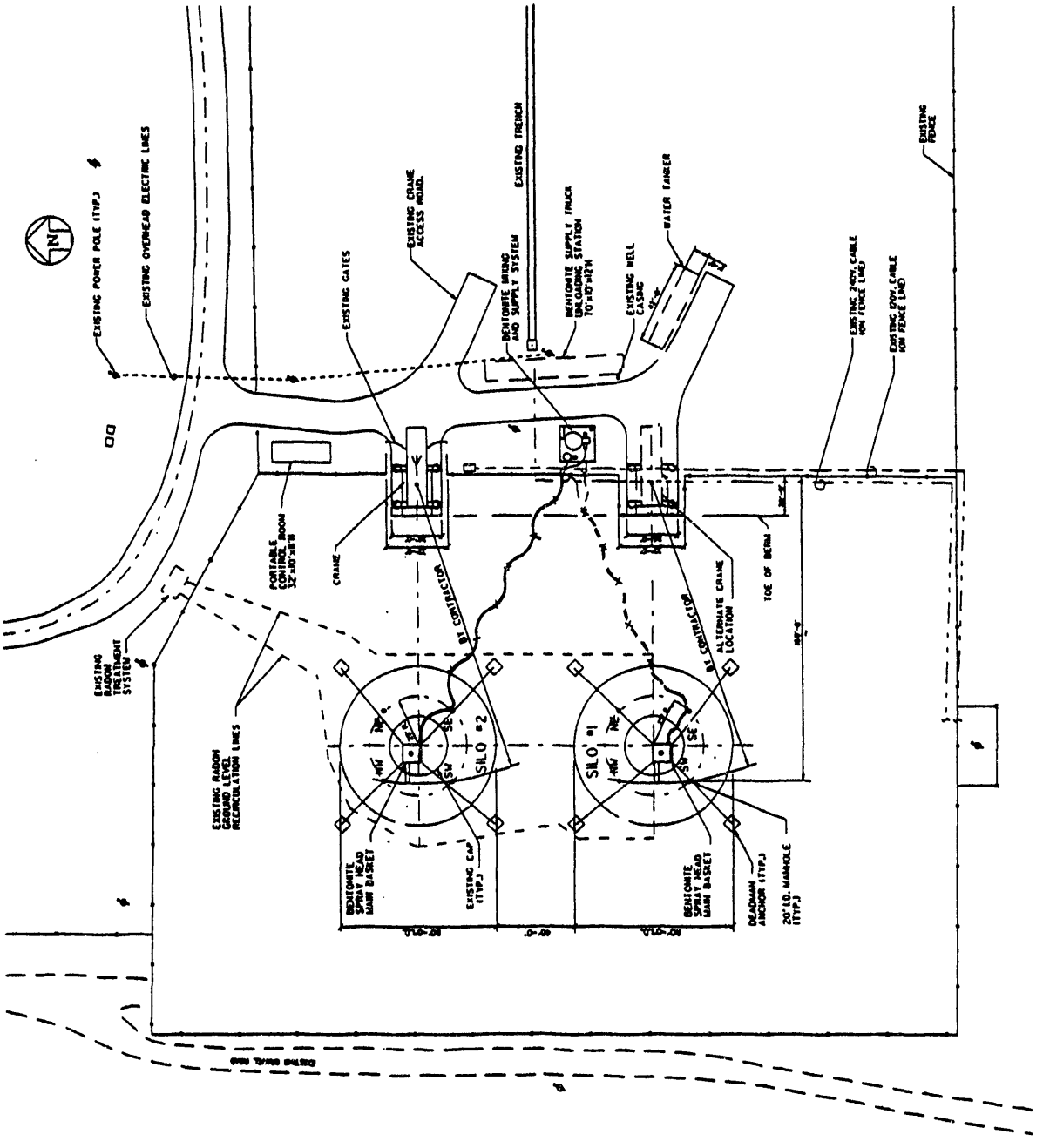


Fig. 5. K-65 Silos Bentogrout covering system facility site arrangement.

REMOVAL OF HEAVY METALS AND RADIONUCLIDES BY SEEDED MAGNETIC FILTRATION

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ABSTRACT

Removal of traces of heavy metal or radionuclide contamination from solution at high flow rate presents a considerable technical challenge. Low flow methods of treatment such as particle gravity settling require expensive large volume equipment, whereas traditional methods of filtration can cause significant energy costs. Magnetic filtration can be used to provide a low cost method of solid-liquid separation at high flow rate, provided contaminants can be selectively bound to a magnetic solid particle. This paper describes the use of such selective magnetic particles made up of inorganic particles coupled with organic polymers.

INTRODUCTION

There are relatively few strategic choices available for removal of a hazardous or radioactive contaminants from solution, and one of the most common and popular is to transfer the contaminant to a solid phase and undertake solid-liquid separation. Examples of other alternatives are detoxification by chemical conversion in solution, membrane processes such as reverse osmosis, or evaporation/condensation.

Solid-liquid separation is particularly appropriate where the contaminant is non-volatile and not suitable for detoxification by chemical conversion and where, in the interests of volume reduction, some selectivity is required to avoid collecting other harmless solutes.

Within the general category of solid-liquid separation, there are many sub-categories, such as floc-precipitation, ion exchange or seeded filtration. Each of these techniques have certain positive and negative characteristics. Floc precipitation, for example, is a convenient and effective way of achieving solid-liquid separation largely by gravity settling, but tends to be a low flow, high volume process not suited to treatment of high flow rates. Ion exchange, because of its chromatographic nature gives an excellent decontamination of the solution, good capacity of absorption, and (in general) reversibility of the absorption process. However, it may be inappropriate where the solution to be treated has a large burden of solid particles, or the contaminant is partially in solid form already. A feature of ion exchange is that the absorbent should ideally be used in the form of a fairly large particle (of the order of a millimeter diameter) to allow suitable flow characteristics. This requirement in turn requires that absorption must take place throughout the internal volume of the particle and not just at the surface. The requirement for a porous structure, and the need to recover the contaminant from deep within the pores, means that many chemically selective absorbents cannot be used because they cannot be manufactured into suitable ion exchange particles.

To overcome this problem the technique of seeded filtration was developed (1). In this process selective solid absorbents could be added or formed in the solution, mixed to bind the contaminant, and filtered out again. Because small particles are used adequate capacity can be achieved by surface absorption only. These characteristics are very advantageous for treatment of solutions where a high degree of selectivity is needed (for example, removal of cesium from solutions having a high concentration of sodium) or where the contaminant is partly in solid form (for example, polymeric plutonium species). Fundamental to the success of the technique is the efficient solid-liquid separation of small particles by advanced filtration techniques. However, filtration is a rather energy intensive process that becomes difficult to apply to high flow rates, particularly if the particles to be removed are small.

A further development of these principles is described in this paper. It became apparent that many of the positive features of the various techniques described above could be combined by the use of seeded magnetic filtration, in which selective magnetic seeds are manufactured which can bind certain contaminants and then be removed by magnetic filtration. The magnetic filtration process allows removal of small magnetic particles at a low pressure drop, and allows discrimination between the magnetic particles of interest and non-magnetic particles of no interest. Our focus in designing such seeds is the development of composites of organic polymers and inorganic particles. Examples of the general process for regenerative magnetic filtration treatment are well established, and the necessary hardware is available (2,3).

General techniques for producing magnetic particle composites of this type have been developed as a result of rapid advances in technology for toners for photocopiers and laser printers. These techniques can be adapted to the development of magnetic particles which can selectively bind contaminants of concern.

PROCESS DESCRIPTION

The elements of the process are as shown in Figs. 1 and 2.

1. Contaminated water enters into a treatment vessel where it is mixed with cleaned activated resin in a controlled manner which guarantees that the flow characteristics and the contact time of the water with the resin particles is sufficient to ensure that the

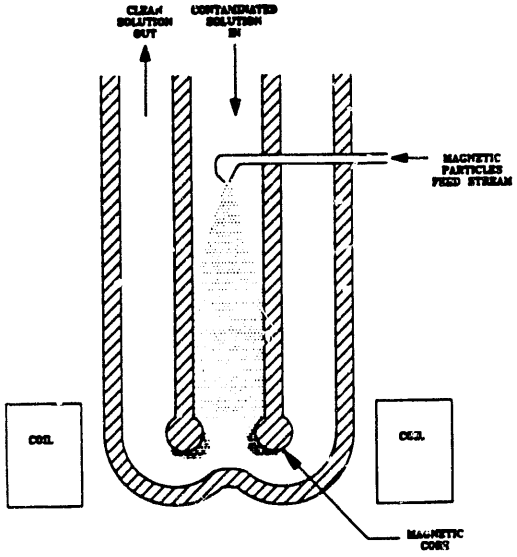


Fig. 1. Continuous feed/adsorption of contaminant from solution.

contamination will be absorbed on to the active surface sites on the resin (Fig. 1).

2. The resin/water mixture then enters a magnetic separation vessel in which the resin is separated from the water.
3. The purified water flows from the separator.
4. The contaminated resin is removed from the magnetic filter and passed through a decontamination cycle (Fig. 2)
5. Purified resin is re-cycled to the mixing vessel, and the contamination is removed for subsequent isolation.

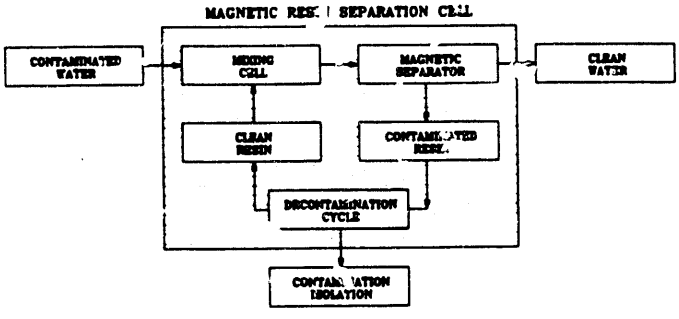


Fig. 2. Process schematic.

The desired objectives of the absorption process are that the kinetics of absorption should be extremely rapid, to allow absorption to take place within a small volume of solution at high flow rate. This property allows process equipment to be kept as small as possible. To achieve rapid kinetics the process requires small particles and interaction with the surface only.

EXAMPLES OF PARTICLE TYPES USED

In most applications of magnetic filtration reported to date, the absorption of contaminant occurs directly onto the magnetite surface, either in the form of solid particles of contaminant bound to the magnetite surface, or as contaminant bound to functional groups on the surface of the magnetic particle. Greater flexibility could be achieved, however, by incorporating the magnetic particle in a composite matrix.

As is well known, absorption of metal ions onto ion-exchange resins takes place at active sites on the resin polymer. Magnetic resins may be designed so that they contain a "functional group" capable of selectively extracting a particular ion, or group of ions in the presence of higher concentrations of other ions which it is not desired to remove.

Selective magnetic particles can be produced by initially producing a composite material by binding magnetic (particularly magnetite) particles within a polymer. The surface of the polymer can then be "functionalized" to create the selective removal capability. Ideally the surface should be convoluted to provide a high surface area for absorption as shown in Fig. 3. Two examples of this type of resin are now described.

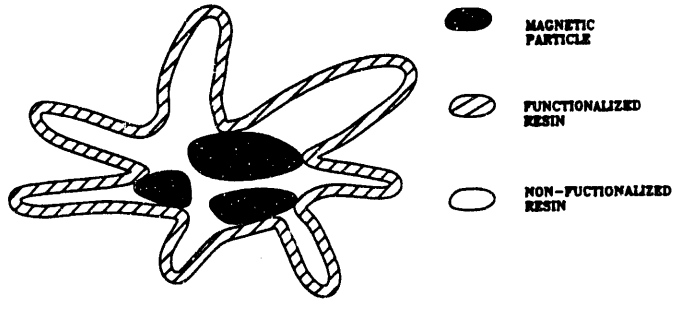


Fig. 3. High surface area magnetic composite particle.

Copper Removal Using Amidoxime Functionalized Magnetic Polyacrylamide Resin

In this example a resin was created which consisted of magnetite surrounded by an amidoxime chelating polymer. To produce the resin powdered magnetite was mixed with acrylamide and N,N'-methylene bis acrylamide, combined with water, tetramethylene diamine and catalytic quantities of ammonium persulphate. After polymerization the resin was crushed, ground, and washed in distilled water. It was then equilibrated with hydroxylamine to convert the $-CO-NH_2$ groups to the amidoxime function prior to the experimental magnetic removal of copper. The functionalized resin was finally conditioned by washing in distilled water, then 0.5M HCl, and cleaned in distilled water.

The resin typically retained 2 grams of copper per liter of wet settled resin, of which about 20% could be recovered by the regeneration procedure.

Potassium Removal Using Bis-phenol 'A' Based Magnetic Polyester Resin

In a separate example a bis-phenol 'A' based magnetic polyester resin composite of a type used for photocopier toner applications was used for the purpose of removing potassium from solution, by the type of procedure outlined above. The superior physical properties of this resin allowed the recovery of more than 90% of the potassium in the regeneration cycle.

Composites Composed of Selective Seeds Bound to Magnetic Particles

It is possible to take small particles which are capable of selective ion removal in their own right and physically bind them to a magnetic particle. This second method is shown in

Fig. 4. An example of such a composite would be potassium cobalt hexacyanoferrate bound to magnetite in an organic polymer for removal of cesium.

SAVANNAH RIVER SITE TEST PROGRAM

A two phase test program is planned at Savannah River Site (SRS) to demonstrate the ability of magnetic particles to remove lead, cadmium and mercury from samples of process effluent and contaminated groundwater with sufficient Decontamination Factors (DF) for full scale application.

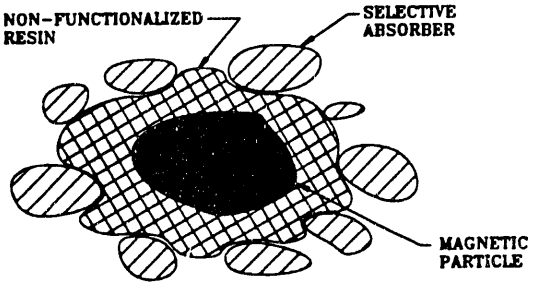


Fig. 4. Bound particle magnetic composite.

Phase 1 Lab Scale Test

The primary objective of the first phase will be to produce magnetic particles that can effectively remove contaminants from simulated process effluent and groundwater prior to investing in the pilot scale equipment. Lab scale tests will be performed with equipment similar to that depicted in Fig. 1 (above). The decontamination factor (ratio of contaminant in the influent to the contaminant remaining in the effluent) will be measured for at least lead, mercury and cadmium. Following completion of these tests, performance of pilot scale equipment will be determined.

Phase 2 Testing

The primary objectives of the second phase will be to perform process optimization studies, determine the actual DFs which can be achieved in the removal of heavy metal contaminants, and determine whether treatment of heavy metals contamination in process water and groundwater by magnetic separation is a viable option for SRS.

A small pilot scale unit (10 - 20 gallons per hour) will be constructed using a magnetic filter which is scaled down from a commercially available design. Initial tests will be performed using a process design similar to that shown in Fig. 5. The tests will seek to optimize the treatment process and determine effectiveness for other contaminants.

Some variables that may be optimized during the pilot scale tests include:

- magnetic filter field strength
- DF as a function of the ratio of magnetic particle concentration to the concentration of contaminant(s)
- DF as a function of mixing zone residence time
- effects of water chemistry (ie. other chemicals, contaminants, pH, etc.)

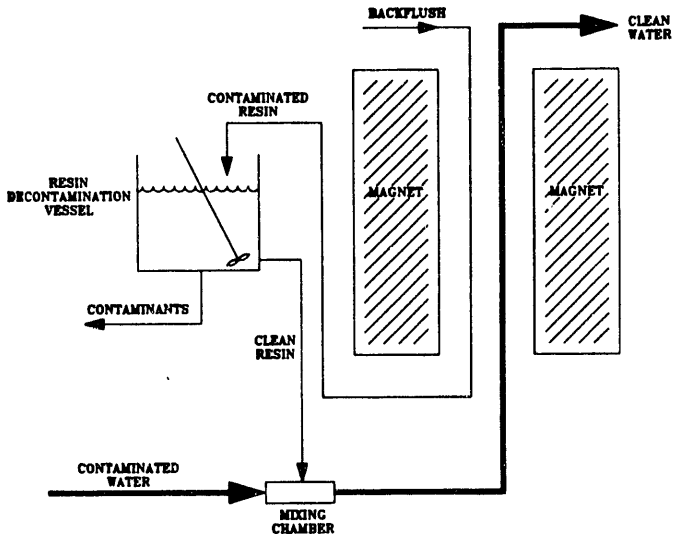


Fig. 5. Magnetic filtration flow diagram.

Additionally, tests may be performed for treating other contaminants including:

- uranium
- plutonium
- pertechnetate
- iodine
- cesium
- strontium
- arsenic

Following completion of the Phase 2 testing, a preliminary design for a full scale treatment system will be developed. Capital and operating costs will be estimated and the anticipated performance of a full scale system will be determined. The performance of the pilot scale magnetic separation unit will be documented and compared both technically and economically with other treatment technologies.

APPLICATION TO WASTE TREATMENT/REMEDIATION PROJECTS

A magnetic filtration system similar to the flow diagram shown in Fig. 5 would be used for full scale applications. Contaminated water would be pumped out of the ground, mixed with clean magnetic resin particles in a mixing chamber, passed through a magnet where the contaminants would be removed and returned to the ground. When the pressure drop across the magnetic zone increases significantly, the water pump would be turned off. The magnetic zone would be backflushed with air or water to remove the contaminated magnetic resin particles. Once the short backflushing operation is complete, the water pump is turned on to continue processing the contaminated water. The backflushed particles would be accumulated in a decontamination vessel where the magnetic particles would be regenerated using acid rinses and the contaminants removed.

The estimated costs for treating groundwater with a magnetic separation process as described in this paper range from approximately $1.89 to $2.80 per 1000 gallons of water. This estimate encompasses treatment of 1 billion gallons of groundwater per year for a ten year period to 0.5 billion gallons per year for a three year period. Total capital costs,

including a magnetic separation vessel, pumps, tanks, piping and instrumentation were estimated at $900,000. Annual operating costs assuming all capital costs are written off during the treatment period, including labor, power, chemicals and materials were calculated to be $1,400,000. to $1,890,000.

CONCLUSIONS

1. Selective magnetic particles made of inorganic particles coupled with organic polymers have been produced.
2. Seeded magnetic filtration has been demonstrated in the laboratory for selective removal of metals from solution.
3. A demonstration program for the removal of lead, cadmium and mercury from process effluents and contaminated groundwater is planned for the fall of 1991 at Savannah River Site.
4. Preliminary cost estimates indicate that magnetic filtration using selective magnetic particles is very attractive ($1.89 to $2.80 per 1000 gallons) compared to other treatment technologies.

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SORTERS FOR SOIL CLEANUP

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ABSTRACT

A soil sorter is a system with conveyor, radiation detectors, and a gate. The system activates the gate based on radiation measurements to sort soil to either clean or contaminated paths. Automatic soil sorters have been perfected for use in the cleanup of plutonium contaminated soil at Johnston Atoll. The cleanup processes soil through a plant which mines plutonium to make soil clean. Sorters at various locations in the plant effectively reduce the volume of soil for mining, and they aid in assuring clean soil meets guidelines.

INTRODUCTION

Environmental remediation can mean cleanup of radioactively contaminated soil. The Defense Nuclear Agency (DNA) is cleaning plutonium contaminated soil from a 24-acre site at Johnston Atoll (JA). Potentially contaminated soil is excavated and processed through a soil cleanup plant. The plant uses various mining and milling methods to concentrate the plutonium in a small volume for waste disposal. Most of the soil from the plant is clean, and it can be used beneficially. The DNA soil cleanup plant is operated by TMA/Eberline with engineering support from Morrison Knudsen.

In every soil cleanup which removes soil from the ground, the removed soil will contain a mix of contaminated soil and clean soil. This happens for various reasons, including spotty site contamination, uncertain boundaries between clean soil and contaminated soil, and use of earth-moving equipment and methods which cannot selectively excavate contaminated soil only.

One feature of the cleanup plant is on-line continuous sampling of soil for plutonium content with automatic sorting of soil to either clean or contaminated paths based on the sampling.

BACKGROUND

Contamination at JA occurred in 1962 when the atoll was used for testing the effects of high-altitude nuclear bursts. The tests used Thor missiles to boost nuclear devices in vertical trajectories. In four instances problems occurred with the Thor, and the nuclear devices were intentionally destructed by chemical explosives to prevent nuclear yield (1). One destruct at 59 sec after launch deposited debris and plutonium throughout the atoll. A second destruct while the Thor was still on the launch pad contaminated a smaller land area but to much higher levels. The other two destructs, at 152 sec and 13.5 min after launch, did not cause significant local contamination.

Plutonium was dispersed by the explosive high temperatures and pressures. It either attached to missile fragments and soil particles or became individual plutonium oxide particles covering a wide spectrum of sizes. Debris and larger particles settled on the ground to contaminate surface soil. Initial soil cleanups removed debris that was visually spotted and contamination sensed by alpha radiation detectors. Some contaminated surface soil was scraped and removed, and some was covered with clean soil.

Over the years, significant changes have taken place to the JA contamination. One change is growth of a plutonium daughter which emits a gamma ray. Gamma detectors now can find plutonium where alpha detectors might not. Gamma surveys have found many small "hot spots" which were then dug up and removed. A comprehensive survey in 1980 defined the major boundaries of contamination (2). In 1984 about 15 acres of contaminated soil were scraped and moved to combine most contaminated soil in a single, 24-acre radiological control area.

The weather has also changed the contamination. Although plutonium oxide is insoluble in general, small oxide particles can be removed from the ground by wind or transported below the ground surface by rain (3). Thus, much of the surface soil is now deficient in small particles, and a hot spot may in fact be only one or a few "hot particles." Some contaminated ground has been moved by erosion.

Many hot spots amount to only a few shovelfuls of soil. Often when this soil is divided, radiation checks show only one half is contaminated. By repeating the divide-and-monitor routine many times, activity may be reduced to a single plutonium oxide particle. The soil that is free of the particle is clean. Sorting soil based on radiation measurements is a soil cleanup.

In 1987 DNA had TMA/Eberline study the feasibility of automatic soil sorting for cleanup (4). TMA/Eberline built a test rig which moved bags of soil on trolleys beneath detectors. Radiation sources were in some bags. The system gave a switching signal when radiation count exceeded set levels. The study evaluated the effect of source strength, trolley speed, count time, background radiation, and detector-soil geometry. It concluded that automated sorting would be beneficial for JA cleanup.

RESULTS

In 1988 DNA had AWC, Inc., design and build a soil cleanup mining plant to include automated soil sorters. AWC constructed the plant at JA with four sorters, each having a conveyor with detectors toward the feed end and a gate at the discharge end. The conveyors have flat, 3-ft wide belts which move soil in 0.75-inch thick layers. Each detector system has fifteen 4-inch square gamma detectors in two adjacent rows crosswise to the belt. The detectors are about 1 inch above the layer of soil. Gates are 3-ft wide, standard pant-leg type with a pneumatically driven flapper for diverting soil to one of two removal conveyors.

DNA set plant design criteria. Sorters must sample continuously and no increment more than 0.1 m^3 may sort clean if it contains more than 500 Becquerels transuranium element alpha activity per kilogram of soil (Bq/kg). To further assure "clean soil" meets the guide, no 0.01 m^3 increment may have more than 5 kBq. The 500 Bq/kg guide represents a limit for dispersed activity, and the 5 kBq guide a limit for particle activity. A plutonium oxide particle at the limit has about 70 microns diameter.

The sorter detectors were connected to a microprocessor which compared the sum of counts over 10 sec for all 15 detectors against a count related to the 500 Bq/kg guide, and the counts over 2 sec for individual detectors against a count related to the 5 kBq guide. If "guideline counts" were exceeded, gates would open to the hot path. System control was through a personal computer assigned operating parameters such as guideline counts, sorter conveyor speed (typically 20 ft/min), and detector-gate distance. Gates would open after a delay for travel from the detectors, and remain open for either the 10-sec or 2-sec count time plus an additional 2 sec to be sure an entire increment sorted to the contaminated path.

The soil cleanup plant was tested in 1989 (5). When optimized, about 2/3 of the plant feed soil sorted as clean and 1/3 sorted as contaminated. Further analysis revealed, however, that the time gates were open was proportional to activity. A hot particle could cause the guideline count to be exceeded for much more than one 2-sec counting interval. It might carry a swath of clean soil 3-ft wide and 10 sec (3 ft) or more long to the hot path. Other shortcomings with the sorter had the opposite effect of sorting contaminated soil to the clean path. For example, belt wipers wiped to the clean soil path, and belt speeds were not constant so hot soil could arrive at gates before or after gate openings.

DNA awarded TMA/Eberline a contract in 1990 to make the plant more efficient and effective, and to operate the plant to complete the cleanup of JA soil. A key factor in the selection of TMA/Eberline for the work was its approach to improving the soil sorters.

The new sorter design has an assembly of eight 4-in wide chutes instead of a 3-ft wide gate. The chutes in this "segmented gate" are extended and retracted by pneumatic cylinders. Full movement in either direction is set at 0.15 sec, and movement is repeatable within 0.02 sec. The sorter has a control panel which displays reaction time of each chute individually or in combinations up to all 8 chutes acting simultaneously. Other system improvements include a belt wiper which guarantees no soil sticking to the belts will fall to the wrong path, and an adjustable frequency drive which controls belt speed at 30 ft/min with less than 0.1 % variation under the most extreme conditions.

A separate single chute gate is in tandem with the segmented gates along the contaminated soil path. It can extract samples for quality control purposes such as verifying that a detected hot particle sorts to the hot path. The tandem gate may also be used to remove particles from further processing by the plant if mining methods which follow would not gain additional volume reduction.

In addition to the significant improvements made to the gates, the new sorters have major advances in radiation source detection. Each detector now has a single board counting computer, and all detectors in an array connect to a single controller computer which connects with a personal computer.

The counting boards compute activity and differentiate particles and dispersed activity. The exact position of particles on the belt is determined from the rate of change of counts. The precise positioning allows chutes to be open for no more than 2 sec when any hot particle is detected. It aids is reducing the volume of soil sorted to the hot path when only a particle warrants sorting.

The controller computer is a single board microcomputer which collects data, makes dispersed activity determinations, signals the activation of gates, handles feedback from the gates in the form of switch closures to confirm chutes are in the proper position, and tests for system upsets such as a failed detector. This computer services a local keyboard and display for the entry and editing of counting board parameters including high voltage and window widths, and it provides a communication link to the personal computer in the cleanup plant control room.

The central personal computer maintains a log of data, sends commands to the controllers, and requests and displays data from the controllers. It also generates summary reports of soil sorted by date, time, detector number, chute number, and activity, and maintains a running inventory of the weight of soil sorted to the clean and contaminated paths and the total activity for the contaminated soil.

CONCLUSIONS

Soil sorters made with precision hardware, microprocessors, and adequate programming cay be very beneficial in contaminated soil cleanup. They substantially reduce the volume of clean soil which goes with contaminated soil for waste disposal, and they provide proof that soil mined of its contamination is clean. They are an environmentally good cleanup tool, as they permit returning some soil to the ground rather than sending it to a disposal facility.

Soil sorters can provide more thorough sampling and higher quality data than is possible from the most comprehensive site survey. Further, the cost of excavating and processing soil through a sorter may be less than the cost of a site characterization. Based on the cost economy and performance of automated soil sorting demonstrated at JA, soil sorting should be useful for other radiological cleanups.

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THREE-DIMENSIONAL COMPUTER SIMULATIONS OF BIOREMEDIATION AND VAPOR EXTRACTION

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ABSTRACT

Numerical simulations of two remediation strategies are presented. These calculations are significant in that they will play a major role in the actual field implementation of two very different techniques. The first set of calculations simulates the actual spill event of nearly 60,000 gallons of No. 2 diesel fuel oil and its subsequent flow toward the water table for 13 years. Hydrogen peroxide saturated water flooding is then performed and bioremediation of the organic material is then calculated. The second set of calculations describes the vacuum extraction of organic vapors subject to various assumed formation properties and boundary conditions.

NUMERICAL SIMULATION OF BIOREMEDIATION

This report summarizes a preliminary set of two and three-dimensional numerical calculations we have carried out of a diesel fuel spill at Sandia National Laboratories, Livermore (also see Ref. 1). Our ultimate goal is to optimize a bioremediation strategy at this site. To simulate a bioremediation experiment successfully, we must first have a good estimate of the subsurface 3-D distribution of water and fuel oil. We are attempting to achieve a reasonable comparison with observed fuel oil subsurface migration as our first goal, and to examine sensitivity to factors such as infiltration of rainfall. This will provide a field validation of our model.

Setting up the TRACR3D Calculations

All the simulations were performed with the TRACR3D computer code (2,3). TRACR3D solves the equations describing unsaturated/saturated flow and multi-component transport in 1-D, 2-D or 3-D heterogeneous porous media. Transport mechanisms include advection (in both phases - air and liquid), diffusion, dispersion and sorption. TRACR3D also treats migration of volatile organics. A version of our model called TRAMP (4) simulates biological activity using Monod kinetic and inhibition equations; this version will be used for analyzing bioremediation tests at the site. All versions are based on a mass- conserving finite difference numerically implicit algorithm.

Our computational mesh consists of a regular array of 30 cells in each horizontal direction and 32 cells in the vertical (28,800 cells in all). The horizontal extent of the mesh is 50 meters on each side and is 32 meters deep, and encloses the trench and the area in which the bulk of the contaminant was observed.

A coarse interpolation of lithologic units was made, based on various cross- sections of the site (5). The resulting soil distribution is truly 3-D; however a better interpolation of units between the cross-sections will be done for future studies, after the laboratory determination of hydrologic properties becomes available. Figure 1a shows the computational block used in the simulations; each soil type is grayscale-coded, with dark to light gradient representing low to high permeability. The block is shown with a large cut-out so that the interior structure can be viewed. The trench is visible on the surface as the dark line lying diagonally, about in the center. The fuel leak occurred at that end of the trench which is not in the large light gray-colored surface soil region. Fig. 1b shows the same block from the reverse side, also with a large cut-out for viewing the interior structure. The soils are obviously varying in all three dimensions. The water table lies at the bottom of the block.

Next, the baseline material properties for the nine soils identified at the site are listed in Table I.

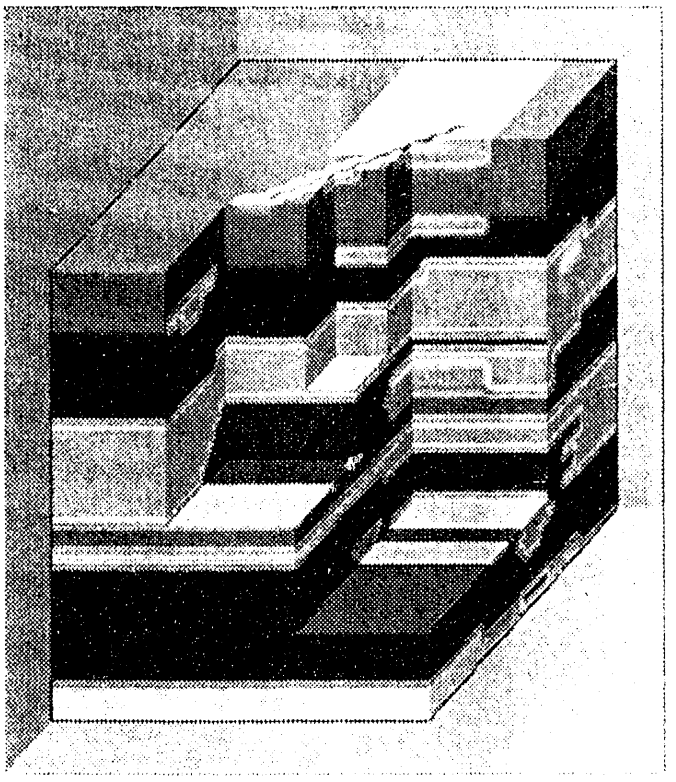
All the soils are assumed to have the same characteristic curves. This is probably far from correct, but will have to do until laboratory measurements are released. The Van Genuchten formulation was used for the matrix potential and relative permeability fields. Average dry soil density is 1.82 g/cc.

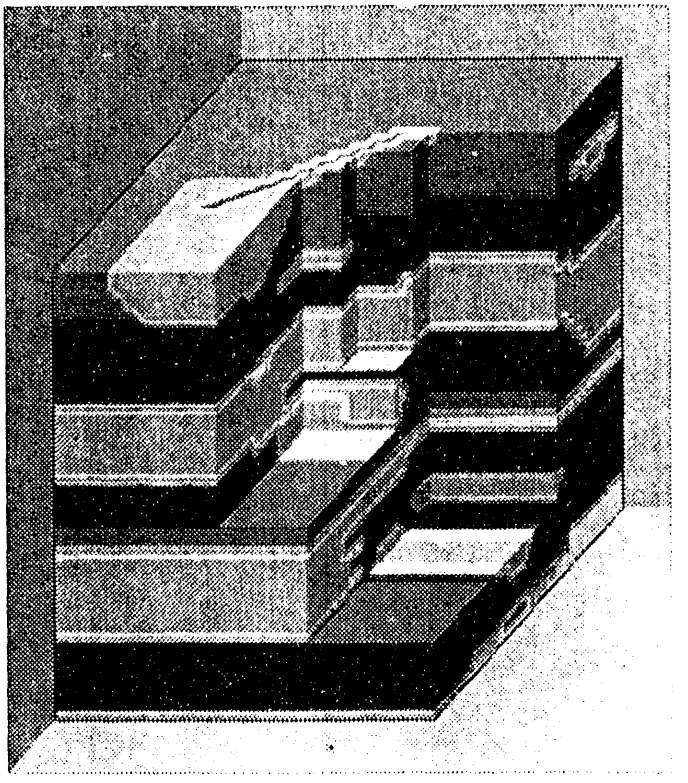
All the fuel oil (162 m^3) was injected at a uniform rate at a point near, but not in, one end of the trench over a ten day period. The point source is a single computational mesh cell centered at a depth of 1.5 feet (0.5 m). The trench (diagonal line on the surface in Fig. 1) was represented as a material with a very high permeability (1000 darcys). Here, as in the actual field event, the diesel fuel percolates laterally toward the trench and begins to flood the trench while at the same time the fuel oil moves downward from the point source. The left and right sides and bottom boundary were held to no-flow conditions; the front and back were also no-flow boundaries except at the bottom layer. This allows water to flow through the saturated zone in the approximate direction of the local groundwater flux, and permits rainwater filtering down to exit the domain without accumulating at the bottom.

A separate transport equation is solved for the diesel fuel. The influx at the top is pure diesel fuel, and the initial fluid saturation (0.356) in the subsurface is only water. We assume that the diesel fuel has the same density and viscosity as water. This constraint will be removed later when data are available on the particular oil components involved in the SNLL spill.

Results From the TRACR3D Calculations: Effect of Water Infiltration

This calculational study is still in progress. As an example of the level of detail considered, two simulations showing the effect of water infiltration are described here. Previous 2-D simulations (1) indicated that the infiltration of rainfall is a very important factor. It has since been established in

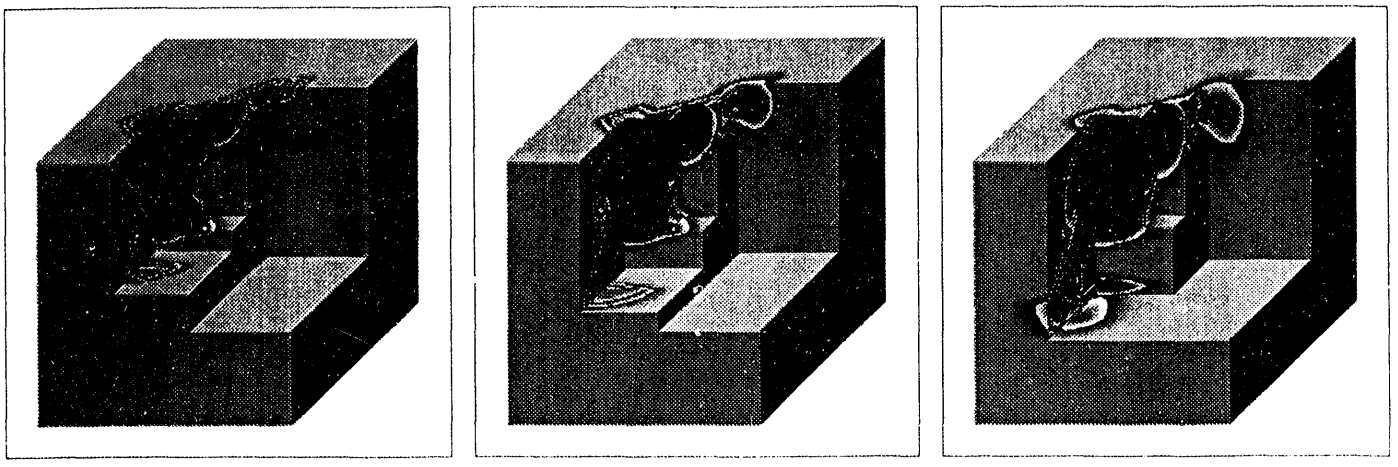




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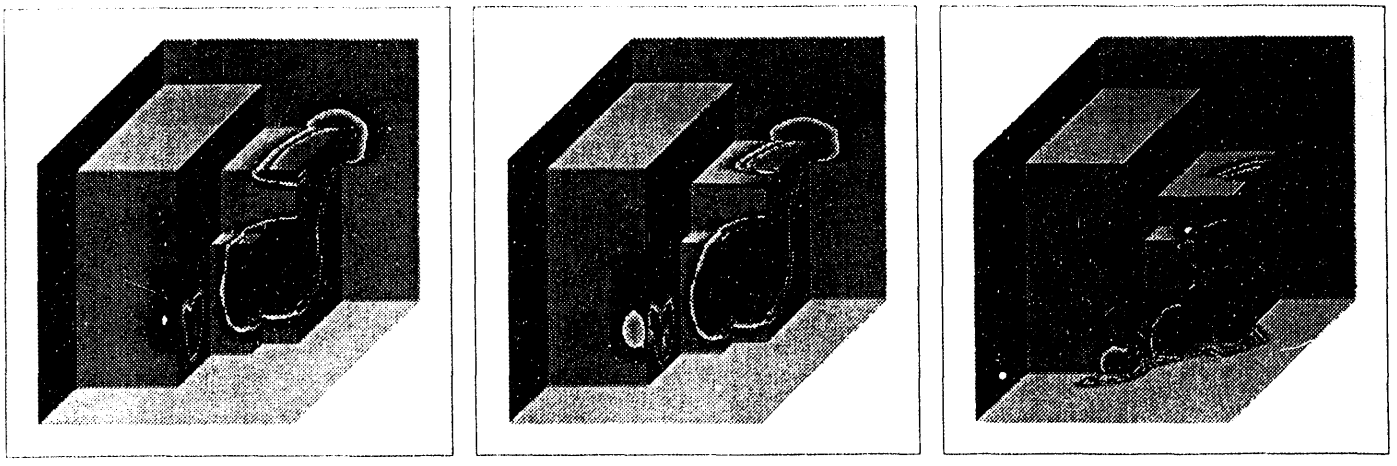
TABLE I

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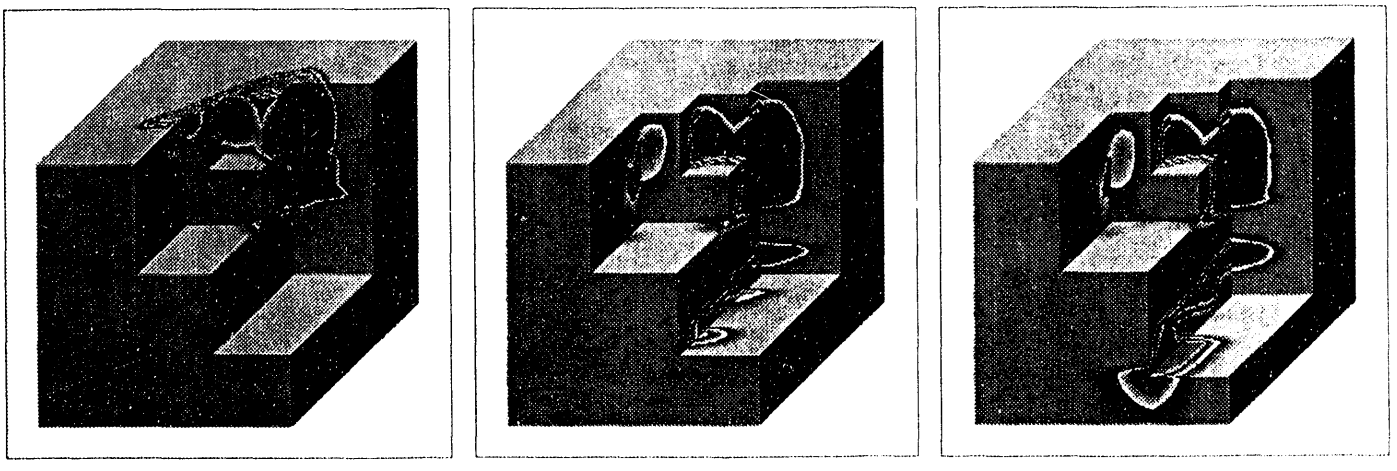
A B C

Fig. 2. Fuel oil concentration distribution after 0.5 years (a), 5 years (b), and 13 years (c), for the low infiltration rate case. Perspective corresponds to Fig. 1a. The total mesh dimensions are 50m x 50m x 32m deep.



A B C

Fig. 3. Fuel oil concentration distribution after 0.5 years (a), 5 years (b), and 6.5 years (c), for the high infiltration rate case. Perspective corresponds to Fig. 1a. The total mesh dimensions are 50m x 50m x 32m deep.



A B C

Fig. 4. Fuel oil concentration distribution after 0.5 years (a), 5 years (b), and 6.5 years (c), for the high infiltration rate case. Perspective corresponds to Fig. 1b. The total mesh dimensions are 50m x 50m x 32m deep.

250 mg/kg, with light shading representing low concentration and dark corresponding to high concentrations. The background shading in Figs. 2-4 does not represent any concentration (nor does it correspond to any soil type). The oil moves a considerable distance downward in the first half-year. For example, the 1,000 mg/kg level has just reached to the 70 foot depth at one very localized spot. By five years, the 10,000 mg/kg concentration has just arrived at that depth, but there is still nothing at the water table level. The deepest fuel oil is moving laterally along the high permeability layer at about 65 -70 feet depth which lies just above a very low permeability zone. The permeability variations are channeling the transport along the paths of least resistance--sometimes that path is horizontal, sometimes vertical. (Lower concentration levels will be present even deeper but we arbitrarily chose 250 mg/kg as the smallest contour level to plot). The distribution of oil is very non-uniform. At five years (Fig. 2b), the general distribution is very similar to that seen at 0.5 years; the major difference is that more oil is present around the 65 foot depth level and less is present near the surface.

From five to 13 years (Fig. 2c), there is little further migration because of the low infiltration rate and the low rainfall (drought conditions). There is still a residual saturation near the surface, especially below the original leak point. Most of the fuel oil is at intermediate depths; only very little has reached the top of the water table. The bulk of the fuel oil is trapped in the low resistance layer at 65 feet depth by the underlying low permeability lens. The 10,000 mg/kg concentration level reaches about 70 feet, and the 1,000 mg/kg concentration level just reaches to the 90 feet depth mark.

In the high infiltration case, eighty percent of the rainfall was assumed to infiltrate the surface. Influx then for the first five years = (0.80) * (38 cm/yr) / (3.15 x 10^7 sec/yr) = 1.0 x 10^{-6} cm/sec and then the drought conditions were 10 percent of that (i.e., 1.0 x 10^{-7} cm/sec) for the following eight years. The concentration surfaces computed for this case are shown in Figs. 3a to 3c for years 0.5, 5 and 6.5, respectively. These correspond to the view of Fig. 1a. Figs. 4a to 4c show the concentration distributions at 0.5, 5 and 6.5 years for the view perspective of Fig. 1b. As in the previous case, the oil quickly flows into the trench; this is followed by a fairly rapid infiltration of oil. The plume migration slows considerably during the next few years. By 6.5 years, the oil has spread out over the high permeability layer at 65 feet depth, and has continued on to the water table region and is beginning to exit the calculational domain (Fig. 4c). There appears to be a discontinuity in the concentration of oil at depth in Figs. 4b and 4c -- this is only apparent. Oil is flowing around a low permeability zone and getting into the high permeability layer near the bottom through the back part of the domain, which can't be seen in this view, but is apparent from the reverse side (Figs. 3b and 3c). We have not continued this simulation further in time. Since we do not yet have the true material properties, these simulations serve primarily as sensitivity and scoping studies. After five years, however, the influence of the additional rainfall has pushed the contamination plume down to the assumed water table (a no flow boundary exists at a depth of 32 m). This simulation looks very much like the low infiltration case but with an accelerated time scale.

The actual diesel fuel distribution was measured in 10-20 foot depth intervals approximately 13 years after the spill occurred. (A summary of the results are shown in Figs. 1.9 to 1.16 in the Remediation report [5].) Figs. 5a-5c compare measured with calculated concentrations on one plane layer centered at a depth of about 40 feet. Fig. 5a shows concentration contours on this plane (at a depth of 40 feet) at 13 years for the low infiltration case and Fig. 5b shows contours from the high infiltration case taken at 6.5 years. Fig. 5c shows the measured concentrations on that same plane. Both simulations show a small region with a peak concentration over 1,000 mg/kg (upper right area of Figs. 5a,b,c), and a larger area of concentration in the region which is directly below the original leak point (lower left area of Figs.5a,b,c). Measured concentrations reached about 17,000 mg/kg in the center of this area; simulated values were close, with both cases showing a core region between 10,000 and 20,000 mg/kg. Measured and simulated peak concentrations in the smaller zone were in the range of 1,000 to 2,000 mg/kg. Even though we are not yet in a position to match the observed concentrations (since we still need to perform the simulations with laboratory measurements of material properties rather than estimates based on soil types), the comparison shown in Fig. 5 is very encouraging. The general shape and concentration levels are comparable (at this level and other levels not shown).

In both simulations, there are clearly three phases to the oil flow -- an initial gravity flow driven mainly by the weight of the oil (first 6 months); a second phase in which oil movement is driven primarily by infiltrating rainfall which displaces the oil; and a third phase, characterized by slow migration (capillary drive and diffusion) of the fuel oil after the "rain drive" is effectively eliminated by the drought. These simulations also clearly show that the three-dimensional nature of the source, boundary conditions and formation properties are strongly reflected in the resulting three-dimensional flow and transport.

Simulation of Bioremediation

Laboratory tests on soil samples from the SNLL site indicate that native bacteria can be stimulated to grow in the presence of diesel fuel oil at oil concentrations representative of the spill site. Further, bacteria will metabolize the diesel fuel oil components, and reduce oil concentrations by as much as a factor of 100. Bacteria were supplied with oxygen from hydrogen peroxide (H_2O_2) and nitrogen from an ammonium ion source. At high concentrations of dissolved oxygen and nutrient, bacteria grew at a furious rate and subsequent activity on the fuel oil resulted in a brown precipitate and a strong reduction in permeability. Gas binding (presence of gaseous oxygen bubbles) was another mechanism for permeability reduction. Permeability was not affected (or could be restored after a reduction induced by high doses of peroxide and nutrient) by flooding with low to moderate concentrations of peroxide and nutrient.

These laboratory experiments suggest that bioremediation of the SNLL site is feasible. Flooding of the site with H_2O_2 and a nitrogen-bearing nutrient should stimulate growth of in-situ bacteria which will in turn consume the diesel fuel. There are, however, questions of how much to inject, where and how fast, that need to be answered to assure a reasonably efficient remediation strategy. Numerical modeling can help by estimating the results of various remediation schedules.

The bioremediation sub-model of TRACR3D calculates bacterial growth and decay in the presence of organics in

porous media. It solves five nonlinear coupled time-dependent 3-D transport equations, one each for oxygen, nitrogen, two substrates (only one is exercised here) and microbes. Anaerobic to aerobic conditions are included. Monod kinetics are assumed. This coupled system is solved by an iterative finite-difference algorithm. The biological activity model (4) is similar to others published in the literature (for example, Ref. 6). The model requires a number of coefficients for the kinetics governing consumption of substrates and oxygen and nitrogen. These must necessarily be provided on the basis of laboratory experiments.

The primary goal of our modeling effort for this site is to provide field engineers with information that will help them decide how to design a good bioremediation strategy. A sensitivity study is in progress. In this paper, due to length

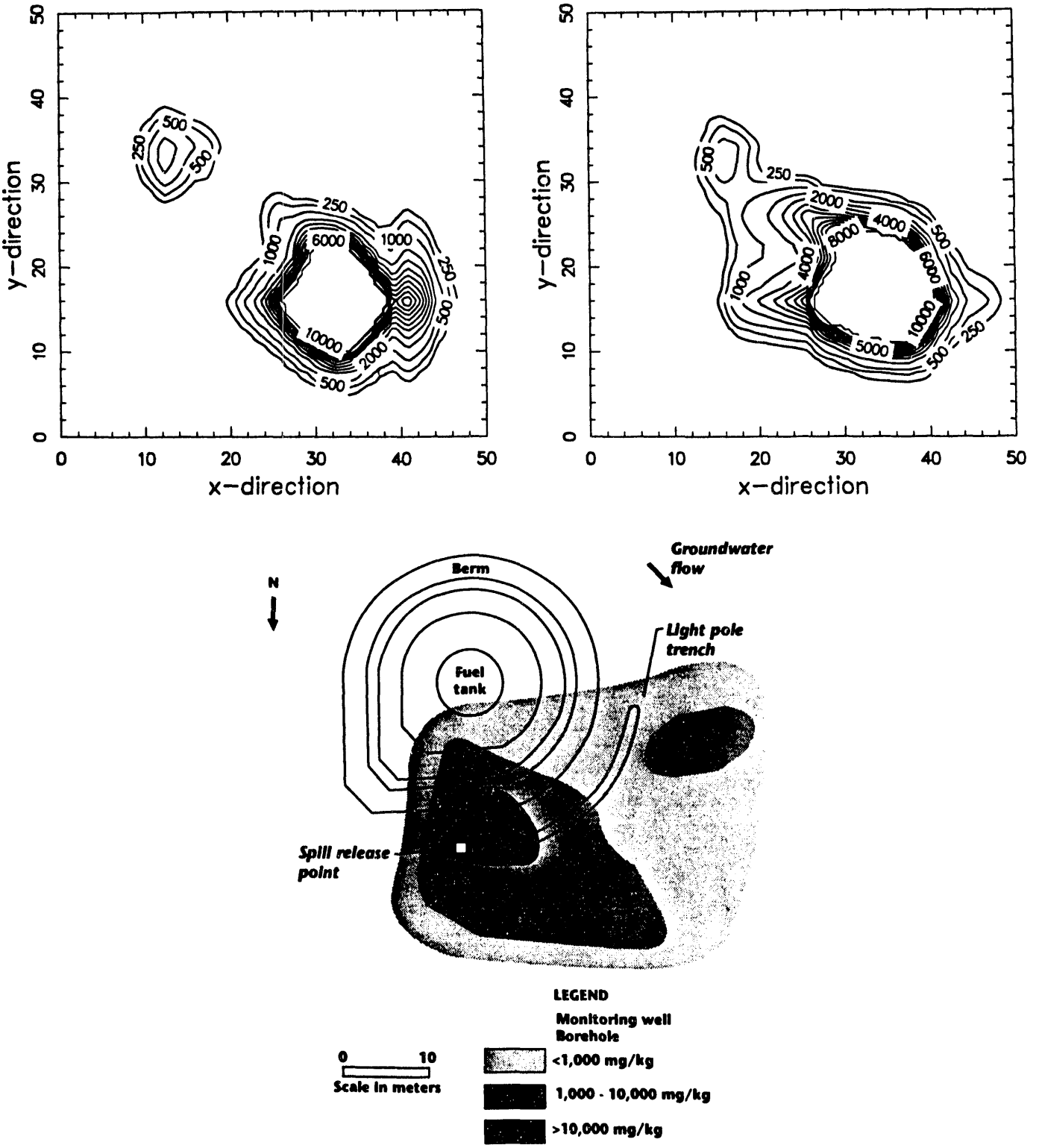
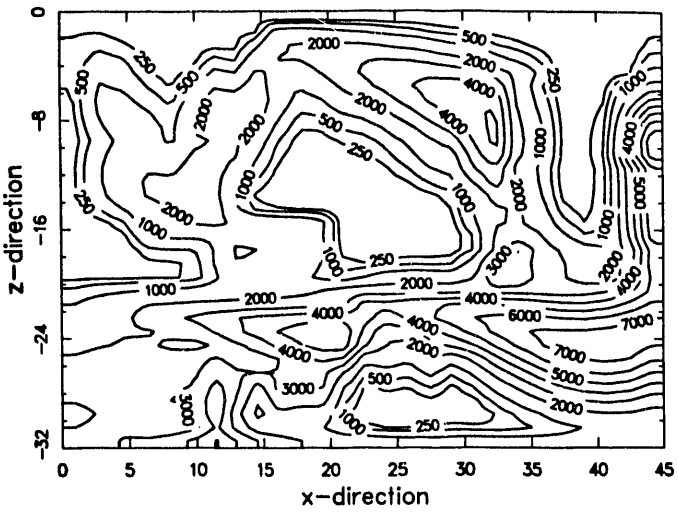
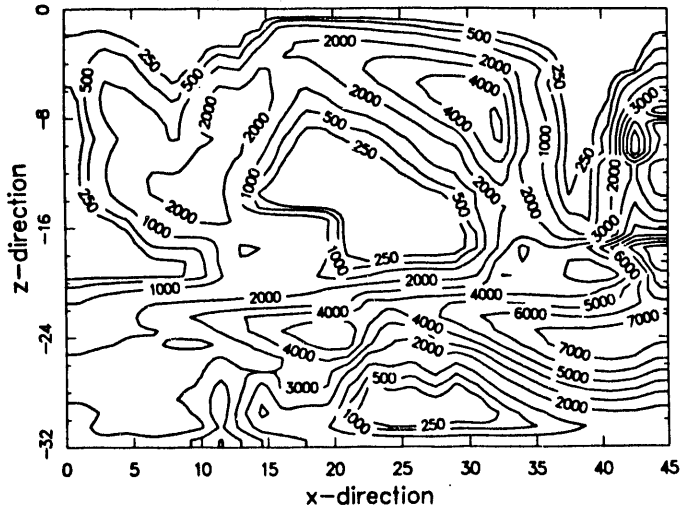


Fig. 5. Fuel oil concentration contours at the 40 foot depth after 13 years assuming low infiltration (a), after 6.5 years assuming high infiltration (b), and after 13 years as measured (c).





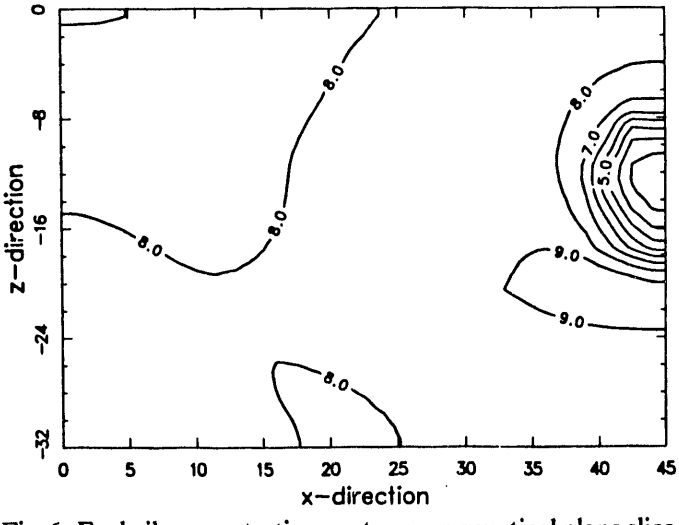
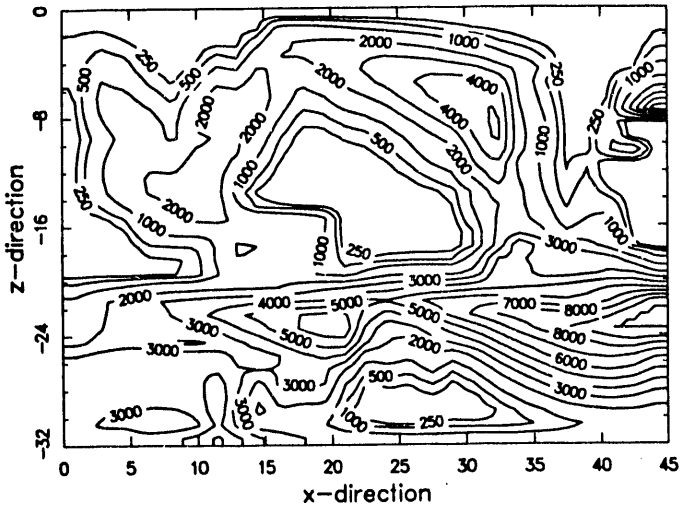
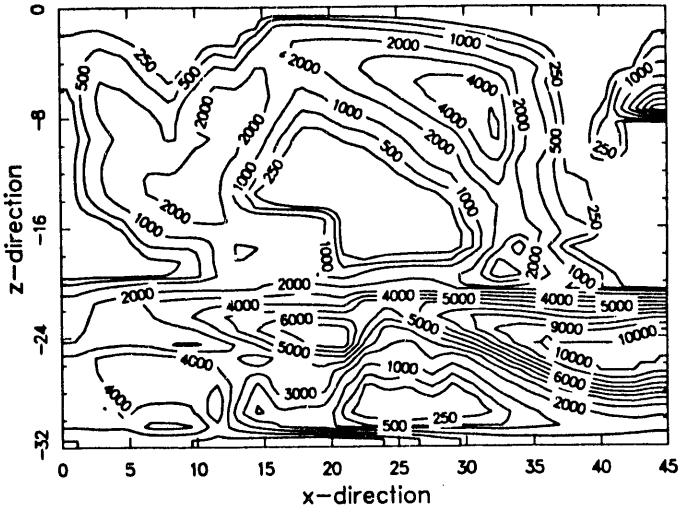


Fig. 6. Fuel oil concentration contours on a vertical plane slice oriented along the surface trench assuming low infiltration. Water is injected at a rate of 36 liters per hour along the right boundary, from z=-8m to z=-12 m. The water contains dissolved oxygen (from H_2O_2) at a concentration of 80 mg/L and a nutrient at a concentration of 30 mg/L. 6a) Initial oil concentration (mg/kg). 6b) Oil concentration contours after one month of injection. 6c) Contours of dissolved oxygen concentration (mg/L) at one month.





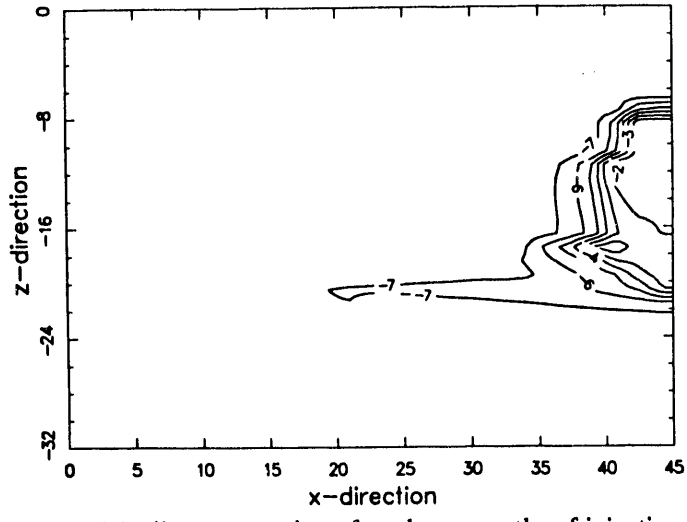


Fig. 6. (d)Oil concentration after three months of injection. 6e) Oil concentration after six months of treatment. 6f) Bacterial population distribution at six months (mg/L) Contours are log of concentration.

restrictions, we will only present a sample calculation to demonstrate the biological activity capability of our simulator.

In this calculation, the initial water saturation and oil concentration distributions are taken from the final state of the previously described flow and transport simulation. Material properties and boundary conditions are also the same as in the previous case. Water containing H_2O_2 and a nutrient are added at a constant rate of 36 liters/hour (about 240 gallons/day) through a single well open between 12 m and 8 m below the surface. The open part of the well is located in a high oil concentration region (right side of Fig. 6a: x = 45m, -12 < z < -8m). The injected water contains dissolved oxygen (from H_2O_2) at a concentration of 80 mg/L and nutrient at a concentration of 30 mg/L. The simulation was carried out to 240 days.

Results of this simulation are summarized in Figs. 6a-f, which show contours of various quantities on a vertical plane slice aligned with the surface trench. In Fig. 6a, the oil concentration contours at the beginning of the bio-stimulation test are shown. After one month (Fig. 6b) bacterial growth has become significant in the vicinity of the open well region; peak concentration of oil has dropped to around 5,000 mg/kg. In Fig. 6c, we see that oxygen is being strongly depleted by the bacterial growth around the well, and some diffusion from the surrounding formation is occurring in the air phase. By three months, bacterial action has reduced the oil concentration in the well region (42 < x < 45m, -18 < z < -8 m in Fig. 6d) to less than 250 mg/kg, from an initial concentration of 6- 8,000 mg/kg. After six months of injection, the cleaned up region has grown in the vertical to about 12 m (-20m < z < -8m) and about 5-6m in the horizontal direction (Fig. 6e). The size of the active region has not grown as fast in the second three month interval as in the first three months. The bacterial colonies have grown so numerous that they are in a roughly steady state with the incoming oxygen and nutrients, and there is no more oil in the immediate vicinity to consume. The injected water is not of sufficient volume to transport the bacteria very far from the well. Figure 6f shows the extent of bacterial transport at six months. Water movement has carried bacteria down to about the 20 m depth, and then horizontally 25m along the interface between a high and an underlying low permeability layer. Bacteria die off as they are transported away from the oxygen and nutrient rich well region. Higher injection rates would certainly move bacteria, oxygen and nutrients through a larger volume, but there is the worry of displacing oil down to the water table if the influx is too strong. In addition, permeability reductions can occur if too much biological activity is produced. This could result in undesirable changes in the flow pattern. Multiple injection wells will allow for more uniform oxygen and nutrient sources for the bacteria, without injecting excessive amounts of water. These are matters we plan to address in the complete sensitivity study.

NUMERICAL SIMULATION OF VAPOR EXTRACTION

For several decades, Area L at TA-54, Los Alamos National Laboratory, has served as a disposal site for many different organic liquids (7). These have included ethylbenzene, bromobenzene, toluene, chlorobenzene, tetrachloroethene, mix-xylenes, carbon tetrachloride, chloroform, benzene, 111- trichloroethene (TCA), trichloroethene, o-xylene and 124-trimethylbenzene. Most of the fluids were placed in pits and shafts, approximately 20 meters deep, spaced horizontally a few meters apart from each other. Detailed records of what was placed in each shaft are not available for the early years so an accurate description of the source term is not possible. An extensive monitoring program has been in place since 1988 to determine the location and nature of the plume of organic vapors which has been migrating from the initial disposal regions through the unsaturated geologic media.

As a result of this unrestrained movement, a vapor extraction program has been proposed in order pull the plume back to within a certain volume. Numerical modeling has been performed in order to evaluate the effectiveness of such a plan and to determine the optimum locations of the wells and anticipated power requirements. All the simulations were performed with the TRACR3D computer code (2,3). TRACR3D solves the equations describing unsaturated and/or saturated flow and multi-component transport in 1-D, 2-D or 3-D in heterogeneous, anisotropic porous and/or fractured media. Transport mechanisms include advection (in both phases - air and liquid), diffusion, dispersion and sorption, and also treats volatilization, biological activity and radioactive decay and decay chains. It employs a mass-conserving finite- difference implicit algorithm. It is very stable and robust.

In order to characterize the extent of the plume and to establish initial conditions for the model, a data base was developed which provides access to contaminant concentrations for each of thirteen chemical species, in nearly thirty monitoring wells, with up to ten sampling depths per well. Monitoring has taken place on nine different occasions, resulting in over 25,000 concentration readings. Three-dimensional volume-rendering graphics are employed to visualize the different contaminant fronts at different times. Figure 7 shows a three-dimensional representation of the TCA component of the vapor plume at Area L as measured on June 28 and 29, 1990. An interpolation scheme was written to weight the existing data set from roughly 30 monitor wells, each with up to 10 sampling depths each, in order to establish the continuous distribution shown in the figure.

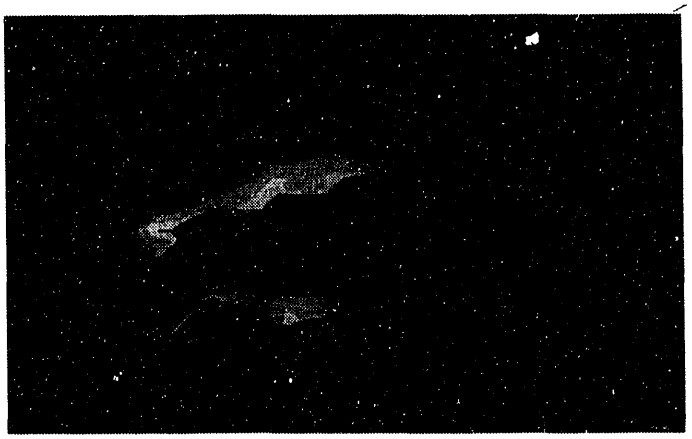


Fig. 7. A three-dimensional interpolated field of TCA vapor concentrations at Area L, TA-54, LANL, on June 28-29, 1990. The dimensions are 300m x 300m x 100m deep. Data was obtained from 30 wells, each of which had up to ten sampling depths. Maximum concentrations ranged up to 6000 ppm (0.6 percent by weight).

The general characteristics of this plume were used to set up an initial concentration distribution for a pilot-scale study of vacuum extraction. The following material properties were assumed for a fictitious contaminant and host formation material:

Molecular diffusivity of the tracer in the water:	0.00001 cm^2/sec
Molecular diffusivity of the tracer in the gas phase:	0.1 cm^2/sec
Molecular weight:	50 g/mole
Henry's Law coefficient	0.001
Sorption coefficient	0 (no sorption)
Dispersivities	0.1,0.1,0.1 cm (x,y,z)
Water saturation	0.10 cm^3/cm^3
Permeability	1,1,1 darcy (x,y,z)
Porosity (total)	0.25
Average particle size	0.1 cm
Compressibility of the matrix	0.0 cm^2/dyn
Irreducible water saturation	0.20 cc/cc

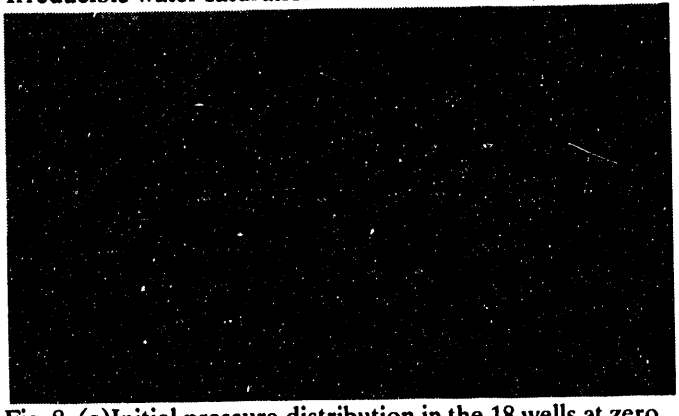


Fig. 8. (a)Initial pressure distribution in the 18 wells at zero time for the pilot- scale vapor extraction simulation. The ambient pressure is 0.9 bars and the pressure in the wells is 0.7 bars. The well spacing is 4m and the dimensions of the mesh are 31m x 31m x 11m deep.



Fig. 8. (b)Steady state pressure distribution after 2 days of extraction. The lighter shades of grey indicate lower absolute (higher vacuum) pressures. Notice the greatest vacuum pressures near the bottom of the mesh and the influence of atmospheric pressure between the wellheads near the surface.

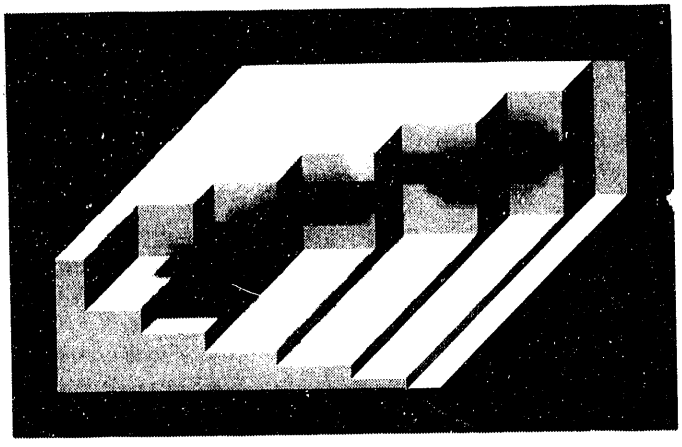


Fig. 9. In-situ TCA contamination vapor plume concentrations for the vacuum extraction simulation. The cutaway sections for these three times are all identical. (a)Initial distribution of vapor plume. Notice there are two primary, interconnected contaminated regions. The maximum concentration is 7000 ppm and is represented by the darkest regions in the plot.

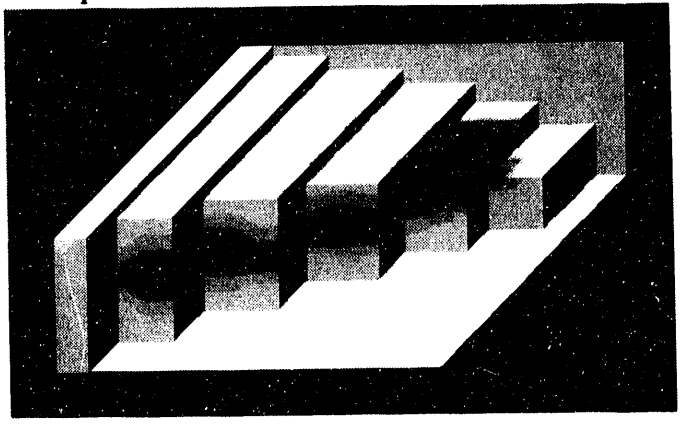


Fig. 9. (b)Distribution of TCA contamination after two days of pumping. The maximum concentration is now only 5520 ppm, as reflected by the less dark shading of the plume.

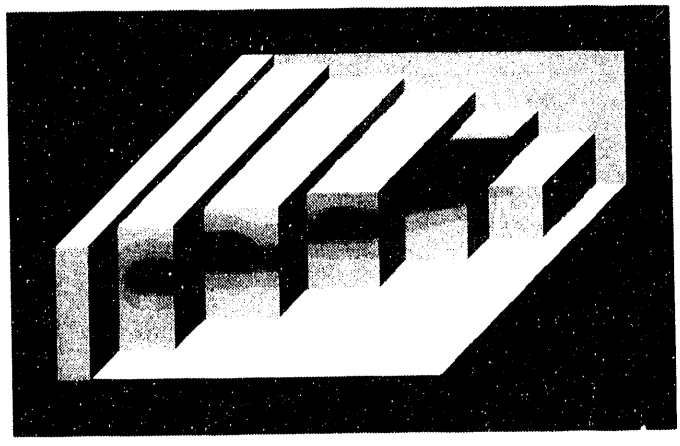


Fig. 9. (c)Distribution of the TCA contamination after seven days of continuous extraction from the wells shown in Fig. 8. The maximum concentration is now down to only 4710 ppm and the two major plume locations are just barely connected, as illustrated by the much lighter shades of grey.

Pore-size distribution index	3.0
Bubbling pressure	1 dyn/cm^2
Bulk matrix density	1.9 g/cm^3
Constrictivity coefficient	0.2

An extraction pattern of 18 wells was selected, as shown in Fig. 8a. The dimensions of the pilot volume are 31m x 31m x 11m deep. The initial pressure distribution was assumed to be a constant 0.9 bars. All the wells were assumed to be drawing throughout their length at a vacuum pressure of 200 centibars, i.e., the pressure in the wells was 0.7 bars. The water saturation in the wells is assumed to be zero. After 2 days, steady state conditions were achieved, as illustrated in Fig. 8b.

The initial assumed contamination plume is illustrated in Fig. 9a. The maximum concentration is 7000 ppm and is represented by the darkest shades. After extracting for two days, the resulting distribution is shown in Fig. 9b, where the maximum concentration is 5520 ppm. After one week of continuous pumping at all wells, the remaining maximum contamination concentration is down to 4710 ppm, as illustrated in Fig. 9c. Notice that significant contaminant extraction has taken place and that the edges of the vapor plume are less distinct.

This test problem indicates that the numerical simulations are well suited to the study of the vapor extraction process. Calculations are presently underway which utilize the actual measured vapor plume distributions and material properties. A study is also underway to optimize the location of the extraction wells and to determine the effectiveness of oscillatory extraction techniques, where only a limited number of the total wells are operating at any given time. The influence of fracture properties and spacing is also being investigated.

CONCLUSIONS

Numerical models which couple chemical and biological processes to traditional models of flow and transport in porous media can be very useful tools for designing remediation strategies of contaminated sites. In this paper, we have described one such numerical model, TRACR3D, and shown its capabilities and utility through sample simulations of bioremediation and of vacuum extraction for two different sites. Simulations of a bioremediation strategy were conducted to estimate the time course and spatial extent of bacterial action on diesel fuel. Keeping in mind the limitations and assumptions underlying present models of biological activity in complex environments, it appears that bioremediation simulations can be very helpful in designing strategies for removing subsurface organics. The action of bacteria can be controlled to a significant degree through careful monitoring of injected oxygen and nutrients. Simulations of vacuum extraction at a site containing a mixture of volatiles and other contaminants were also described. Vacuum extraction of volatiles is clearly a very economic and efficient means of greatly reducing in situ concentrations of a class of contaminants.

ACKNOWLEDGEMENTS

Sandy Leo at Sandia National Laboratories, Livermore and John Krueger at Los Alamos National Laboratory are gratefully acknowledged for their support of the bioremediation and vapor extraction work, respectively. The three- dimensional, volume-rendering graphics were implemented at LANL by Lynn McDonald. Alice Barr of LANL is credited with compiling and maintaining the pore gas sampling data for Area L. This work was performed under the auspices of the U.S. Department of Energy.

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APPLICATION OF SPHAGNUM PEAT, CALCIUM CARBONATE, AND HYDRATED LIME FOR IMMOBILIZING RADIOACTIVE AND HAZARDOUS CONTAMINANTS IN THE SUBSURFACE

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ABSTRACT

Batch experiments, mineralogical studies, and geochemical modeling were conducted to evaluate the effectiveness of sphagnum peat, calcium carbonate, and hydrated lime in removing dissolved concentrations of As, Mo, NO_3, and U present in uranium-tailings pore water at Gunnison, Colorado. Amounts of As, Mo, and U removal by sphagnum peat, calcium carbonate, and hydrated lime at 5.0, 2.5, and 2.5 wt.%, respectively, were typically above 97 %. Nitrate removal ranged between 55 and 80 %. Significant contaminant removal was achieved by sphagnum peat alone at pH 3.18. Results from base potentiometric titrations and IR spectroscopy investigations suggest that U(VI) binds onto carboxylate and phenolate groups. Addition of 2.5 wt.% hydrated lime to the acidic tailings increased Mo concentrations by a factor of 2 under moderately alkaline conditions (pH 12). During neutralization of tailings-pore water, precipitation of ferric oxyhydroxides may provide additional removal of As, Mo, and U(VI) from solution through adsorption and coprecipitation processes. Sphagnum peat and other forms of solid organic matter effectively remove anthropogenic organic compounds from solution through hydrophobic sorption and partitioning processes.

Impacts on groundwater quality from uranium-tailings leachate are extensive at Gunnison, Colorado (1). Proposed groundwater-restoration programs at Gunnison, Colorado would require a long-term effort using conventional pump and treat technologies. A geochemical approach to controlling contaminant migration associated with uranium tailings-leachate at this and other uranium tailings sites consists of using materials with high geochemical attenuation and neutralization capacities.

This investigation examined the effectiveness of sphagnum peat, calcium carbonate, and hydrated lime to immobilize As, Mo, NO_3, and U concentrated within uranium-tailings leachate at Gunnison, Colorado. Fixation of U onto peat and other forms of solid organic matter is well established (2-6). Solid organic matter is frequently observed within sandstone-type uranium deposits (7). Therefore, solid organic matter such as sphagnum peat may provide an excellent constituent of a geochemical barrier designed to remove redox sensitive elements and complexes from solution. Opitz et al. (8) conducted neutralization experiments on uranium tailings from Wyoming using calcium carbonate and hydrated lime, where contaminant concentrations decreased by 98 %. The objective of this investigation was to determine the combined effect of sphagnum peat, calcium carbonate, and hydrated lime on the solubilities and therefore, the mobilities of As, Mo, NO_3, and U.

SAMPLE CHARACTERIZATION AND EXPERIMENTS

Acid-leach tailings samples and pore-water samples were collected at the Gunnison Uranium Mill Tailings Remedial Action (UMTRA) site, Gunnison, Colorado from 1988 to 1989. The sphagnum peat samples were obtained from Los Alamos National Laboratory Peat Sample Library. Details of sample collection, preparation, and chemical analysis procedures for the sphagnum peat are provided by Raymond et al. (9). Peat is a precursor to coal and consists primarily of plant components and secondarily of mineral matter (9). Elemental composition of C, H, O, and N are 41.6, 6.8, 49.7, and 0.1 wt.%, respectively, for sphagnum peat used in the batch experiments. The wt.% distributions of ash and sulfur on dry-sphagnum peat (moisture free basis) samples are 1.82 and 0.05, respectively (9). The surface area of the sphagnum peat (1 mm particle diameter, minus No. 20 sieve) was found to be 25 m^2/g, using the BET-N_2 method. The cation exchange capacity of sphagnum peat ranges from 121 to 224 meq/100 g, with a mean value of 149 meq/100 g (10).

Minerals tentatively identified in the tailings samples by powder X-ray diffraction (XRD) analysis, using Cu-K α radiation with quartz as an internal standard, include ferrihydrite ($Fe_5O_7(OH).4H_2O$), ferrimolybdite ($Fe_2(MoO_4)_3.8H_2O$), rameauite($K_2CaU_6O_{20}.9H_2O$)uranopilite($(UO_2)_6(SO_4OH)_{10}.12H_2O$),ilsemannite($Mo_3O_8.xH_2O$ gypsum ($CaSO_4.2H_2O$), scorodite ($FeAsO_4.2H_2O$), and goethite (α-FeOOH). The mineralogical content of the sphagnum peat determined from

XRD analysis included quartz (SiO_2), albite ($NaAlSi_3O_8$), corundum (Al_2O_3), muscovite ($KAl_2(AlSi_3O_{10})(OH)_2$), and kaolinite ($Al_2Si_2O_5(OH)_4$) (9).

Tailings sand- and clay-sized material were collected and volumetrically mixed (75 % sand and 25 % clay) to obtain representative composite field samples for batch experiments. The batch experiments consisted of a mixture of 250 g of tailings material, 800 ml of deionized water, 12.50 g of sphagnum peat, 6.25 g of calcium carbonate, and 6.25 g of hydrated lime. Sphagnum peat was air dried for several hours prior to the batch experiments. Sphagnum peat by itself and with calcium carbonate and hydrated lime were added at 2.5 wt.% relative to the tailings samples. The experiments were conducted in 1 L glass erlenmeyer flasks. The flasks were tightly sealed and shaken for 72 hours at 25 C. All solutions were passed through a 0.45 micron filter prior to analysis.

Molybdenum, Fe, As, and major cations were analyzed by using Jarrell-Ash emission spectrometers with an inductively coupled plasma (ICP) source and graphite-furnace atomic absorption (GFAA) spectroscopy, respectively, at Barringer Laboratories, Denver, Colorado. Uranium solutions were analyzed by fluorometry. Sulfate and NO_3 concentrations and carbonate alkalinity were analyzed by ion chromatography and titration, respectively. Field and laboratory analyses included measurements of temperature, pH (Orion Ross), Eh (Orion 96-78 platinum electrode), alkalinity, and specific conductance.

Infrared spectra of sphagnum peat and its corresponding uranium adduct were recorded on a Bio-Rad FTS-40 spectrophotometer using the KBr-pellet technique. Potentiometric titrations, using an Orion 960 automatic titrator with 1-g sphagnum peat samples, were carried out under an argon gas atmosphere using degassed deionized water in order to eliminate any uranyl carbonato complexing. The accuracy of the measurement at 25 $\pm$ 0.1 °C at u = 0.1M (Na_2SO_4) was $\pm$ 0.01 pH. The titrant consisted of 0.01M KOH and 0.05M U(VI), in the form of $UO_2SO_4.3H_2O$, was added to sphagnum peat prior to the titration experiments.

RESULTS

The infrared spectra of sphagnum peat and the corresponding uranium adduct within the range of 4000 to 500 cm^{-1} are shown in Figs. 1 and 2, respectively. The most dominant absorption maxima are also shown in these figures in which both spectra exhibit typical bands of terrestrial organic matter (11). The uranium-rich sample is characterized by 1) the presence of an absorption band at 890 cm^{-1}, which is attributed to the stretching band of the uranyl ion (12); 2) an increase of absorption of the 1710 cm^{-1} band, which only exhibits a slight shoulder; and 3) a slight widening of the 1400 cm^{-1} band. Features 2 and 3 indicate transformation of the carboxylic groups into carboxylate anions. The IR pattern similar to that in Fig. 2 have been observed in samples from uranium-rich bogs (4) and in laboratory experiments dealing with the fixation of uranyl ions by humic acids and brown coal (13). Shanbhag and Choppin (14) have used a solvent extraction technique to demonstrate the binding of uranyl with $R\text{-}COO^-$. Infrared spectroscopy suggests that uranyl undergoes complexing with carboxylate groups. The binding of uranyl ions onto sphagnum peat (denoted as HA) leads to the dissociation of UO_2SO_4 and $UO_2(SO_4)_2^{2-}$:

$$HA + UO_2SO_4 = A^- + UO_2^{2+} + +SO_4^{2-} + H^+ \quad \text{(Eq.1)}$$

$$HA + UO_2(SO_4)_22- = A^- + UO_2^{2+} + 2SO_4^{2-} + H^+. \quad \text{(Eq.2)}$$

The presence of other functional groups such as phenolic hydroxyl groups, however, is not demonstrated by the IR data but may also participate in metal complexing (15).

Results of base potentiometric titrations for blank- and uranium-loaded sphagnum peat samples are shown in Fig. 3.

The objective of these experiments is to determine the nature of U(VI) binding sites present on the sphagnum peat. Results of the potentiometric titration experiments for blank sphagnum peat indicate two regions where deprotonation reactions occur as a function of pH (Fig. 3). Deprotonation of the carboxylic acids result in a substantial buffering capacity of the sphagnum peat. Within the pH range between 4 and 8, sphagnum peat exhibited less buffering capacity, indicating that deprotonation reactions are not extensive. Above pH 8, sphagnum peat undergoes additional deprotonation reactions with phenolic functional groups. Deprotonation reactions produce negatively-charged surface sites on the sphagnum peat, which are potential binding sites for cations including the uranyl ion. Fixation of uranyl onto sphagnum peat occurs under acidic conditions, where the buffering capacity decreases (Fig. 3). Uranyl fixation is shown by the following reactions:

$$UO_22+ + R\text{-}COOH = R\text{-}COOUO_2+ + H^+. \quad \text{(Eq.3)}$$

$$UO_2+ + 2R\text{-}COOH = (R\text{-}COO)_2UO_2o + 2H^+. \quad \text{(Eq.4).}$$

Based on results of the titration experiments, uranyl ions displace protons associated with carboxylic acid and phenolic functional groups (Fig. 3). Fixation of uranyl ions onto sphagnum peat decreases the buffering capacity of the sphagnum peat. Results of the base-potentiometric titration experiments show that the sphagnum peat has a high capacity for removing uranyl complexes from aqueous solution under acidic to alkaline pH conditions.

Results of selected chemical analyses on tailings-pore water, obtained from suction lysimeters completed within the Gunnison tailings impoundment, are shown in Table I (16). The composition of the tailings-pore water is dependent on: (1) type of ore; (2) type of leach circuit; (3) byproduct recovery; (4) initial quality of process water; and (5) surface evaporation. These factors account for the concentration distribution of species reported in Table I. Sulfuric acid and $NaClO_3$ were used during the ore-extraction process, which generated a SO_4-rich tailings pore water (17).

Results of batch experiments using 5.0 wt.% sphagnum peat, 2.5 wt.% calcium carbonate, and 2.5 wt.% hydrated lime, relative to the mass of uranium tailings, are provided in Figs. 4 and 5. Sphagnum peat (with deionized water), sphagnum peat-calcium carbonate, sphagnum peat-hydrated lime, and sphagnum peat-calcium carbonate-hydrated lime combined with tailings solids comprised the different batch systems investigated. Substantial concentration decreases of As, NO_3, SO_4, U, and total dissolved solids (TDS) in all batch systems are evident. Addition of sphagnum peat, without calcium

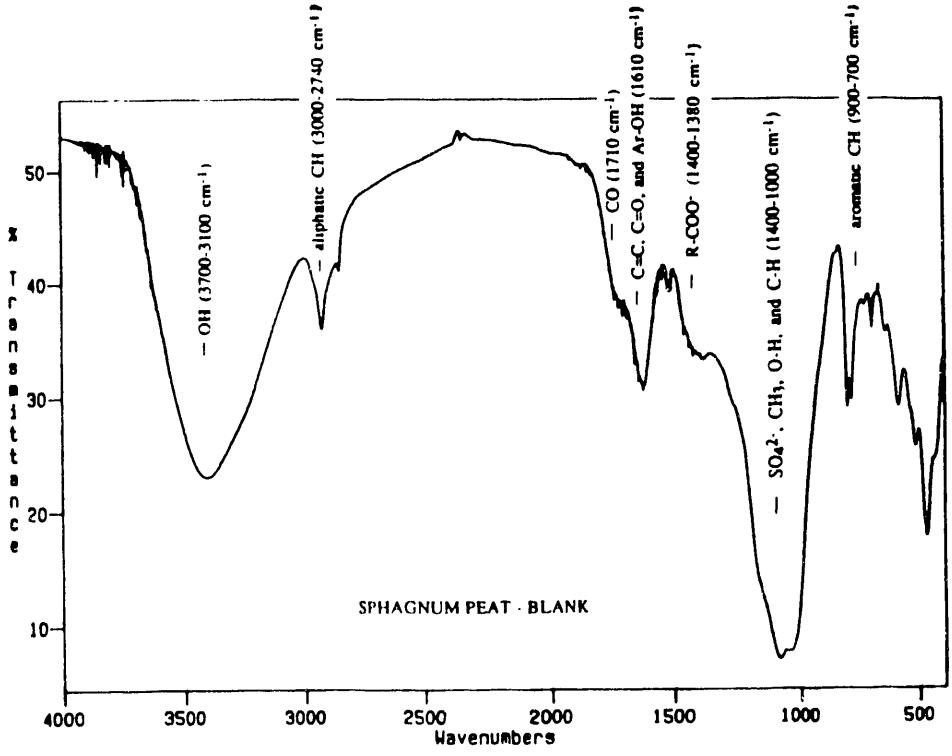


Fig. 1. Infrared spectrum of sphagnum peat.

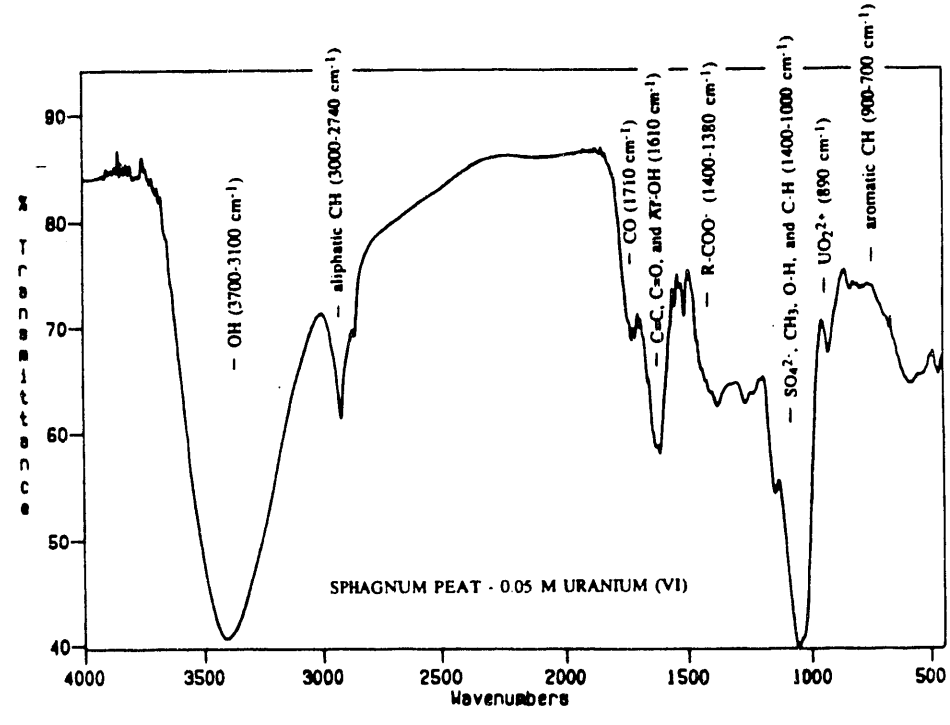


Fig. 2. Infrared spectrum of sphagnum peat and uranium adduct.

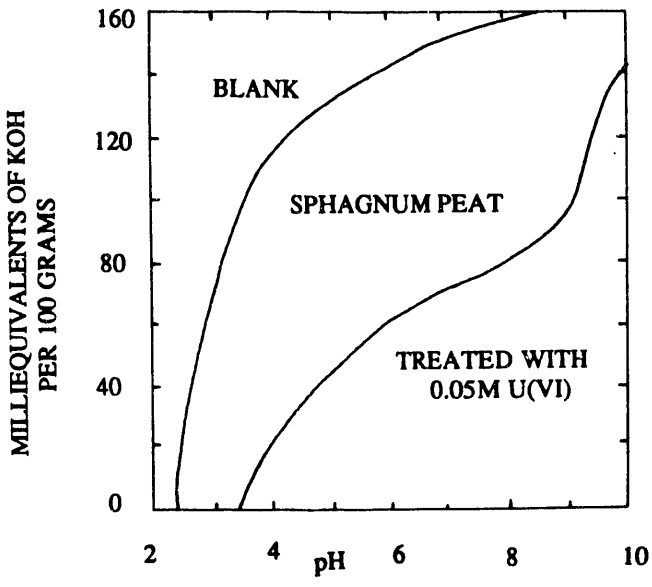


Fig. 3. pH titration of sphagnum peat and its uranium adduct.

carbonate and/or hydrated lime present, resulted in significant concentration decreases of Mo, NO_3, and U. Maximum removal of As was achieved within the sphagnum peat-hydrated lime-tailings system. Concentrations of Mo increased by a factor of 1.8, however, within the sphagnum peat-hydrated lime-calcium carbonate tailings systems under alkaline pH conditions. Concentrations of Se were below analytical detection limit (0.005 mg/L) for all batch solutions analyzed by GFAA spectroscopy. Percentage removal of the different species is greater than 97 %. Molybdenum concentrations, however, are an exception, where 60 to 250 % of Mo was apparently released to solution for runs involving hydrated lime.

Relative effectiveness for contaminant removal by sphagnum peat, calcium carbonate, and hydrated lime is presented in Table II for As, Mo, NO_3, and U. These affinities were determined from mass balance distributions of species associated with sphagnum peat, calcium carbonate, and hydrated lime. Sphagnum peat was present in all of the batch experiments conducted in this study. Solid organic matter, consisting of humic substances, is considered to be the dominant adsorbent for hydrophobic non-ionized organic compounds (18-20).

Calculated Kd values, at 5 wt.% sphagnum peat concentrations, for tributyl phosphate, benzene, carbon tetrachloride, trichloroethene, and tetrachloroethene are 300, 5, 14, 8, and 13 ml/g, respectively. These contaminants are frequently found at uranium and plutonium processing facilities. The Kd values were calculated from the relationship, Kd = KOC x (wt.% solid organic matter/100), where KOC is the soil organic matter-water partition coefficient (18). The KOC values for tributyl phosphate, benzene, carbon tetrachloride, trichloroethene, and tetrachloroethene are 6000, 102, 275, 166, and 257 ml/g, respectively. These calculations, along with other empirical data (20), suggest that sphagnum peat and other forms of solid organic matter are strong adsorbents for most hydrophobic organic compounds. Further experiments, however, are required to quantify the effectiveness of sphagnum peat to remove organic contaminants from solution.

GEOCHEMICAL MODELING

The geochemical code, PHREEQE (21) was used to compare theoretical to observed mineralogical assemblages to determine if precipitation reactions were thermodynamically possible within the batch experiments. Speciation calculations were also performed to assess importance of humate complexing with U(VI). For meaningful model simulations, however, it is important that the thermochemical data base is accurate and internally consistent. The data base contained in PHREEQE has been reviewed critically by Noronha and Pearson (22). Equilibrium is assumed among aqueous species found in the different solutions; and species present in solution, but not included in the model, may cause misleading results. Dissolved concentrations presented in Figs. 4 and 5 were used as input for model simulations. The sphagnum peat-hydrated lime-tailings and sphagnum peat-hydrated lime-calcium carbonate-tailings systems were not modeled with PHREEQE because of the extremely alkaline conditions.

Saturation indices (SI) of several solid phases were calculated using analytical data for different solutions. These results are shown in Table III. Thermochemical data for uranyl-humate complexing were incorporated in the model simulations. Gypsum precipitation probably controls dissolved SO_4 concentrations within both the unamended tailings-pore water and sphagnum peat-calcium carbonate-tailings system. Sulfate fixation onto sphagnum peat may account for concentration decreases of this species when the solution is undersaturated with respect to gypsum. Precipitation of metal sulfides is unlikely under the moderately oxidizing conditions that prevailed during the batch experiments. Ilsemannite probably controls dissolved concentrations of Mo within tailings-pore water and batch- tailings solution, based on XRD analysis and SI calculations. Ilsemannite is stable under oxidizing and acidic conditions (23), which prevailed in the tailings-pore water and blank-tailings solution. Dissolution of ilsemannite occurs within sphagnum peat-tailings and sphagnum peat-calcium carbonate-tailings systems. Fixation of Mo onto sphagnum peat, however, results in a concentration decrease of this species (Fig. 3). All solutions are predicted to be undersaturated with respect to U(IV) and U(VI) minerals contained in the PHREEQE data base. Therefore, U concentrations are not controlled by precipitation reactions in the batch experiments, based on modeling results.

Fixation of U(VI) onto sphagnum peat has been shown to be attributed to ligand exchange and sorption processes with carboxylic and possibly phenolic functional groups (2-6). We have used published dissociation and conditional stability constants for humic acid and uranyl humate complexing to simulate surface reactions occurring on sphagnum peat. Dissociation constants of humic acid ($pK_1 = 4.10 \pm 0.06$, H_2L; $pK_2 = 10.97 \pm 0.09$, HL^- at u = 0.1) reported by Kribek and Podlaha (24) have been added to the PHREEQE thermochemical data base to assess the importance of uranyl-humate complexing within the sphagnum peat-tailings and sphagnum

TABLE I

Geometric Mean and Range of Selected Chemical Analyses of Suction Lysimeter Samples, Gunnison, Colorado (In mg/L, except as noted).

Parameter/Species	Value	Range	Number of Analyses
pH (SU)	3.73	1.43-4.17	10
Aluminum	309	15-653	11
Arsenic	1.19	0.04-17.05	11
Iron	575	0.31-6100	11
Molybdenum	0.32	0.03-12.50	11
Nitrate	5.80	10-190	7
Selenium	0.20	0.10-4.50	11
Sulfate	10,404	2400-23000	11
Uranium	4.72	0.02-50	11
Vanadium	0.51	0.10-13	11
Field Eh (mV)	+600	+550- +650	10

peat-calcium carbonate-tailings systems. H_2L represents part of a micelle containing two protonized functional groups, which may include carboxylic and phenolic binding sites. Dissolved organic carbon (DOC) concentrations provided in Fig. 5 were used as input for humic acid concentrations for the PHREEQE code. A number-average molecular wt. of 2000 for dissolved humic acid (19,25) was selected for model calculations. Conditional stability constants ($\log B_1 = 5.11 \pm 0.02, UO_2(HA)^+$ and $\log B_2 = 8.94 \pm 0.03, UO_2(HA)_2$ at pH = 4.04, u = 0.1) were taken from values given by Shanbhag and Choppin (14) for uranyl-humate complexing. Humic acid is denoted as HA. Results of the simulations indicate that the complex, $UO_2(HA)_2$ dominates (100 %) in both of the sphagnum peat-tailings and sphagnum peat-calcium carbonate-tailings systems. The dominant aqueous species in the different batch experiments are tabulated in Table IV. The batch solutions are undersaturated with respect to U(VI) minerals due to acidic conditions and uranyl-humate complexing.

DISCUSSION AND CONCLUSIONS

The successful decrease in contaminant concentrations of As, Mo, NO_3-, and U(VI) has been demonstrated from batch experiments as a function of pH. Active surfaces present on sphagnum peat evidently cause enhanced fixation of U(VI) under the acidic pH conditions during the batch experiments. The uranyl ion is a hard acid that has a strong preference for carboxylate groups (14). Infrared studies conducted by Koglin et al. (13) on uranyl-humate complexing also have strong interactions with the carboxylate sites.

Adsorption of As, Mo, and U onto ferric oxyhydroxides may also account for contaminant removal. These findings are consistent with those of Opitz et al. (8), in which neutralization, using calcium carbonate and hydrated lime, enhanced precipitation of amphoteric solid phases including ferric oxyhydroxides. Buffering of pH is an important waste-processing step for removing contaminants from solution. Iron concentration within the sphagnum peat is 3.4 wt.% (9), which may be due to the presence of ferric oxyhydroxide since pyrite was not observed during XRD analyses. Adsorption of oxyanions of As and Mo occurs onto ferric oxyhydroxides below the pHzpc ranging between 6 and 7 (26). However, desorption of Mo from hydrous oxides, in addition to dissolution of ilsemannite, may have taken place under alkaline pH conditions in the presence of hydrated lime. This phenomenon has been observed by Hingston et al. (27). These results suggest that a careful balance of neutralizing material is necessary to achieve optimum removal of Mo.

ACKNOWLEDGMENTS

This work was supported by a Department of Energy-Waste Energy and Research Consortium Grant, contract number 89-018, to the University of New Mexico. Dr. James Brainard of the INC-4 group and Dr. Robert Raymond Jr. of

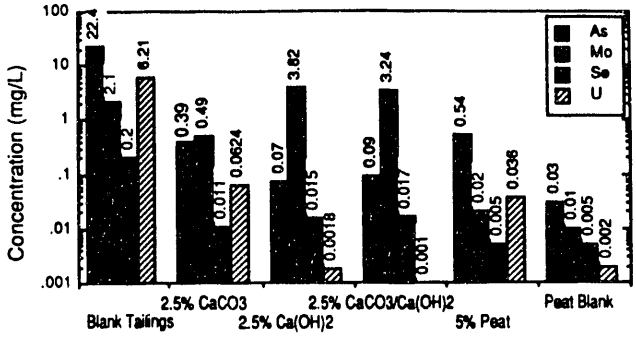


Fig. 4. Results of batch leach experiments (16)

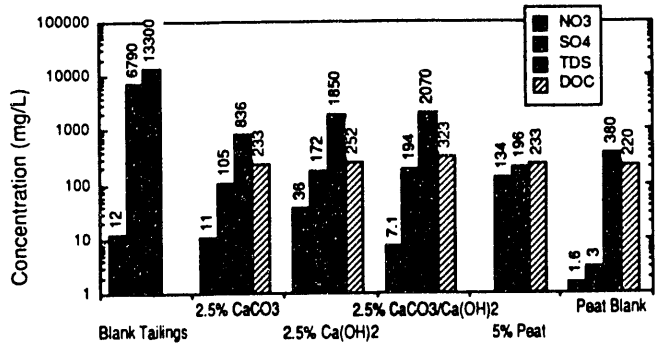


Fig. 5. Results of batch leach experiments (16).

TABLE II

Relative Effectiveness for Contaminant Removal

Species	Order
Arsenic	$CaCO_3$ > $Ca(OH)_2/CaCO_3$ > > Sphagnum Peat
Molybdenum	Sphagnum Peat $CaCO_3$ > > $Ca(OH)_2$
Nitrate	Sphagnum Peat > $CaCO_3$ = $Ca(OH)_2$
Uranium	$Ca(OH)_2$ > > Sphagnum Peat > $CaCO_3$

TABLE III

Saturation Index Values for Gunnison Batch Experiments

Solid Phase	Batch Tailings Solution	Lysimeter Tailings Solution	Blank Peat	Peat Plus Tailings	Peat Plus $CaCo_3$
Gypsum	0.05	0.42	-4.10	-1.39	-0.96
Goethite	1.09	5.53	0.89	-0.44	3.98
B-$UO_2(OH)_2$	-6.77	-4.68	-14.52	-15.25	-8.15
Uraninite	-13.76	-12.92	-20.42	-18.61	-9.98
Schoepite	-6.63	-4.50	-14.38	-14.76	-8.01
UO_2 am	-19.40	-18.71	-26.06	-24.25	-15.62
Ilsemannite	-0.01	-0.96	-9.15	-6.50	-22.91
pH	2.22	3.73	3.55	3.18	6.35
Eh (mV)	+650	+600	+540	+487	+254

S.I. = $\log_{10} \frac{IAP}{Kt}$

the GG group (Los Alamos National Laboratory) provided expertise in the areas of spectroscopy and peat geology-geochemistry, respectively. Dr. Michael Eastman and Dr. Cynthia Hartzell, both of the Department of Chemistry, Northern Arizona University, provided additional support by conducting electron paramagnetic resonance and solid state ^{13}C nuclear magnetic resonance experiments, respectively. We greatly appreciate their technical contibutions made during this investigation. This paper was presented at the WM Conference, Tucson, Arizona, February 24-28, 1991. (28)

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TABLE IV

Dominant Aqueous Species for Different Batch Solutions

Species (log m)	Blank Tailings Solution	Peat-Tailings Solution	$CaCO_3$-Peat-Tailings Solution
U	UO_2SO_4 (-4.98)	$UO_2(HA)_2$ (-6.82)	$UO_2(HA)_2$ (-6.58)
As	$H_2AsO_4^-$ (-3.76)	$H_2AsO_4^-$ (-5.19)	$H_2AsO_4^-$ (-6.23)
Mo	MoO_2^+ (-4.65)	MoO_4^{2-} (-6.73)	MoO_4^{2-} (-6.46)

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DEVELOPMENT OF A POLISHING SYSTEM FOR FEMP WASTEWATER DISCHARGES

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Duratek Corporation

ABSTRACT

The Fernald Environmental Management Project (FEMP) in Fernald, Ohio generates a wide variety of wastewaters, ranging from process water to stormwater runoff. The current practice is to treat water from process areas prior to discharge into the Great Miami River. Stormwater, on the other hand, is discharged with only settling prior to release. The discharge to the river can contain up to 1-2 parts per million (ppm) of uranium. A treatment process to remove contaminants from the discharge water has been developed. Process development included a series of laboratory evaluations to determine the most effective treatment technologies, followed by a series of on-site pilot-plant tests to further define the treatment system and provide the data required for scale-up to a full-scale treatment system.

BACKGROUND

The FEMP generated a wide variety of wastewaters, ranging from process to stormwater runoff. Wastewaters are combined and monitored at the National Pollutant Discharge Elimination System (NPDES) discharge point located at Manhole 175. Specifically, the following five steams constitute the flow monitored at Manhole 175:

- General Sump
- Biodentrification (BDN) Facility
- Sewage Treatment Plant (STP)
- Stormwater Retention Basin (SWRB)
- Storm Sewer Lift Station (SSLS)

Stormwater runoff discharged via the SWRB and SSLS is the highest volume water source in the Manhole 175 discharge. The stormwater runoff flow is highly variable and is relatively low in total dissolved solids (TDS). The water from the General Sump is a relatively clean stream which results mostly from treated waste streams resulting from drinking water production and controlled coal pile stormwater runoff. The BDN stream contains wastewater resulting from production facilities and controlled runoff from waste storage units at the facility. The STP stream contains wastewater resulting mostly from sanitary water usage. The BDN and STP streams are the most contaminated of the five, representing the greatest challenge to the treatment system in terms of the amount of contaminants to be removed. Since Manhole 175 represents the final sampling point for all FEMP discharge streams, it represents a weighted average composition and total flow of all the FEMP discharge waters.

The current practice is to treat process wastewaters prior to discharge into the Great Miami River. Stormwater, which is tested before it is released, on the other hand, is discharged with only settling prior to release. The combined discharge to the river could normally contain up to 1-2 ppm of uranium.

The FEMP is designing an Advanced Waste Water Treatment (AWWT) Plant for treating the waters generated or collected at the facility. The objective of this project is to develop an effective and efficient process for final treatment of the discharge water before it is released into the river.

The goal of these studies is to provide an effluent containing less than 20 parts per billion (ppb) uranium and that all other contaminants be within the Maximum Contaminant Levels (MCL) cited under the Safe Drinking Water Act (SDWA), as amended. It was also desired that the TDS be below 500 ppm and the total suspended solids (TSS) be below 30 ppm.

The experimental program was designed with the following additional criteria in mind, which are important for the development of an effective, reliable and cost-effective treatment system:

- Radioactive wastes separated from non-radioactive wastes to the maximum extent possible
- Volume of radioactive wastes minimized
- Treatment technologies and overall process "robust," i.e. minimally affected by wide variations in water composition and flow rate
- Process as simple and inexpensive as possible

These goals assure that the treatment system developed will be practical to operate as well as effective in removing residual contaminants in FEMP waters.

Process development started with a series of laboratory evaluations, using samples of BDN and Manhole 175 water, to determine the most effective treatment technologies. This was followed by on-site pilot-plant tests to further optimize the treatment system and provide the scale-up data required for incorporation into the AWWT.

LABORATORY TECHNOLOGY EVALUATIONS

The bench-scale laboratory evaluations were conducted with samples of BDN and Manhole 175 waters, provided in lined 55 gallon drums. These two waters represent the worst case and the average of the FEMP waters to be treated, respectively. Thus, these evaluations bracket the compositions the treatment system must be capable of handling.

* Westinghouse Environmental Management Company of Ohio with the U.S. Department of Energy under Contract No. DE-AC-05-86OR21600

Table I summarizes the analyses of the water samples from the drums. These data show a wide variability among the critical measurements obtained. For the BDN samples, uranium content varied from 700 to 1,700 ppb, chromium content varied from 3 to 150 ppb, and the total organic carbon (TOC) content had an especially wide range of concentrations (4-28,600 ppm). Subsequent analyses showed the high TOC to be excess methanol from the BDN process.

TABLE I

Analyses of FMPC Water Samples

Biodenitrification (BDN) Samples

Parameter	BDN #1	BDN #2	BDN #3
U, ppb	1,170	1,730	696
Cr, ppb	254	3	36
TOC, ppm	28,600	30	2,280
TSS, ppm	1,120	78	328
TDS, ppm	1,300	1,730	643

Manhole No. 175 (MH-175) Samples

Parameter	MH-175 #1	MH-175 #2	MH-175 #3
U, ppb	1,820	1,050	474
Cr, ppb	108	2	8
TOC, ppm	10,030	10	4
TSS, ppm	89	158	260
TDS, ppm	733	1,192	515

The Manhole 175 samples showed similar variability. The uranium content varied from 500 to 1,800 ppb, chromium content varied from 2 to 110 ppb, and two of the drums had high TOC levels, again due to methanol from the BDN process.

The laboratory evaluations consisted of the technologies shown in Fig. 1, arranged in series. At each treatment stage, several alternative technologies/materials were evaluated, as shown on the figure. The specific technology that was most effective in removing the uranium and the non-radioactive contaminants, e.g. chromium, was used to treat the water samples for subsequent treatment stage evaluations.

The major results of the laboratory tests were:

- Pretreatment - The most effective pretreatment were a combination of chemical treatment (alum and Polypure A-210) followed by electrocoagulation with both iron and aluminum anodes. Pretreatment removed a large portion of the uranium and heavy metals, e.g. chromium.
- Filtration - Deep bed filtration (sand or carbon) was more effective than membrane microfilters in removing additional uranium and chromium, and was considered the better material due to its lower cost.
- Organics Removal - There was insufficient organics in the available water samples to discriminate between activated carbon adsorption and ozonation.
- Ion Exchange - Dowex 21K at pH 5 and 8, and Durasil 70 and 70A at pH 5 were able to remove uranium from the partially treated waters, although uranium contents were too low to predict column life or relative performance among the media.
- Reverse Osmosis - Both brackish water and sea water membranes were able to polish the effluent waters from the successful ion exchangers.

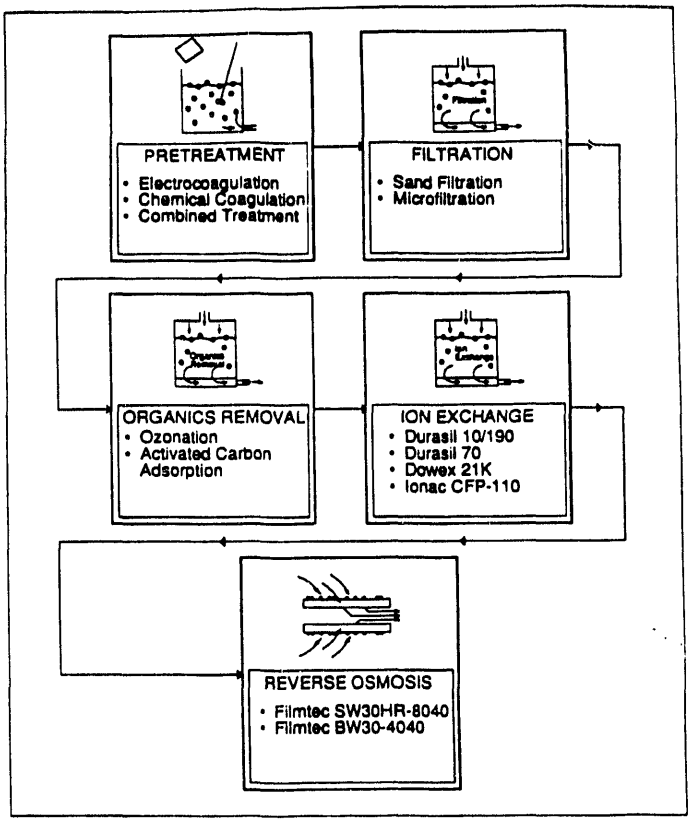


Fig. 1. FMPC wastewater treatment system evaluation technologies.

Variations on the basic process scheme were also studied in an attempt to completely separate radioactives and heavy metals by removing them in separate treatment stages. While the data indicated that this may be achievable, the low concentration of non-radioactive contaminants in the test waters prevented the attainment of a conclusive answer.

PILOT-PLANT EVALUATIONS

Based on the results of the laboratory evaluations, a 0.0379 m^3/min (10 gallons/min) pilot-plant Demonstration Unit (DU) treatment system was built inside a trailer and delivered to the FEMP. The purpose of the DU was to evaluate alternative system configurations using actual FEMP discharge water. Testing with actual discharge water was considered very important in light of the wide variability encountered among the drummed water samples studied during the laboratory evaluations. The DU was designed to evaluate the following treatment technologies, as needed:

- Chemical Pretreatment
- Filtration
- Ion Exchange (2 stages)
- Reverse Osmosis

The system was designed to accept ozonation as an add-on in the unlikely event that organics were encountered.

The DU was designed to continuously withdraw feed from either Manhole 175 or from a 15.1 m^3 (4,000 gallon) tank which would hold water from other sources. Several runs were made with water from the Stormwater Retention Basin using this feed tank.

A set of preliminary runs were performed to determine the simplest set of technologies required to effectively treat the water. Based on the results of the preliminary tests using both SWRB and Manhole 175 waters, it was concluded that the following three-stage treatment configuration would provide the necessary level of contaminant removal:

- Filtration (50 mesh sand)
- Ion Exchange (Dowex 21K)
- Ion Exchange (Purolite A600)

The sand was included for particulate removal. The Dowex 21K was included for uranium removal; it was found to be very effective at removing uranium over a wide pH range during the laboratory evaluations. The Purolite A600 media was included to capture any chromium, if encountered. Each media was in a separate tank to facilitate handling and interstage sampling. Each tank contained 0.425 m^3 (15 cubic feet) of media.

The system was run essentially continuously from the beginning of January through mid-June 1991 to provide long-term data for use in designing the AWWT. The results of this long-term Demonstration Test are provided in Figs. 2-5 and Table II.

Figures 2-5 show the uranium concentration at each point in the treatment system as a function of the total number of gallons of water processed. The average influent uranium concentration was 1,370 ppb. The data show that almost one-third of the uranium is captured by the sand filter, indicating that a significant portion of the uranium is associated with particulates. This phenomenon was also observed during the laboratory evaluations and does not appear to be a chromatographic effect. The remaining uranium was captured very effectively on the Dowex 21K resin. The effluent from this media consistently contained 0-2 ppb uranium until breakthrough was approached. Breakthrough was defined as the point where the effluent concentration was consistently above 20 ppb (the targeted effluent discharge limit). The Dowex 21K processed 3,910 m^3 (1,033,000 gallons) of water (9,200 column volumes) before the uranium broke through this media by the definition just cited. However, numerous spikes in the uranium effluent concentration were encountered during processing of the 189 m^3 (50,000 gallons) of water prior to the formal breakthrough point. Before the spiking started, that average uranium concentration in the Dowex 21K effluent was 1.85 ppb with a standard deviation of 2.0 ppb. If the spiking is included, the average uranium concentration in the water from the Dowex media was 3.53 ppb with a standard deviation of 10.3 ppb. This performance was considerably better than was expected, based on the laboratory data, although the water challenging the ion exchange media during the field test was much cleaner.

There was a short period at about the 757 m^3 (200,000 gallon) point when the DU was inadvertently challenged with water containing up to 13,300 ppb uranium. This was due to some lagoon water being fed into the discharge line. The DU responded very well to this upset condition - the uranium content in the Dowex 21K effluent never exceeded the 20 ppb requirement during this period.

TABLE II

Average Influent and Effluent Concentrations in Parts Per Billion Unless Otherwise Noted

Parameter	Influent		Effluent		MCL*
	Average	Standard Deviation	Average	Standard Deviation	
Cr	8	11	7	9	50
Mn	6	8	6	28	50
Ni	13	38	13	30	--
Cu	41	397	13	64	1,000
Zn	72	319	77	146	5,000
As	27	53	23	42	50
Cd	2	22	1	1	10
Hg	1	2	1	2	2
Pb	8	106	1	1	5
U(total)	1,370	1,580	2	3	--
Cl^-, ppm	105	105	104	55	250
NO_3^-, ppm	15	6	13	8	10
SO_4^{-2}	96	40	83	72	250
TOC, ppm	2.86	1.08	1.72	1.00	--
pH	8.08	0.31	8.11	0.30	6.5-8.5
COND,umho	737	394	730	239	--
TDS, ppm	413	108	410	110	500
TSS, ppm	4.83	5.10	2.72	4.35	--

*Maximum Contaminant Level under the Safe Drinking Water Act, as ammended.

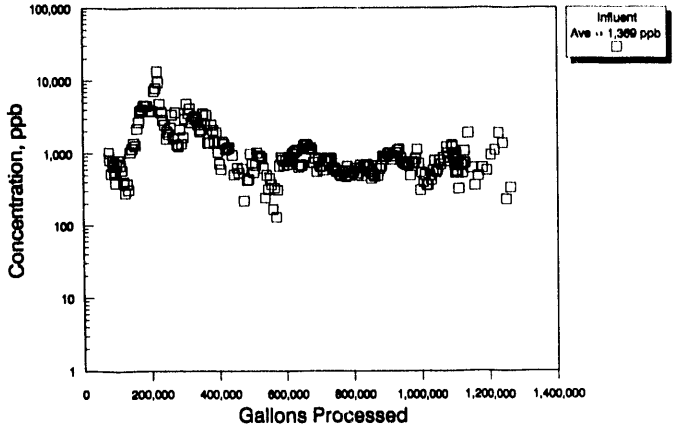


Fig. 2. Influent uranium concentration.

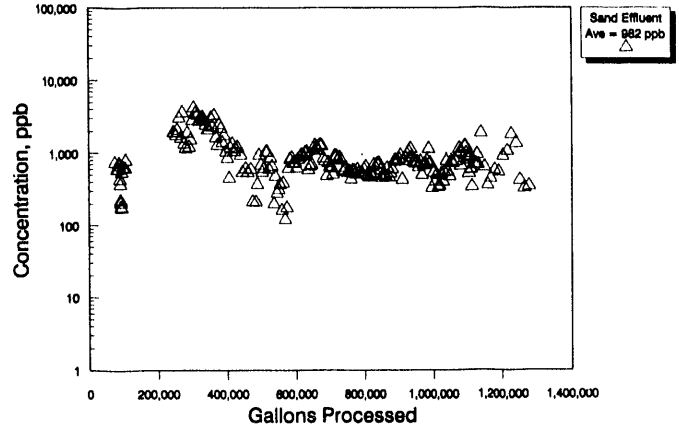


Fig. 3. Sand effluent uranium concentration.

The Dowex 21K column was left on line after breakthrough was reached in an attempt to determine when it would become saturated (effluent uranium concentration equal to the influent concentration). Even after processing 4,540 m^3 (1.2 million gallons) of water, the Dowex 21K was still not fully saturated. The uranium not removed by the Dowex 21K was captured by the Purolite A600 ion exchange media. The ability of the Purolite A600 to capture uranium not removed by the Dowex 21K due to saturation of the Dowex 21K provides confidence that the AWWT, which will operate with three Dowex 21K columns in series, will capture all uranium when the lead column becomes saturated.

The concentrations of the contaminants regulated under the SDWA were all under their MCL, except for nitrates, as shown in Table II. The effluent nitrates level was slightly above the MCL but well within the NPDES requirement for the FEMP (72.7 ppm 30 day average). The pH of the water was also within the limits prescribed in the SDWA, as shown in the table. The TDS and TSS levels were also well under the FEMP discharge goals of 500 ppm and 30 ppm, respectively. Throughout the test periods, the entering levels of chromium were below the MCL. Therefore, no removal information on chromium was obtained.

CONCLUSION

These tests clearly indicate that a combination of filtration and ion exchange, using Dowex 21K media, is effective in polishing the waste water from the FEMP prior to discharge to the Great Miami River. This polishing treatment, which

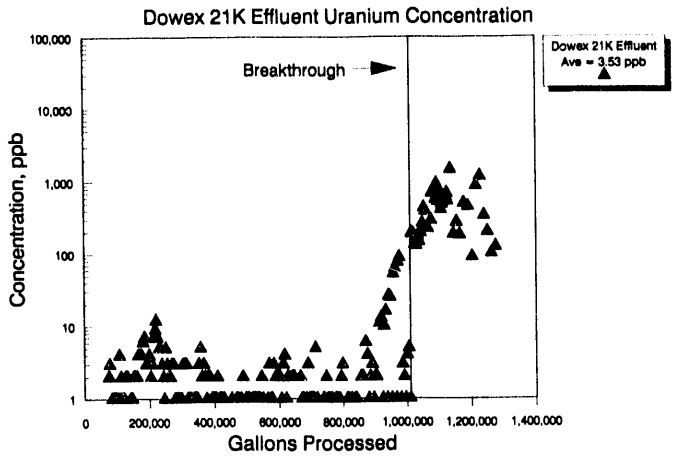


Fig. 4. Dowex 21K effluent uranium concentration.

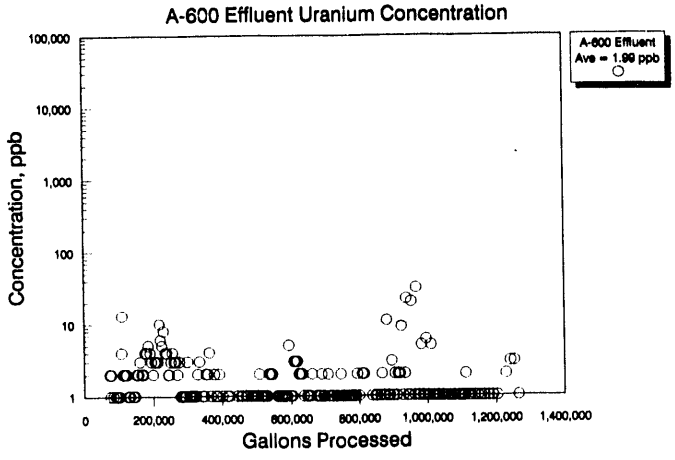


Fig. 5. A-600 effluent uranium concentration.

will be incorporated into the Advanced Wastewater Treatment Plant, is designed primarily to reduce uranium levels to below 20 ppb. While the AWWT is being built, an Interim Advanced Wastewater Treatment (IAWWT) System, based on the current results, is being implemented. The reduction of the uranium discharged to the river, as a result of the IAWWT and the AWWT, will represent a significant improvement over past practices.

DISCLAIMER

This paper was prepared as an account of work sponsored by an agency of the United States Government. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

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DESTRUCTION OF COMPLEXANTS USED IN GROUNDWATER DECONTAMINATION

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ABSTRACT

A supported liquid membrane process is being developed to remove uranium from aqueous solutions. The uranium would be concentrated into a strip solution containing either vinylidene-1,1-diphosphonic acid (VDPA) or 1-hydroxyethane-1,1-diphosphonic acid (HEDPA). This study compares the degradation of HEDPA and VDPA under similar conditions. For the time of the tests in this study (3 h) the maximum amount of HEDPA that was destroyed was 83.5% using hydrogen peroxide and the maximum amount of VDPA destroyed was 64.6% using nitric acid.

INTRODUCTION

A new class of reagents for use in nuclear waste processing was developed by the chemical division at the Argonne National Laboratory (ANL). These reagents, which are substituted methane diphosphonic acids, have been referred to as thermally unstable complexants (TUC).(1,2)

The TUCs possess a unique combination of properties that include: organic complexes that are highly stable in very acidic media, metal ion complexes that are aqueous soluble, and the ability to readily decompose to innocuous substances when heated in the presence of moderate oxidizing agents. Some of the major applications of TUCs are the stripping reagent in solvent extraction and ion exchange processes, holdback reagent in strontium and cesium extraction processes, and decontamination reagent.

The reagents evaluated in this study, which are substituted methane diphosphonic acids, were vinylidene-1,1-diphosphonic acid (VDPA) and 1-hydroxyethane-1,1-diphosphonic acid (HEDPA). The VDPA, developed by ANL as a TUCs, is not readily available. The ability to decompose HEDPA, which was not developed by ANL, was discovered after the development of TUCs. The HEDPA is readily available and could possibly be used in a supported liquid membrane process as a stripping solution for uranium.

The purpose of this study was to compare the degradation of HEDPA and VDPA using degradation conditions for VDPA similar to those developed by ANL. The conditions used for the degradation of VDPA and HEDPA included temperature change (25 °C, 60 °C, and 95 °C), an oxidant (H_2O_2) with a sodium orthovanadate catalyst at 25 °C and 60 °C, and adjustment of the pH to less than 1 by adding HNO_3 at 25 °C, 60 °C, and 95 °C.

The possible decomposition products for HEDPA and VDPA were phosphoric acid (H_3PO_4) and carbon dioxide (CO_2). The method used to characterize the decomposition of the complexants was ion chromatography.

PHYSICAL DESCRIPTION AND THEORY

Theory

The TUCs complexants developed by the chemical division at ANL are substituted methane diphosphonic acids. These complexants can be used for the aqueous complexation of transition metals, lanthanides, and actinides found in nuclear waste. Figure 1 shows a substituted methane diphosphonic acid in the general sense. The X and Y are used to adjust the lability of the C-P bond to oxidation, increase the acidity of the $-PO(OH)_2$, and increase the water solubility of the complexes.

Fig. 1. Substituted methanediphosphonic acids.

Physical Description

Figure 2 gives the structure, name, and acronym for both complexants that were used in the testing.

The VDPA solution was obtained from a supported liquid membrane demonstration in which natural uranium was removed from a synthetic groundwater feed. The conditions and extent of decomposition for the VDPA solution were characterized to establish the VDPA effectiveness as a complexant. Approximately 8 L of the 0.086M VDPA solution were available. For comparison, 3.9 L of 0.086M HEDPA solution were made.

Fig. 2. Structure of the organic complexants.

TEST APPROACH

Each test was done in a glass beaker and continuously stirred. The amount of VDPA, HEDPA, H_2O_2, HNO_3, and Na_3VO_4 that were used in making the chemical mixtures for each test are given in Table I. Each mixture was made at ambient conditions. Some of the tests required that the samples be heated on a hot plate.

TABLE I

Chemical Mixtures

Test Numbers	VDPA 0.086M (ml)	HEDPA 0.086M (ml)	H_2O_2 30% (ml)	HNO_3 70.4% (ml)	Na_3VO_4 (g)
1,3,5	500	-	-	-	-
2,4,6	-	500	-	-	-
7,9	488	-	40	-	-
8,10	-	488	40	-	0.1
11,13,15	448	-	-	74	-
12,14,16	-	448	-	74	-

Table II shows the conditions that were tested for the degradation of the VDPA and HEDPA complexants. These conditions included temperature variation, oxidation using hydrogen peroxide (0.504 gM H_2O_2) with a sodium orthovanadate catalyst (5.44×10^{-4} gM Na_3VO_4), and pH adjustment to less than 1 by nitric acid (1.234 gM HNO_3) addition.

TABLE II

Test Matrix of Degradation Conditions

Test No.	Complexant	Temp (°C)	Oxidant	pH Adjust	Catalyst ($NaVO_4$)
1	VDPA	RM	--	-	-
2	HEDPA	RM	--	-	-
3	VDPA	60	--	-	-
4	HEDPA	60	--	-	-
5	VDPA	95	--	-	-
6	HEDPA	95	--	-	-
7	VDPA	RM	H_2O_2	-	-
8	HEDPA	RM	H_2O_2	-	yes
9	VDPA	60	H_2O_2	-	-
10	HEDPA	60	H_2O_2	-	yes
11	VDPA	RM	--	yes	-
12	HEDPA	RM	--	yes	-
13	VDPA	60	--	yes	-
14	HEDPA	60	--	yes	-
15	VDPA	95	--	yes	-
16	HEDPA	95	--	yes	-

The H_2O_2 was added in two parts because of the slow reaction rate. The first half was added initially and the second half was added an hour later.

Tests 7 and 9 with VDPA required no catalyst, since the uranium in the solution acted as the catalyst. Tests 8 and 10 with HEDPA required catalyst addition because there was no uranium in the solution to act as the catalyst. Sodium vanadate was added to obtain a vanadium concentration of 1.0×10^{-5}M.

RESULTS

Test Solutions

Since the decomposition of the complexants yielded H_3PO_4 and CO_2 as the products, the amount of complexant degradation was determined by the concentration of free PO_4 in the final samples. The analysis of the degradated TUCs samples were completed using ion chromatography.

The VDPA and HEDPA degradation percentages are given in Tables III and IV. These percentages were found by calculating the amount of VDPA or HEDPA that corresponded to the free PO_4 present in each sample and then comparing the corresponding VDPA or HEDPA to the original concentrations. None of the VDPA or HEDPA complexants were completely decomposed during any of the tests. The total time for each test was 3 h. The highest degradation for VDPA occurred in test 15 with a 64.6 percent decomposition. The highest degradation for HEDPA occurred in test 10 with an 83.5 percent decomposition.

Figure 3 shows test 1-6 using only temperature variation. Both HEDPA and VDPA display an increase in degradation with increasing temperature; however, all the tests had less than 11 percent degradation. Moreover, VDPA was affected more by temperature than HEDPA.

Figure 4 shows the effects of H_2O_2 addition and temperature increase in tests 7-10. The Na_3VO_4 catalyst was added

TABLE III

VDPA Degradation Percentages Calculated Using PO_4 Analytical Results

Test No.	PO_4 (ppm)	PO_4 (wt%)	PO_4 (g)	VDPA (g)	Degradation (%)
1	692	0.069	0.34	0.35	4.3
3	773	0.077	0.31	0.32	3.8
5	5,292	0.529	0.85	0.88	10.5
7	4,424	1.442	2.36	2.42	29.7
9	7,682	0.768	3.20	3.27	40.2
11	1,149	0.115	0.63	0.65	8.6
13	1,510	0.151	0.76	0.78	10.5
15	16,980	1.698	4.72	4.83	64.6

TABLE IV

HEDPA Degradation Percentages Calculated Using PO_4 Analytical Results

Test No.	PO_4 (ppm)	PO_4 (wt%)	PO_4 (g)	HEDPA (g)	Degradation (%)
2	55	0.006	0.02	0.03	0.3
4	79	0.008	0.03	0.03	0.4
6	390	0.039	0.04	0.04	0.5
8	10,210	1.021	5.46	5.93	68.9
10	13,980	1.398	6.61	7.18	83.5
12	712	0.071	0.39	0.42	5.4
14	694	0.069	0.33	0.36	4.6
16	2,169	0.217	0.51	0.56	7.1

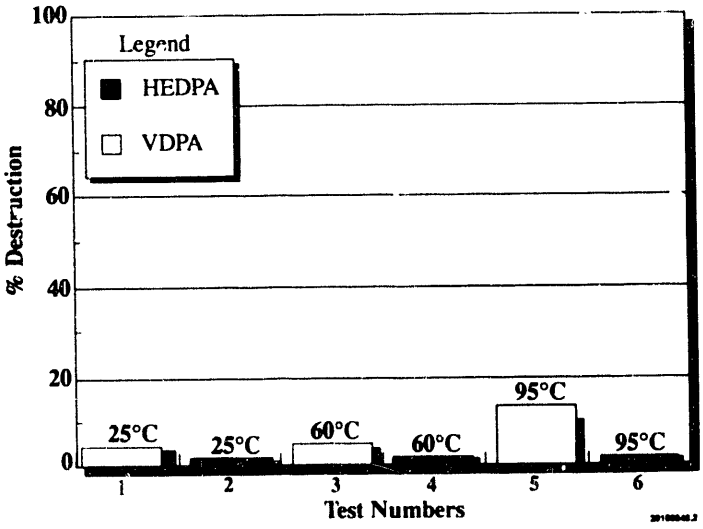


Fig. 3. Temperature effect on destruction.

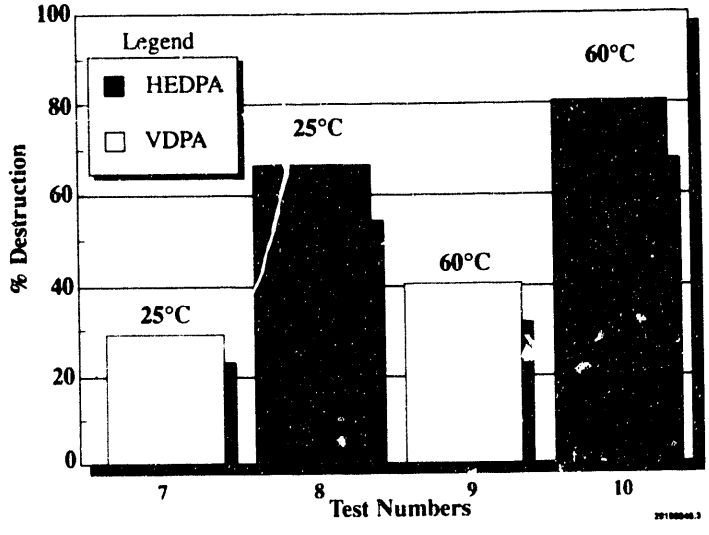


Fig. 4. Destruction with peroxide addition.

to the HEDPA solutions. Increasing temperature increased degradation. Addition of the oxidant (H_2O_2) in tests 8 and 10 caused significantly more degradation of the HEDPA relative to VDPA.

Figure 5 shows the effects of HNO_3 addition and temperature increase in tests 11-16. Again, increasing temperature increased degradation. The results from ANL for decomposing VDPA indicated that decomposition occurred only at a low pH.(2) Adjusting the pH using HNO_3 decomposed the VDPA more than the HEDPA. At 95 °C, the VDPA was decomposed by 64.6 percent, while the HEDPA was decomposed by only 7.1 percent.

In test 15, a precipitate formed on the bottom of the glass beaker, possibly containing uranium phosphate. The precipitate was not analyzed. There was 0.0016 gM of natural uranium present in the VDPA solution used in test 15. A uranium phosphate precipitate, therefore, could have accounted for only 2.0 percent of the phosphate.

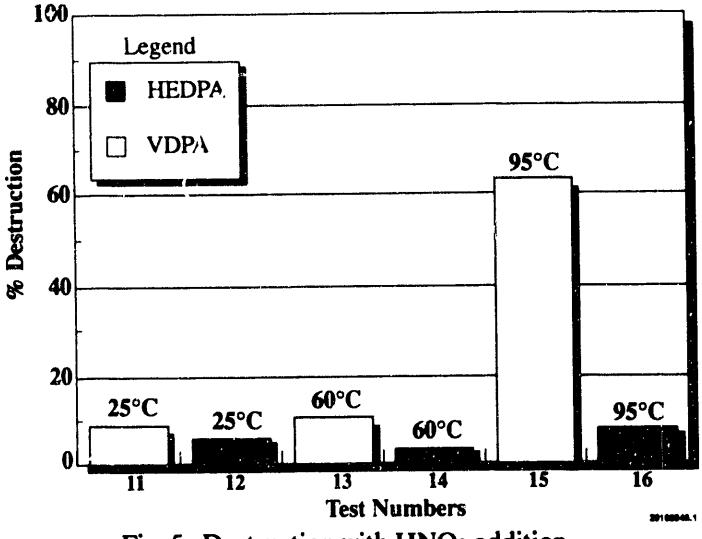


Fig. 5. Destruction with HNO_3 addition.

CONCLUSIONS

The best degradation of HEDPA was attained using Na_3VO_4 as the catalyst and H_2O_2 as an oxidant at 60 °C. It is possible that increasing the temperature could result in complete degradation of the HEDPA complexant. The best degradation of VDPA was attained using HNO_3 at 95 °C.

Increasing the temperature of the samples resulted in a definite increase in complexant degradation; however, increasing temperature alone degraded the complexants by only 10.5 percent at 95 °C for VDPA and 0.5 percent at 95 °C for HEDPA.

Using H_2O_2 as an oxidant with a catalyst (uranium for VDPA and vanadium for HEDPA) mixed with the complexants dramatically increased the degradation of both VDPA and HEDPA. The HEDPA decomposed more than VDPA. The VDPA degraded by 29.7 and 40.2 percent at 25 °C and 60 °C, respectively. The HEDPA degraded by 68.9 percent and 83.5 percent at 25 °C and 60 °C, respectively. Increasing the temperature of the HEDPA solution possibly could have resulted in almost complete degradation. The test matrix used was based on the conditions of decomposition employed by ANL.

At 95 °C, the VDPA degraded by 64.6 percent using the HNO_3 addition to adjust the pH. This was based on the amount of free PO_4 in solution. For all other tests with HNO_3 the degradation was less than 10.5 percent.

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"SMART" PUMP AND TREAT

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ABSTRACT

Lawrence Livermore National Laboratory (LLNL) (see Fig. 1) is approaching the final phase of the Superfund decision-making process for site restoration and will soon initiate full scale cleanup (1). Despite some well-publicized failings of the pump and treat approach, we have concluded that intelligent application of this strategy is the best choice for ground water restoration at LLNL. Our proposed approach differs sufficiently from the pump and treat methods implemented at other sites that we call it "smart" pump and treat.

Smart pump and treat consists of four distinct, but interrelated, elements: three pre-remediation strategies and one modification to pump and treat itself. Together, these techniques are an integrated program that utilizes an understanding of crucial aspects of contaminant flow and transport to speed up the remediation of contaminated aquifers. The four elements are: (a.) a spatially detailed site characterizatic linked with regional hydrogeologic models; (b) directed extraction, where the extraction and recharge locations are controlled by field-determined hydrogeologic parameters; (c) field-validated modeling that matches the complexity of the collected data; and (d) adaptive pumping, whose pattern varies with time. Together, these techniques minimize the cost and the time to reach regulatory directed cleanup goals and maximize the rate of contaminant removal.

BACKGROUND

At LLNL, we have inherited a legacy of contaminated soil and ground water from years of inadequate toxic materials handling and disposal practices, which are clearly unacceptable by today's standards. Contaminants at LLNL are primarily in the ground water and predominantly comprised of the chlorinated volatile organic compounds (VOCs) trichloroethylene and perchloroethylene. Until we began pilot remediation in 1987, the contaminants migrated naturally for over 40 years and, during that period, have dispersed over an area of about 2.5 km^2. Contaminants were initially discovered in ground water in 1983, and LLNL was added to EPA's National Priority List in 1987. A formal Remedial Investigation (2), Feasibility Study (3), and Proposed Remedial Action Plan (1) have been completed. Pilot remediation efforts were initiated in 1988. Over 33 million gallons of ground water has been extracted, treated, and recycled. Surface treatment with ultraviolet light oxidation has purified the ground water, eliminating all measurable VOCs. Results of the pilot studies provide the basis for the pump and treat strategy now proposed for ground water restoration. In this paper, we discuss components of this plan and the techniques used in arriving at our decisions.

DETAILED CHARACTERIZATION

The first step in characterizing a site to the level of detail needed to perform smart pump and treat is to conduct regional studies and determine the size and orientation of preferred ground water flow pathways. The Livermore Valley is a relatively flat basin underlain by a complex of alluvial sediments of late Tertiary and Quaternary age. The thickness of unconsolidated sediments increases from the eastern margins of the Valley westward toward the city of Livermore. VOCs exist in the upper part of the saturated zone, called the Upper Member of the Livermore Formation, which consists of sand, gravel, silt, and clay deposits with multiple water-bearing zones of relatively high permeability (see Fig. 2). Layers and lenses of low permeability silts and clays act as local aquitards, resulting in semi-confined permeable sediments at depth with horizontal hydraulic communication within water-bearing zones up to 250 m depth. The top of the Lower Member of the Livermore Formation is distinguished from the base of the Upper Livermore Formation by a 5- to 20-m-thick zone of clay-rich blue or greenish sediments with occasional interbeds of sand and silt. These low-permeability sediments comprise a regional confining layer.

A detailed characterization is unrealistic at the scale of the 2 mi^2 LLNL site; thus, a representative area was investigated (the detailed study area, or DSA), and the results from this area were used to characterize the VOC and lithology distributions, as well as critical sorption and other transport parameters for the entire site (see Fig. 3). The findings from the DSA provide important information for implementation

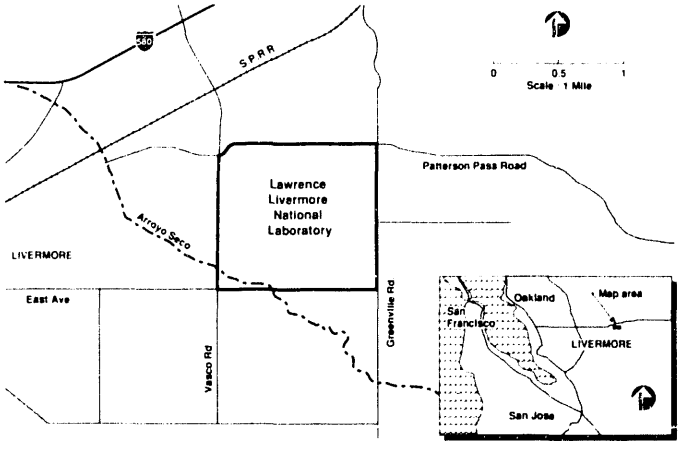


Fig. 1. Location of LLNL.

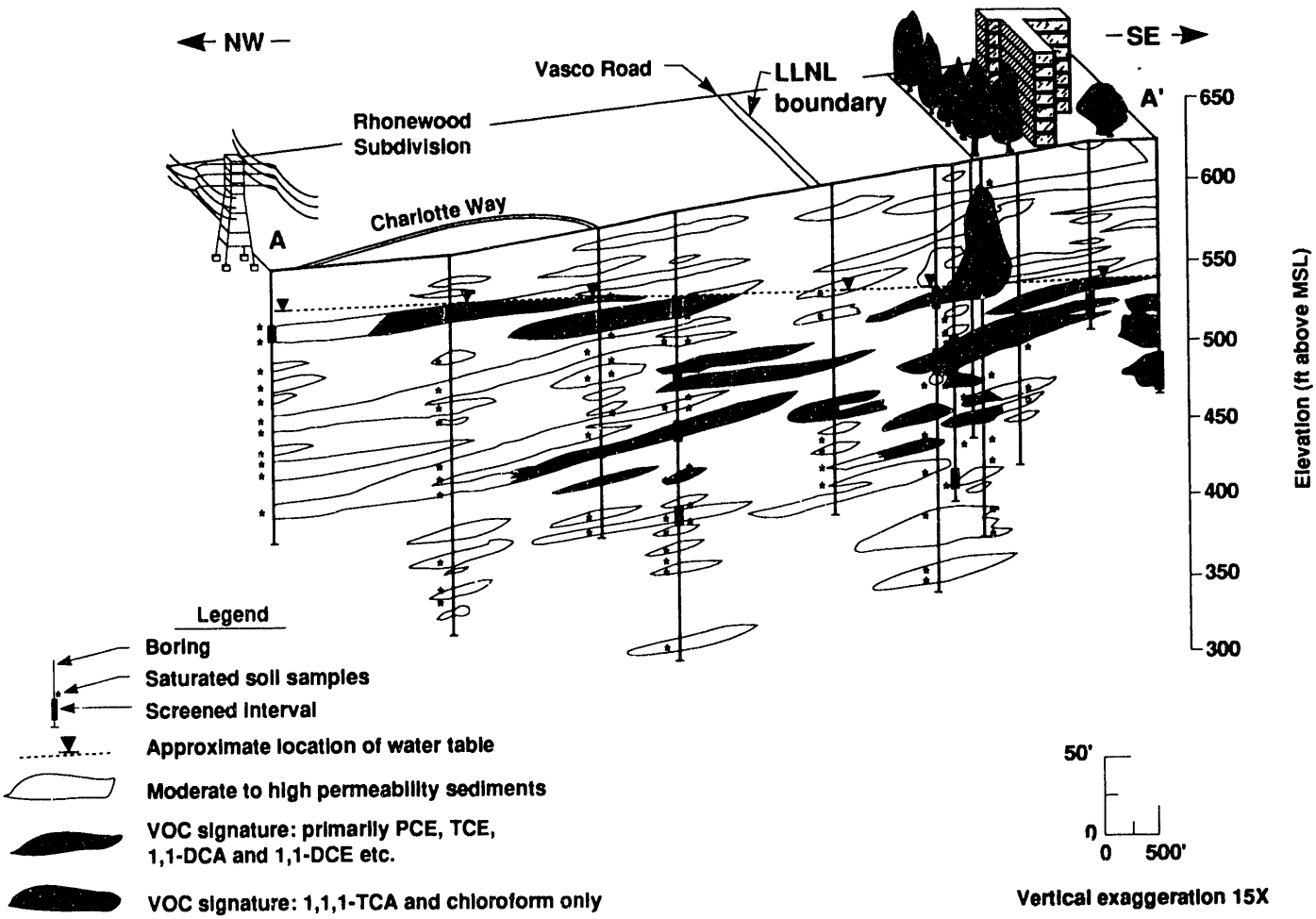


Fig. 2. Generalized geologic section showing distribution of VOCs in the subsurface west of LLNL.

of an extraction and reinjection program. The choice of the representative area was dependent on our understanding of the regional geologic and depositional environments.

We used technology developed by LLNL to collect sediment samples for characterization of the DSA. Our depth-sampling method allowed us to collect saturated samples from each water-bearing zone without contamination from other zones and without removing the drill rod from the borehole during sampling (4). At the DSA, we found that, within a water-bearing zone of permeable sediments, changes in VOC concentrations occur on a vertical scale of 0.3 to 1.0 m (see Fig. 4). In addition, VOCs have migrated less than a meter into the low-permeability sediments (see Fig. 5). Consequently, the spatial distribution of VOCs is strongly related to the distribution of permeable materials.

Other information from the DSA impacted our proposed pump and treat plan. Our correlation analysis of lithology versus sediment parameters is summarized in Table I. Results indicate that sediment PCE concentrations, bulk density, normalized TCE and PCE K_d values, organic carbon, and carbon exchange capacity are highly correlated with lithology ($P \leq 0.0001$). We also found that sorption constants are related to percent silt and clay and cation exchange capacity (5). In fact, these variables can be used to predict spatially varying sorption. In addition, a strong correlation has been observed between observed lithological facies and hydraulic conductivity (see Fig. 6) (6).

FIELD-VALIDATED MODELING

We have found that it is essential to initially use the least-complex model that the data can support. We started with very simplistic models and gradually increased the complexity and sophistication of models employed as the data and desired results required. At each stage, the modeling was further calibrated with new field results. Estimates of certain model input parameters can be made by comparing predictions with field data.

All models used assume that VOCs partition between sediment and ground water according to a linear equilibrium isotherm, resulting in a constant retardation factor. In addition, VOCs are assumed to transform into non-toxic compounds according to a first-order decay rate.

We initially used a zero-dimensional "well-mixed tank" model to obtain an estimate of the time necessary to reduce concentrations within the plume to concentrations below regulatory prescribed limits (see Fig. 7). The contaminant plume was idealized as a single, homogeneous volume of sediment and ground water. This volume was estimated using a three-dimensional volume integrator from the measured VOC concentrations in samples of ground water and sediment, with interpolations constrained by "soft" geologic data, such as sediment type and soil VOC concentrations. The plume volume is flushed with clean water at a rate equal to the expected extraction flow rate under a particular pumping scenario. Given the above assumptions, the average water

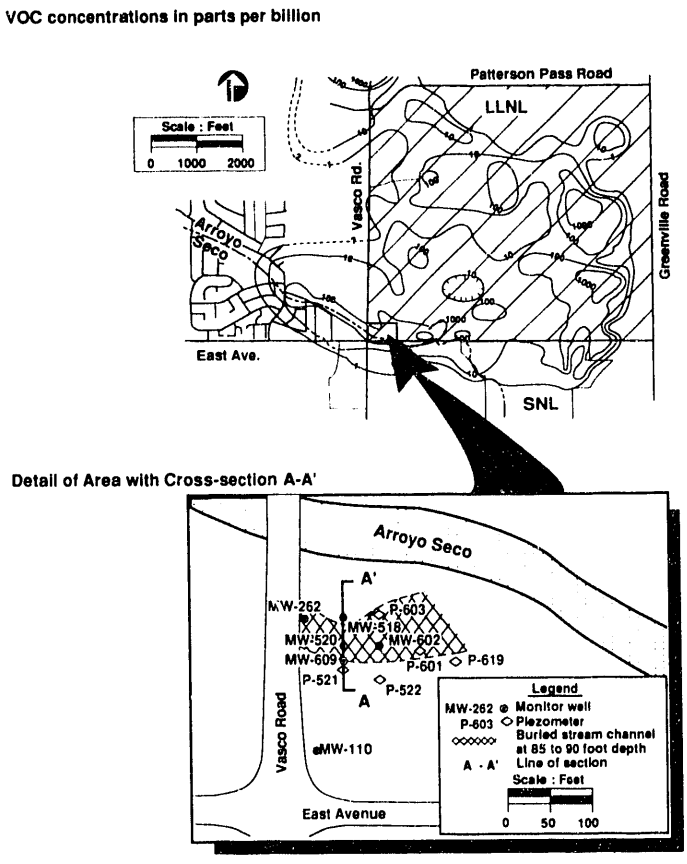


Fig. 3. Isoconcentration boundary map of total VOCs with location of detailed study area and detail of possible buried stream channel location.

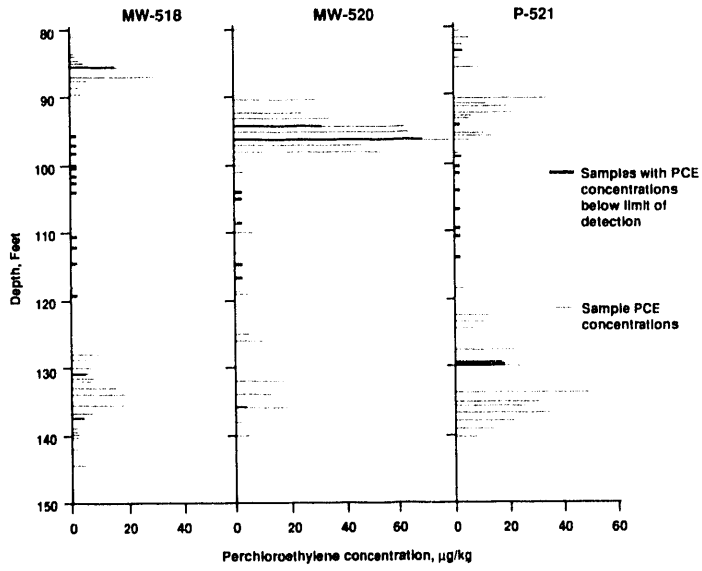


Fig. 4. Vertical distribution of PCE in three adjacent boreholes.

concentration can then be predicted based on a simple analytical expression. The concentration as a function of time for this model decreases exponentially.

A two-dimensional, semi-analytical model of VOC transport was used to predict contaminant concentrations for a "no action" alternative, as part of a baseline public health risk assessment. Ground water flow was assumed to advect at a uniform velocity throughout the region of interest. Initial VOC concentrations were defined by current field measurements, and transport was assumed to occur by one-dimensional advection and two-dimensional dispersion. In addition, VOCs were allowed to adsorb and transform. Simulations were performed to forecast VOC concentrations that may occur in hypothetical receptor wells downgradient of the plume.

A two-dimensional numerical model of ground water flow was next developed to provide a basis for future simulations of various ground water restoration alternatives (7). This model allows for spatially varying velocity, permeability, and sorption constants, as well as sinks and sources where

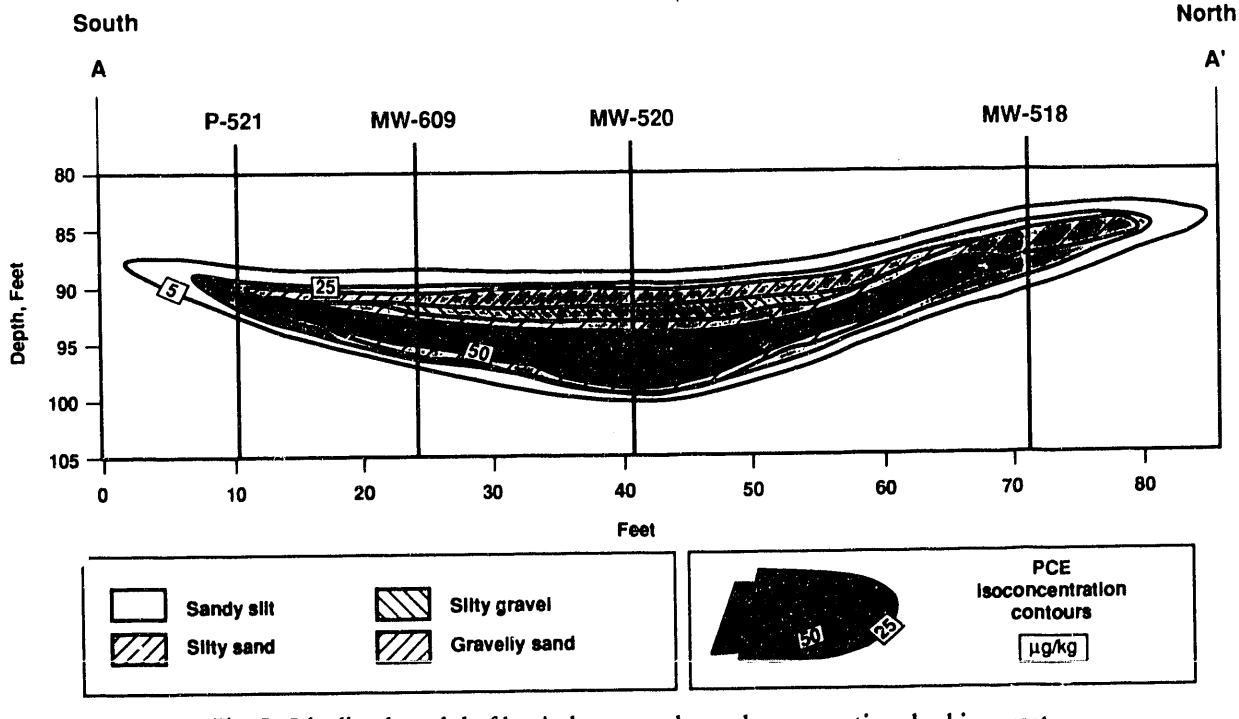


Fig. 5. Idealized model of buried stream channel cross section, looking west.

TABLE I

Summary of Detailed Study Area Average Sediment Properties

Lithology		PCE sediment Concentration ug/kg	TCE norm Kd	PCE norm Kd	Porosity %	Perm xE-07	Gravel %	Sand %	Silt %	Clay %	C E C	Org C
Sandy gravel	Average:	0.0232	0.22	0.91	27.7	763.1	56	33	6	5	5.93	0.04
	Count:	17	10	9	6	8	12	11	11	11	11	11
Gravelly sand	Average:	0.0183	0.42	1.42	27.1	267.3	29	53	9	8	8.87	0.052
	Count:	28	13	9	7	13	15	14	14	14	14	14
Silty gravel	Average:	0.009	-	-	-	11.7	-	-	-	-	-	-
	Count:	11	-	-	-	6	-	-	-	-	-	-
Silty sand	Average:	0.0096	0.74	1.99	29.7	10.6	6	53	26	16	17	0.06
	Count:	28	23	16	6	13	23	21	21	21	21	21
Clayey sand	Average:	0.0207	0.76	1.94	-	7.5	12	48	19	21	17.5	0.06
	Count:	2	2	2	-	1	2	2	2	2	2	2
Gravelly silt	Average:	0.0003	-	-	-	2.3	-	-	-	-	-	-
	Count:	5	-	-	-	4	-	-	-	-	-	-
Sandy silt	Average:	0.0047	0.83	2.48	30.3	2.6	3	42	36	20	22.3	0.07
	Count:	65	27	20	12	39	28	26	26	26	27	27
Clayey silt	Average:	0.007	0.78	2.4	30.3	4.25	1	39	40	20	20.9	0.11
	Count:	23	6	1	6	17	7	7	7	7	7	7
Sandy clay	Average:	0.0017	1.11	3.03	30	1.3	2	30	29	39	29.7	0.07
	Count:	3	3	3	1	3	3	3	3	3	3	3
Grand Average:		0.0098	0.67	1.96	29.2	96.0	15	45	25	16	16.7	0.06
Grand Count:		182	84	60	38	104	90	84	84	84	85	85

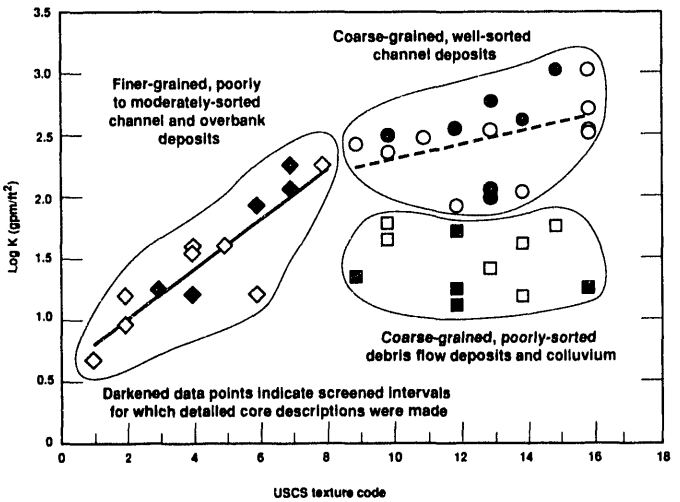


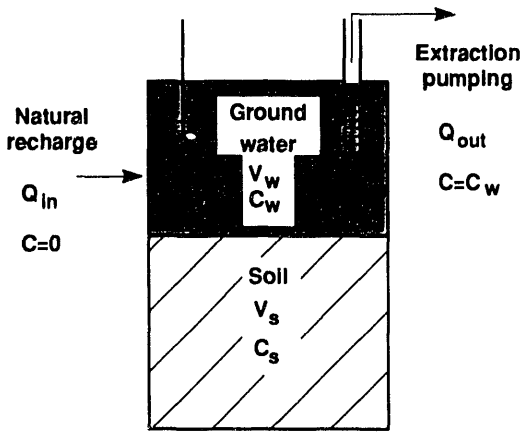
Fig. 6. Cross-plot of log K versus sedimentary (USCS) textures with depositional facies interpretations superimposed.

extraction and recharge wells are placed. Each feature of the conceptual and numerical model is based on careful evaluation of the field data. The effective hydraulic conductivity of the basin sediments compares closely with predictions based on stochastic theory (8). Calibration of the model has yielded a good match to observed water levels. The model is now being used to forecast the response of the ground water basin to different remediation pumping scenarios. The CFEST code being used for this task also allows for future extension to three dimensions as results warrant.

DIRECTED EXTRACTION

For directed extraction, the information on the spatial distribution of hydrogeologic, geologic, chemical, and sorption parameters gathered during detailed characterization are used to establish the initial distribution of extraction and recharge wells. Two-dimensional vertically integrated models (CAPTURE and two-dimensional plume contour maps) of ground water flow and VOC distribution are used to identify the approximate locations of extraction well clusters (see Fig. 8).

If only simplified two-dimensional homogeneous isotropic models are used, one might choose initial well locations that cause contaminants to be transported from coarse-grained permeable materials into fine-grained, highly sorptive sediments, where VOCs may become more difficult to remove. The use of a three-dimensional conceptual model of the VOC distribution, derived from depth sampling, two-dimensional cross sections, and three-dimensional interpolation, focuses the extraction locations on discrete water-bearing zones in order to maximize VOC mass removal and to minimize transport of VOCs into highly sorptive sediments (see Fig. 9). Wells screened in coarse-grained



- **Lumped parameters**
- **Used to obtain first estimates of cleanup time**

$$C_w(t) = C_{w_0} \exp\left[-\frac{Q_p}{V_w R} + \frac{\lambda}{R} t\right].$$

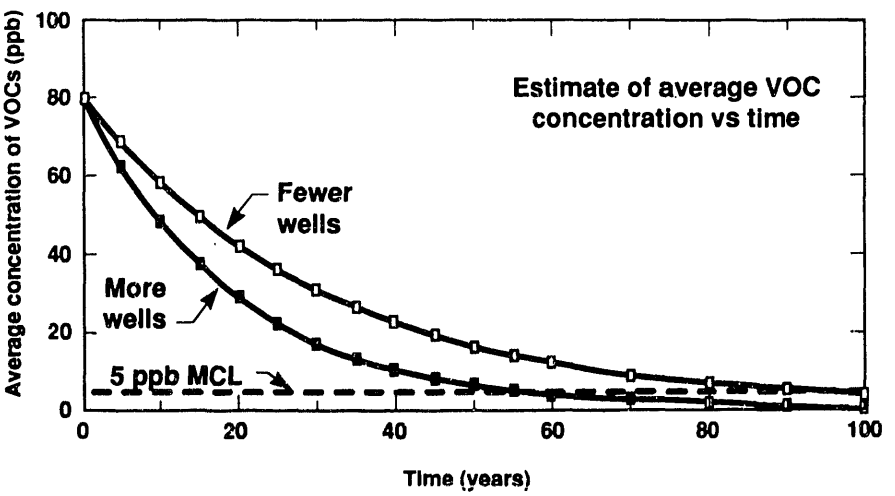


Fig. 7. A zero-dimensional model: the "well-mixed tank".

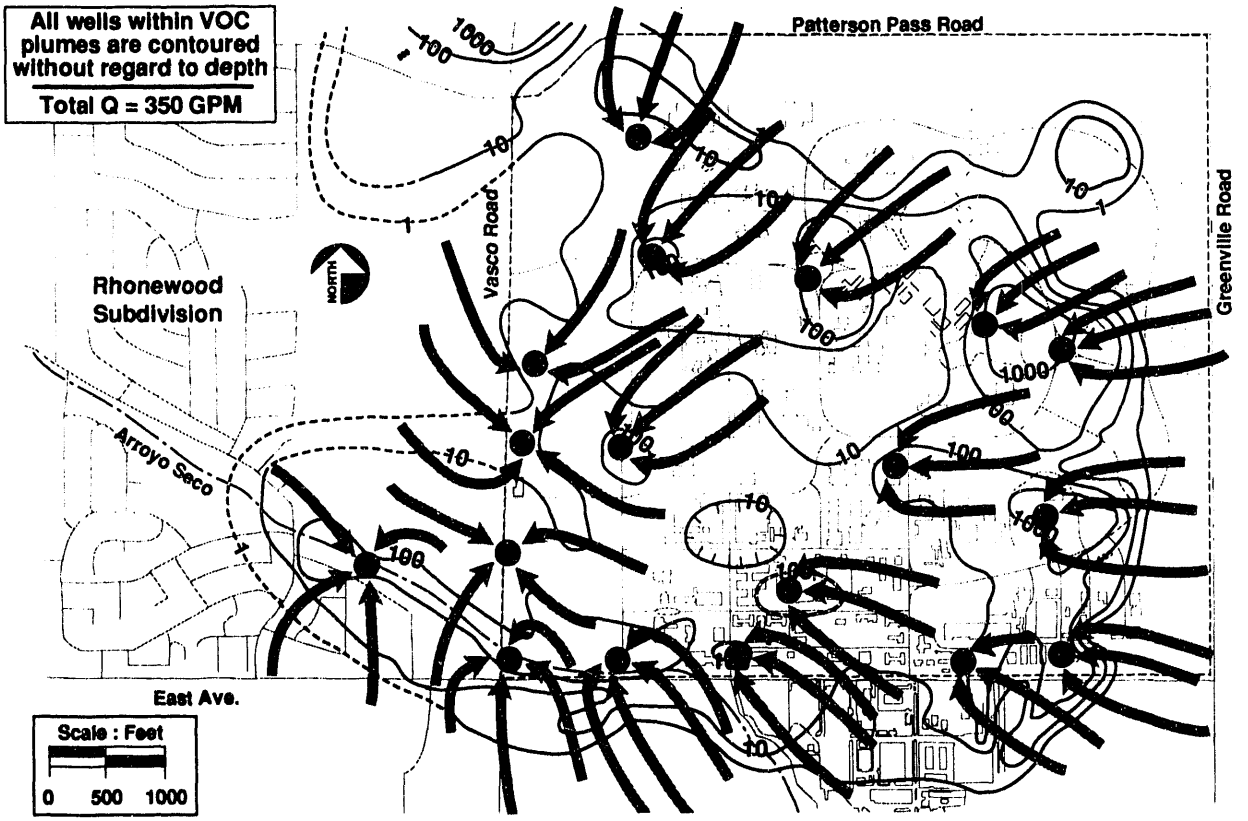


Fig. 8. Two-dimensional vertically integrated models of ground water flow and VOC distribution are used to identify approximate locations of extraction well clusters.

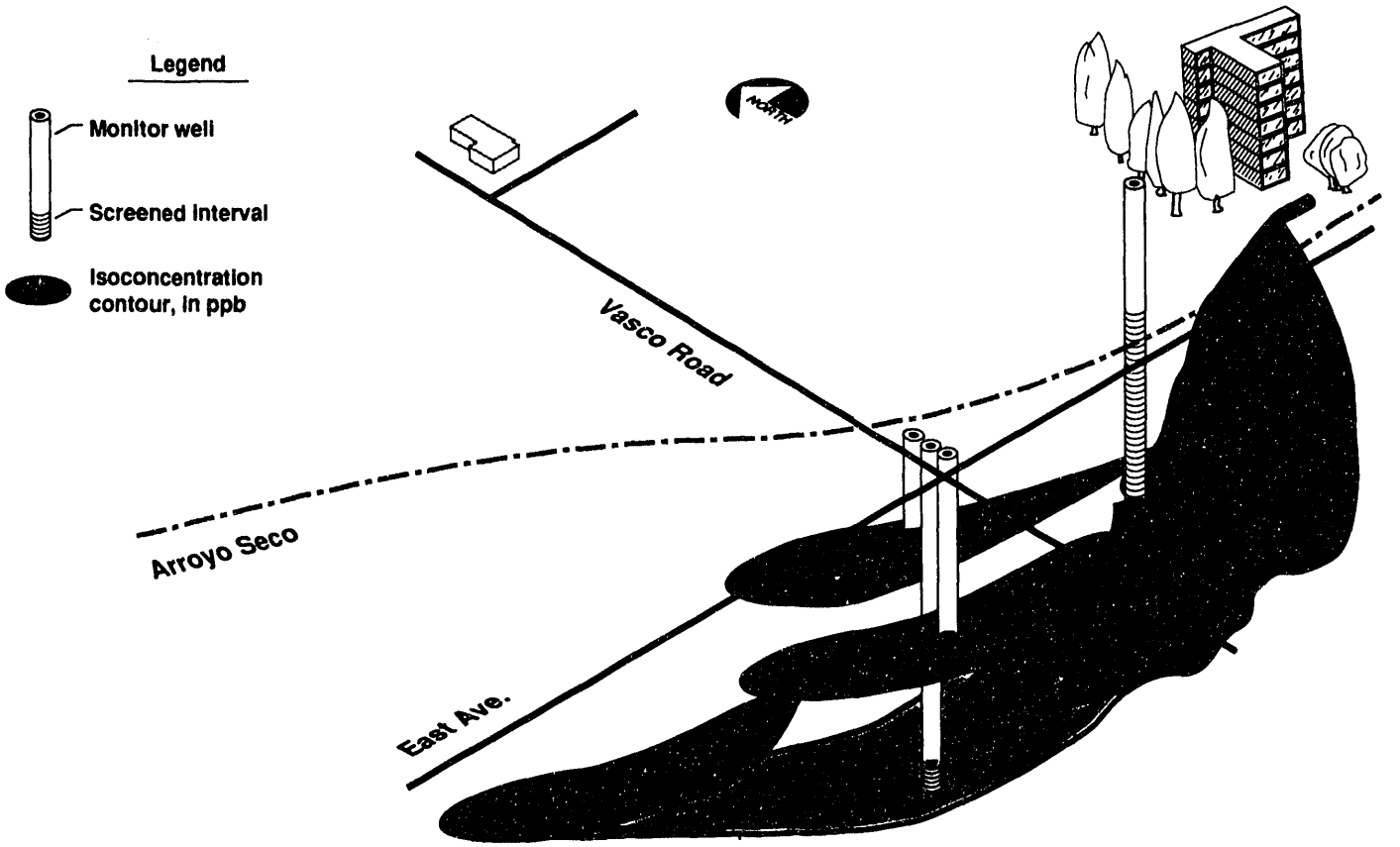


Fig. 9. Wells are sited during directed extraction to minimize transport of VOCs into highly sorptive sediments.

materials take advantage of natural pathways of preferred flow that originally distributed the VOCs. Near source areas, fully screened extraction wells may be used because sampling has shown all sediment to contain VOCs. Away from source areas, extraction cluster wells are more effective if screened in permeable zones requiring remediation only.

In cases where VOCs have migrated into fine-grained sediments to a significant degree, increased flushing by recirculation cells can significantly increase mass removal (see Fig. 10). The addition of heat is being explored as a means of decreasing viscosity and sorption and increasing molecular diffusion, thus reducing cleanup times (see Fig. 11).

ADAPTIVE PUMPING

Our modeling demonstates that by varying the locations and pumping rates of the extraction and recharge wells, the time required to reach cleanup goals can be reduced. We call this technique adaptive pumping. Adaptive pumping minimizes the negative effects of stagnation zones and well-to-well interference zones. Resources are conserved by turning off extraction wells and treatment facilities when they are no longer effective in achieving the cleanup goals.

The total cleanup effort is divided into management periods of one to five years. After each management period, the previously existing extraction/injection scenario is evaluated, optimized, and changed to reflect new information. Preliminary modeling results suggest that adaptive pump and treat versus an invariant pump and treat scheme can reduce cleanup time by up to a 50% (see Fig. 12). More formal optimization techniques are being explored.

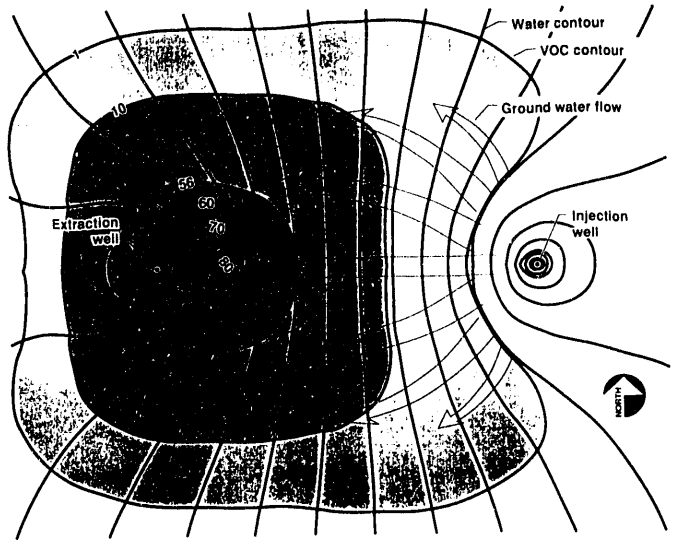


Fig. 10. Plan view of recirculation cell to enhance cleanup.

SUMMARY

Ground water pump and treat methods can be most effective if they are based on detailed characterization, field-validated modeling, directed extraction, and use of adaptive pumping schemes. Detailed characterization must be linked to regional geologic and hydrologic models and should

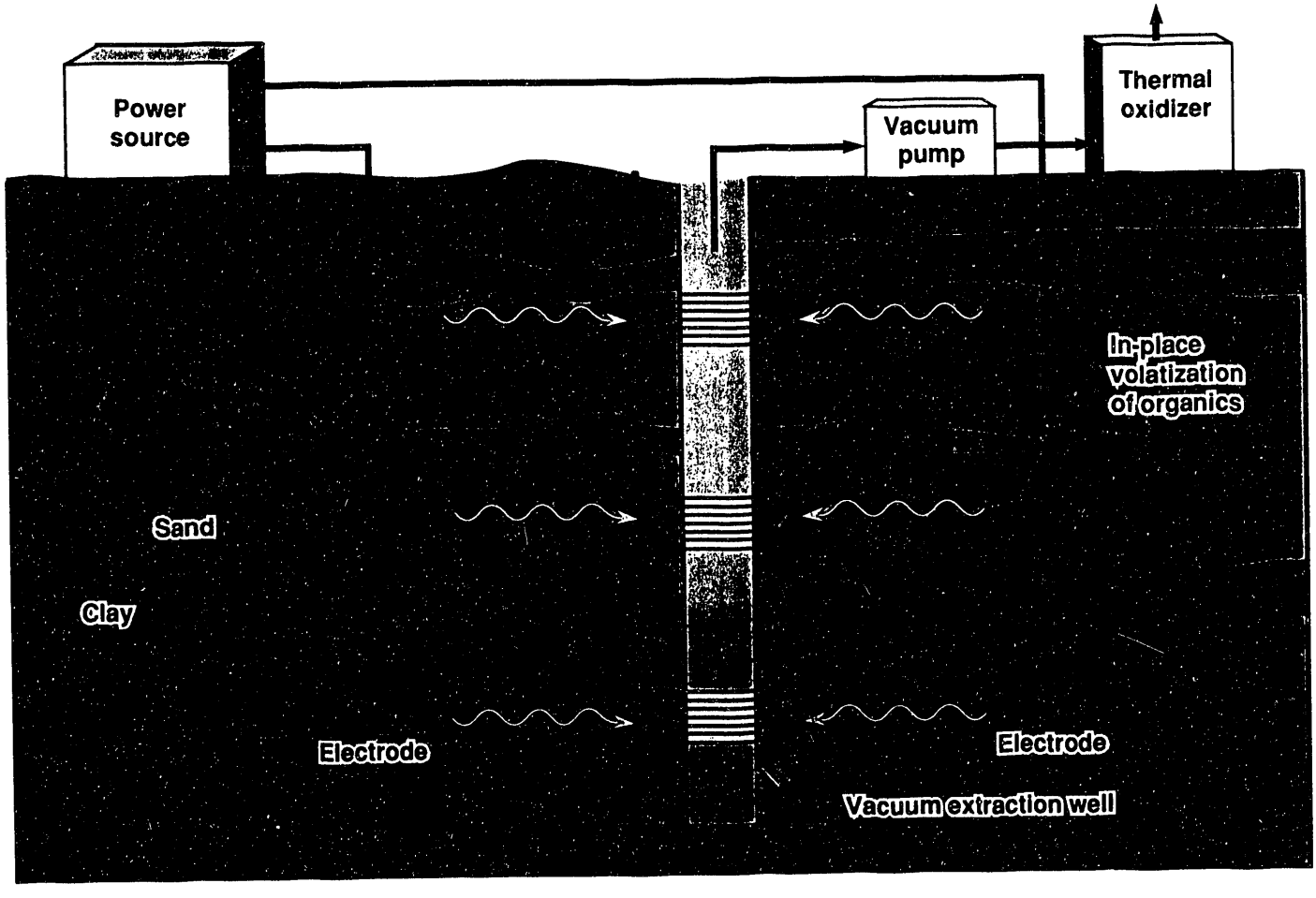


Fig. 11. Induction heating to enhance removal of VOCs.

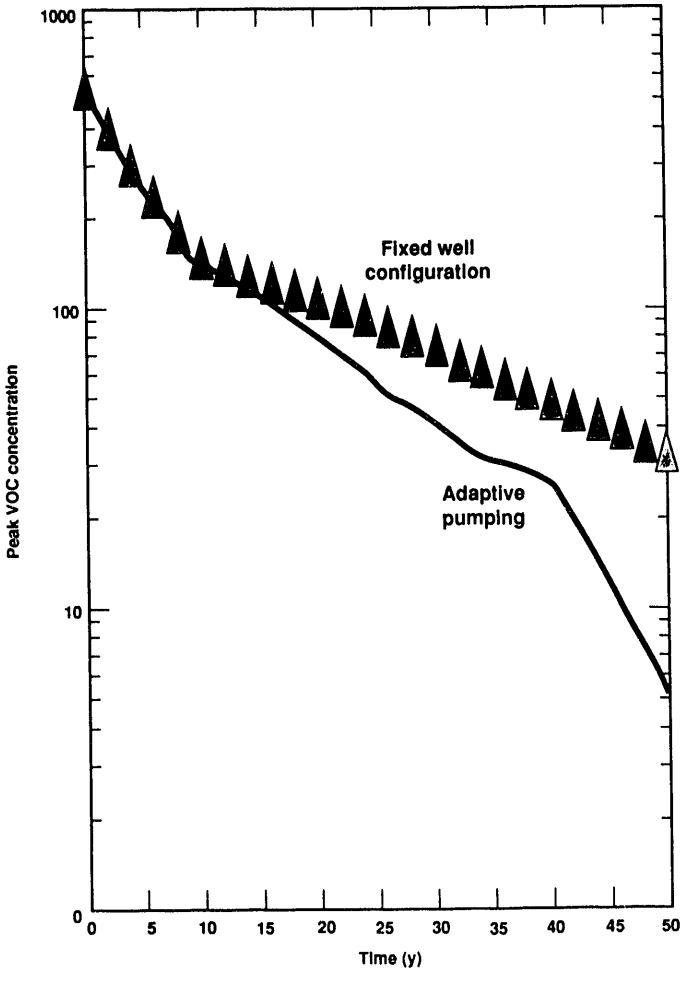


Fig. 12. Effect of adaptive pumping on clean-up time.

include geology, chemistry, hydraulic conductivity, degradation, and sorption measurements.

Field-validated modeling tightly integrates field data collection with standard modeling techniques. The modeling complexity must be commensurate with the current detail in the data and the level of understanding. Directed extraction uses the results gathered from detailed characterization and field-validated modeling to select the initial locations and pumping rates of the extraction and recharge wells. Adaptive pumping optimizes the ground water extraction in both time and space to reduce the effects of stagnation and interference zones. Choice of an optimal pumping strategy can make pump and treat effective by dramatically reducing the time and cost of cleanup.

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VISUAL SYSTEM FOR WASTE TANK CLEANUP

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ABSTRACT

The single-shell underground radioactive waste storage tanks at the U.S. Department of Energy's Hanford Site are briefly described and their physical complexities discussed. The attributes of a remote visual system needed to work productively in this environment are reviewed. The vision subsystem of the Naval Ocean Systems Center's TeleOperator/telePresence System, which closely approaches the required attributes, is briefly described. The possibility and usefulness of overlaying the visual image of the tank and its contents with a virtual model are discussed.

INTRODUCTION

The cleanup of the single-shell radioactive waste tanks at the U.S. Department of Energy's Hanford Site will be a long, demanding task that will require considerable technical effort to safely and efficiently complete. The internal tank environment is physically complex, and the waste, in addition to presenting certain explosion hazards, varies widely in physical form. Since it will likely require a remote robotic system to remove this waste and since the task is beyond the sole capability of current autonomous control systems, human oversight and control will be required. Vision will be the primary sense used by a human operator in guiding the waste removal equipment, and the safety and productivity of the removal operation will depend strongly on the quality of the vision system. It has been demonstrated that the attributes of vision most valuable to a human operator in a task such as this are depth perception, color and spatial correspondence (natural orientation). The vision subsystem of the Naval Ocean Systems Center's (NOSC) TeleOperator/telePresence System (TOPS) is a functional example of equipment incorporating two of these attributes--depth perception and spatial correspondence; it is likely that the third, color, can be added. The test results from TOPS, as well as other research, indicate that such a system would add significantly to the safety and productivity of a remote waste removal system for single-shell tanks. Figure 1 shows the interior of one of the single-shell tanks.

BACKGROUND

Hanford Waste Tanks

The Hanford Site, located in southeastern Washington, contains 177 large underground radioactive waste storage tanks, 149 of which are the older single-shell, carbon-steel-lined, concrete tanks. These tanks, built between 1943 and 1964, are of four sizes: 16 tanks with capacities of 55,000 gal.; 60 tanks of 500,000 gal.; 48 tanks of 750,000 gal. and 25 tanks of 1,000,000 gal. The 55,000 gal. tanks have a diameter of 20 ft. and a height of about 25 ft.; the 500,000, 750,000 and 1,000,000 gal. tanks have diameters of 75 ft. and wall heights of about 18, 24 and 32 ft., respectively. The tanks are buried from 5 to 12 ft. underground to provide radiation shielding. The tanks contain residue from the production of plutonium for the nation's nuclear weapons program; the last waste was added to the tanks in 1980. The waste consists primarily of chemicals from the chemical separation of reactor fuel and subsequent waste processing. The bulk chemical waste is in physical forms ranging from thick, sticky sludge described as being like peanut butter to saltcake described as being as hard as concrete. There is a small amount of supernatant liquid as well as some liquids in pockets in the saltcake.

The internal tank environment is not simple: it is complicated by a considerable amount of internal tank structure, hardware from previous processes, and the disposal of miscellaneous components and radioactive materials. The tanks have numerous vertical pipes (called risers) penetrating the dome into the tank to various depths; common diameters for risers are 4, 12, and 42 in., with other diameters occurring less frequently. Many of the tanks contain air circulators from

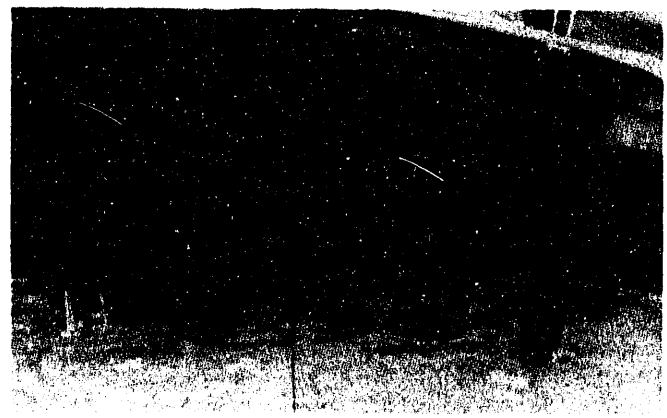


Fig. 1. Interior of a single-shell tank.

* Pacific Northwest Laboratory is operated by the U.S. Department of Energy by Battelle Memorial Institute under Contract DE-AC06-76RLO 1830.

past cooling operations, as well as pumps and pump shafts. Furthermore, many contain numerous long, steel tapes, level instruments and other contaminated scrap. Some tanks are known to have unique contents, such as tank 101-U which contains a small amount of experimental reactor fuel and slugs with kilocurie amounts of Co-60. It is believed that other articles were disposed of in the tanks and never recorded.

In addition to the complexities discussed above, the bulk contents of some of the tanks present additional hazards. A number of tanks (24) contain significant quantities of ferrocyanide material that is believed to be potentially explosive at elevated temperatures. There are 23 tanks with a potential for inflammable gas (hydrogen) accumulation above the lower flammability limit, and 11 tanks have high enough heat loads from radioactive decay to require forced air cooling.

Remote Vision Systems

Since autonomous control systems are not yet sufficiently developed to direct waste tank operations, the safety and productivity of the cleanup will depend largely on the ability of the operator to quickly and correctly assess the situation in the tank and guide the retrieval equipment. This assessment and guidance capability will, in turn, depend largely on the quality (naturalness in depth perception, clarity, color, and orientation) of the visual information presented to the operator.

There are several reasons why high quality visual information is of paramount importance to an operator of remote equipment:

- Vision is the primary means by which all people interpret the world, allowing them to immediately adapt to a changing environment. This is so important that approximately 70% of the brain's "circuitry" is devoted to processing visual information (1).
- Vision assumes even greater importance when other sensory information is degraded or missing.
- Vision supplies the majority of the reliable information that an operator uses to deal with the immediate concern of guiding the retrieval equipment in the tank.

The complex tank environment does pose a challenge to the operator's vision, but one that he can readily overcome if provided with a natural view, i.e., like the one that he would have if he were physically located in the tank. Therefore, one of the major goals of the vision system design should be to provide the operator with a natural view of the tank internals in order to take full advantage of his inherent ability to adapt to a changing environment and to intelligently direct the interactive, sometimes murky and sometimes delicate retrieval process.

There are three aspects of "normal" or "natural" human vision that have been demonstrated to provide substantial performance advantages when correctly implemented in a remote vision system: stereoscopic (3-D) viewing, color and spatial correspondence (natural orientation). Each of these aspects is an inherent part of the human visual capability and is used so effortlessly that its importance is often not appreciated. The importance of each aspect to remote manipulation and the results of quantitative studies are discussed below.

Three-dimensional viewing provides a number of advantages (as compared to 2-D) to a vision system for remote manipulation. Foremost among these is the ability to immediately and effortlessly perceive the (often complex) waste surface and the relative location and orientation of the work tools with respect to the waste surface (2,3). This allows the operator to place and guide the tools with a minimum of effort. Camera location with respect to the manipulator is less critical for 3-D systems than for 2-D systems, providing a more forgiving visual system (4,5). Also of importance to this application, 3-D viewing has been found to provide substantial improvement over 2-D viewing under conditions of reduced visibility such as might be encountered in the tank when salt cake is being removed (6). Three-dimensional viewing might also be helpful in identifying certain types of materials since the 'glint' of light off certain materials (e.g., many metallic, crystalline or moist surfaces) is highly directional. This 'glint' is the difference in patterning of brightness between the two eyes' views. Another positive feature of 3-D viewing systems is the inherent redundancy of a two camera system–failure of one camera does not blind the system from that viewing angle.

Color provides a means to distinguish materials when other means might fail. For example, crystals incorporating differing types and concentrations of contaminates may be readily distinguishable by color, but virtually indistinguishable without it. Color variation is also a useful visual clue for detection of areas of corrosion in the tank liners and in distinguishing between moist and dry materials. Given experience, waste removal operators will learn to judge the best removal techniques to use based on the visual characteristics of the material, including color.

Human beings learn from infancy the normal physical relationship between themselves and their world; that is, they learn that certain orientations and distances between them and objects in their environment are "normal" or "natural." Many years are spent learning how to efficiently manipulate objects in their environment from these orientations and distances. The notion of "spatial correspondence" means that objects are at their natural distances and are in their natural orientation with respect to an observer. A remote visual system that maintains this spatial correspondence (he sees it as he would if he were actually at the location of the cameras) allows the operator to use the efficiency that he has acquired by years of practice. If spatial correspondence is lost, people can adjust, but only at a cost in performance (imagine standing on your head). The costs show up in objective measures of performance such as the training required to attain proficiency, higher error rates, longer times to complete tasks, as well as mental and muscular fatigue among operators. When the normal relationship between the head movements and what is being observed is closely approximated by a remote viewing system, performance payoffs are seen. Controlled experiments have shown that not only does an operator's perception of 3-D space become more accurate (7), but his ability to remotely maneuver around obstacles and to manipulate objects within the remote environment is substantially improved (8,9).

In summary, a well-designed and implemented visual system would result in improved productivity and safety in waste retrieval. Productivity would be improved by minimizing operator training time, reducing the time required to complete tasks, reducing error rates, and minimizing operator fatigue. Equipment safety would be reduced by minimizing

the chance of a collision, because the operator can understand the spatial relationship between the objects in the tank.

TOPS VISION SYSTEM

The TOPS (Fig. 2) is under development to demonstrate an anthropomorphic work system which approaches a diver's ability to perform undersea work tasks. The TOPS comprises a dexterous, master–slave manipulator system and a spatially correspondent, stereoscopic vision system. The TOPS vision system is a particularly appropriate example of a system that might be used in a waste tank since it was originally conceived to work with a mechanical manipulator system.

Description

The TOPS vision system (Fig. 3) allows high quality 3-D viewing of the remote site in direct correspondence with the

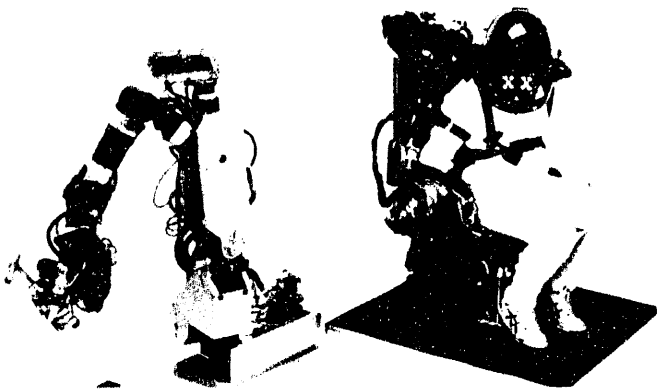


Fig. 2. TeleOperator/telePresence System.

orientation of the operator's head. The vision system is comprised of a pair of high resolution, stereo TV cameras mounted on a mechanical torso and neck assembly; a helmet-mounted display (HMD) with a head tracking mechanism; and sophisticated display electronics. The cameras, which are separated at approximate human pupil distance, provide the left-eye and the right-eye TV video which are sent via the display electronics to the appropriate left-eye and right-eye display in the HMD which the operator wears. The operator, therefore, views the remote site through the vision system with a near-normal view for each eye. The present TOPS vision system configuration is limited in resolution (approximately 20/80 vision), field of view (approximately 68°), and lacks color.

The stereo TV cameras are high resolution, monochrome cameras that have fixed focus lenses with an approximate 68° field of view (approximately that of a diver). See Table I for technical specifications.

The HMD (Fig. 4) consists of a helmet, optics, and cathode ray tubes (CRTs). The helmet is large enough to fit a wide range of head sizes, with pads available to adjust for proper fit, and accommodates operators with glasses. It has cooling air ventilation for long-term comfort, and hinges in the back of the helmet make it easy to get on and off. The optics are designed to allow natural viewing of the video displayed by the CRTs.

The display electronics (DE), developed by Wright-Patterson Air Force Base, were designed to allow mixing of various TV video and graphics signals. The DE has sophisticated distortion correction capabilities to allow precise matching (eliminates "ghosting" effects) from the video and graphics sources.

TABLE I

TeleOperator/telePresence System Technical Specifications

Helmet-Mounted Display

Manufacturer	Technology Innovation Group
Helmet subcontractor	Gentex Corp.
Monocular field of view	68° horizontal x 51° vertical
Binocular overlap	Adjustable from 68° to 50°
Interpupilary distance	Adjustable from 62 mm to 74 mm
Eye relief	32 mm
Exit pupil	18 mm diameter
Image sources	Hughes 1426, 1-in. CRTs (monochromatic)
See-through transmission	All but center 20°
Helmet size	Adjustable from 50th to 95th percentile male
System weight	7.5 lb

Stereoscopic Cameras

Manufacturer	Dage-MTI
Type	70 Series, high resolution, monochromatic
Lenses	Fixed focus, "C" mount with 68° field of view
Distances between optical axes	2.75 in.

Helmet-Mounted Display VS Panel-Mounted Display

The TOPS HMD was compared with a panel-mounted stereo display for underwater manipulator tasks. The panel mounted display (PMD) consisted of a pair of Electrohome Model EVM variable scan rate, 12-inch, monochrome, TV monitors (Fig. 5). The camera view was controlled by the operator moving a joystick. The underwater manipulator tasks included removal of various fasteners, making snap-hook attachments, securing objects to gratings, rigging frames, sorting objects, and inspecting objects for size and marking.

The general results are:

- Task performance is faster and less variable with the HMD.
- Operators strongly prefer the HMD over the PMD.
- The advantages associated with the HMD are greatest for the most difficult tasks.
- The operators benefitted from the sense of telepresence provided by the HMD. Having each of the monitors fixed in the optical pathway of the eyes and using naturally occurring eye/head motions, rather than a joystick, to position the cameras may provide a sense of telepresence and the benefits in visual search/feedback that the term implies. That is, operators can move the cameras naturally and accurately

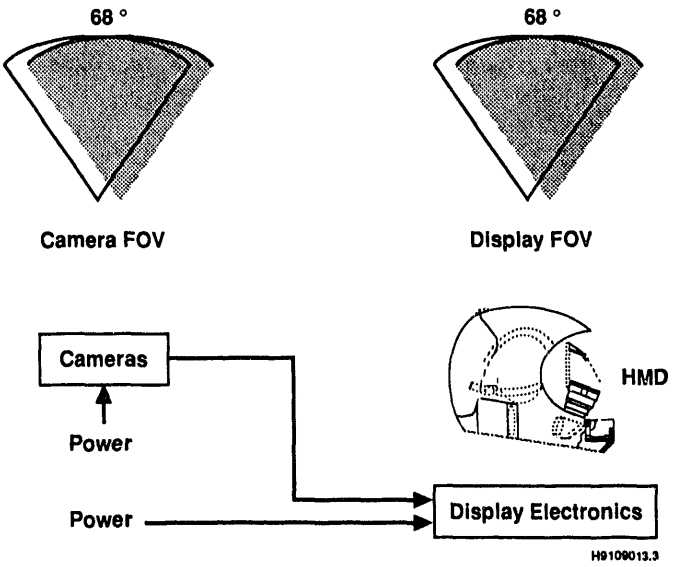


Fig. 3. TOPS vision system.

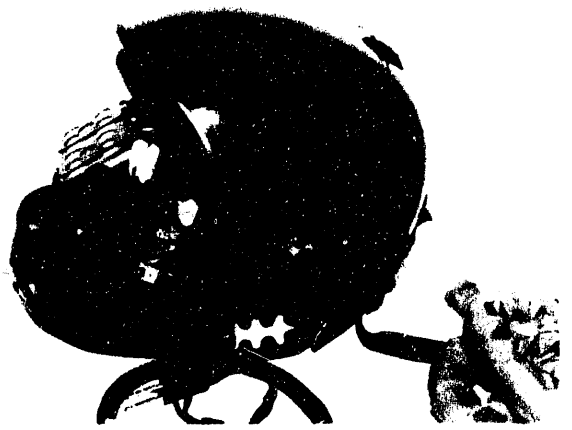


Fig.4. Helmet-mounted display.

without conscious effort. Images and motions produced by head-coupled camera movements are easily tracked by means of the inherent coordination of eye/head/image tracking abilities. The tracking of moving images produced by hand movements of the cameras and displayed on a panel monitor is a more difficult task requiring conscious effort to coordinate hand/eye/image movements.

HMD VISION WITH A VIRTUAL MODEL OF THE TANK'S CONTENTS

The use of the HMD can be enhanced by overlaying the image of the tank's contents and retrieval equipment with a computer-generated model of the tank's contents and retrieval equipment. Depending on the progress with sensors, this might also include an image of objects buried in the waste mass. This would give the operator added confidence to continue if for any reason (such as dust or a physical obstruction) his view is degraded. Furthermore, this same capability could, by means of other information displayed in the virtual space, be used to provide the operator with the status of

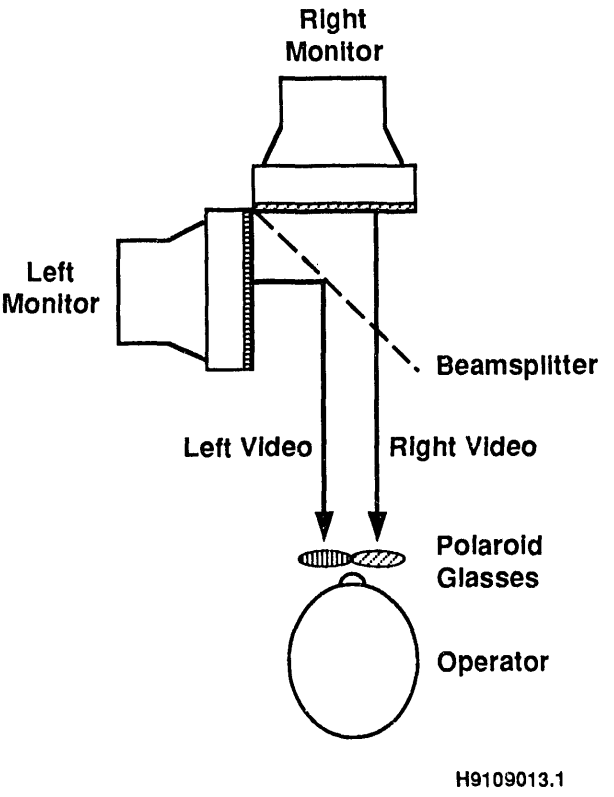


Fig. 5. Panel-mounted display.

sensor-generated monitoring information, such as temperature and radiation level. In particular, the display could immediately warn the operator of an unusual circumstance.

Virtual Model

Current thinking envisions obtaining a 3-D computer map of the internals of the tank prior to loading the waste removal equipment into a tank. This initial model will be used to plan the waste removal campaign. Waste removal equipment will have sensors that will provided real–time updates to this initial "world map" of the tank and its contents. This real–time "world map" will be used by the equipment control system to assist the operator in following the waste surface and avoiding obstacles in the tank. Sophisticated computer modeling software will be used to generate this "world model" from the sensory inputs of the removal equipment. By using this computer modeling software to generate images of the tank internals and the removal equipment from the perspective of the stereo TV cameras, it will be possible to generate a computer graphics virtual model which will match the scene viewed through the camera lenses.

Overlaying this virtual model of the tank and its contents onto the image in the HMD will provide the operator with an improved understanding of the remote environment, particularly under poor viewing conditions such as might be encountered when removing saltcake with a dry tool. For instance, the retrieval equipment including the end–effector, the waste surface, and any nearby object could be outlined in the proper perspective. The operator will determine the level of computer enhancement by selecting which portion of the virtual model to overlay and the intensity of the overlayed images. For example, if the removal equipment consists of a robot manipulator positioning an end–effector and a portion

of the scene is being blocked due to the position of the manipulator in front of the camera, the operator could fade in an overlay of the virtual model, thus making the manipulator appear translucent. In this way, the operator could see both the manipulator and the portion of the tank behind it.

Interfacing Virtual Model With HMD Electronics

In order to implement the concept of an overlayed virtual model, it will be necessary for the output of the graphics computer creating the "world model" to be integrated with the display electronics driving the HMD. Input from the position sensors on the pan/tilt and zoom/focus mechanisms for the stereo cameras will provide the necessary information for the computer graphics software to generate the appropriate views of the virtual model. The output of the graphics computer can provide a standard video signal that can be overlayed onto the camera images.

The position of reference points attached to objects within the virtual model can be used by the graphics computer to create wireframe drawings. The ability of the DE to multiplex stroke information with raster video inputs provides an efficient method of overlaying the vectors composing a wireframe drawing onto the standard video output of the stereo camera system.

CONCLUSIONS

The retrieval of waste from the single-shell tanks at the Hanford Site will be a demanding task, requiring intensive operator interaction with the waste retrieval equipment. The productivity and safety of the operation will depend largely on the quality (depth perception, clarity, color and spatial correspondence) of the visual information presented to the operator. The NOSC TOPS visual system is an example of an existing system that, with the exception of color, provides these qualities. The TOPS can, in principle, accept color if studies show that color is required. Productivity might also be improved if a wireframe virtual model of the tank contents were overlayed onto the 3-D image. It has been shown, in principle, that the graphics computers envisioned to provide a "world model" of the tank can provide acceptable input to the TOPS display electronics which can then overlay the virtual image onto the video image.

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REMEDIATION TECHNOLOGY DEVELOPMENT FROM THE UMTRA PROGRAM

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ABSTRACT

The Uranium Mill Tailings Remedial Action (UMTRA) Project is being performed by the U.S. Department of Energy to accomplish environmental remediation at 24 abandoned uranium processing sites. In order to meet the 200- to 1000-year design life requirement the DOE has sponsored technology development in several areas, including: 1) determining the relationship between optimum moisture content and the initial tailings water content which will cause drainage from the tailings at a rate corresponding to adherence to groundwater standards, and 2) accounting for rock quality measurements in designing riprap for the specified design life. The technology for Item 1) includes the application of quasi-theoretical procedures to generate relationships between suction, moisture content and permeability, and the use of the computer program UNSAT2 to model the unsaturated flow involved. The technology for Item 2) consists of a scoring system, utilizing the results of durability tests and accounting for the relative importance of the different durability parameters to various rock types, combined with a quantitative procedure for increasing riprap diameter to allow for future weathering.

INTRODUCTION

In accordance with the Uranium Mill Tailings Radiation Control Act of 1978 (Public Law 95-604), the U.S. Department of Energy is performing environmental remediation of approximately 40 million cubic yards of uranium tailings at 24 sites. The tailings are radioactive and contain varying amounts of leachable heavy metals. The governing regulations specify:

"Controls shall be designed to be effective for up to 1,000 years, to the extent reasonably achievable, and in any case for at least 200 years".

Meeting this criterion has required technology development in two areas:

1. Predicting the rate of flow of leachate from compacted tailings as a function of placement moisture content and other parameters.

This allows determination of an upper bound limit on compaction moisture content so as to avoid drainage of excess water at a rate which would cause exceedance of ground water standards.

2. Providing a rational basis for riprap design which allows the use of the best available rock within a reasonable haul distance of the site to be reclaimed.

This permits the use of oversizing to allow for deterioration of average size during the 200- to 1,000-year design life required by the regulations.

Descriptions of these technology developments are provided in this paper.

DISCUSSION

Tailings Water Content to Prevent Groundwater Contamination

The EPA proposed groundwater standards for disposal of uranium mill tailings at Title I sites (published September 24, 1987 in 40 CFR Part 192-02 (a) (3)) require that stringent maximum concentration limits (MCL's) be met at a location called the "point of compliance" (POC) of the disposal facility. The POC is defined (1), as, "a vertical surface that extends downward into the uppermost aquifer along the hydraulically downgradient limit of the disposal area." (See Fig. 1.) In general, the POC concept is implemented by using a series of monitor wells installed along this surface to monitor groundwater quality. The POC should be as close to the disposal area as practical and should provide access for monitoring groundwater quality without disturbing disposal facility components used for long-term isolation of the tailings.

The design limiting flux is defined as the maximum flux allowed to leach through the tailings material into the groundwater such that the resulting concentrations of chemical constituents at the point of compliance will be at or below the MCL's set forth in the proposed EPA groundwater standards. Because the background quality of groundwater for some of the sites exceeds the MCL's, seepage from the tailings material cannot be allowed to discharge into groundwater in order to meet the proposed standards. The limiting design flux becomes zero, and the travel-time concept is applied to the buffer zone which is the region between the bottom of the tailings, and the top of the ground water. In this case, the groundwater standards can be met if it can be demonstrated that the time required for moisture to travel from the tailings to the groundwater will be at least 1,000 years (2).

The tailings and buffer materials must have saturated hydraulic conductivity (K_s) values greater than the radon barrier above them, to avoid the creation of a bathtub effect. Even if placed at the practical lower limit of placement moisture content, the partially-saturated hydraulic conductivity (K_u) for the tailings and offpile materials may be high enough to cause post-compaction water to drain faster than permissible through the buffer layer.

After the placement, the moisture content is assumed to be uniformly distributed in each type of material; minor variations in moisture content due to construction procedures and materials are neglected. This results in a vertical hydraulic gradient (i) of one within each material immediately after compaction, because every point throughout the material will be at the same suction. As time progresses, the distribution of suction will change, causing i and K_u to change so that the flux velocity, which is the product of K_u and i, will change as well.

The method used to predict the flux through the profile consists of computer simulation of post-construction moisture flow. The purpose of the simulation is to determine the maximum compaction moisture content of the tailings material such that the travel time through the buffer layer will be at

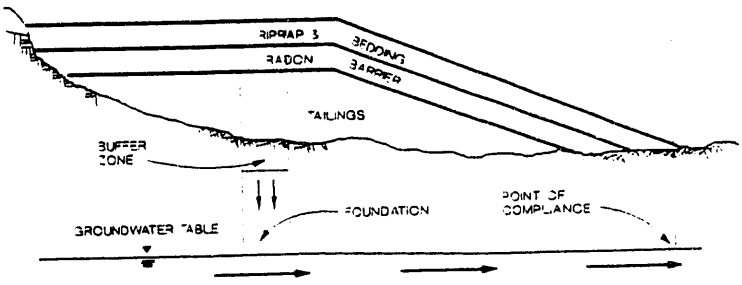


Fig. 1. Cross-section for analysis of reclaimed tailings deposit.

least 1,000 years. The simulation, in general, is performed for a long enough time such that either the profile of suction/moisture has been practically stabilized or a trend can be established for the long-term condition.

A finite element computer program UNSAT2 (3), is used to simulate partially-saturated flow in the tailings and buffer materials. The following hydraulic properties of the materials are required as input to the predictive model:

1. **Relationships of Suction Vs. Moisture Content and Partially-Saturated Hydraulic Conductivity (K_u) Vs. Moisture Content** - Numerous methods using mathematical relationship are available to fit laboratory suction vs. moisture content data. The fitted suction vs. moisture content relationships are then used together with K_s to derive K_u as a function of moisture content. Among these methods are Vauclin, Brutsael, Brooks/Corey (used in computer program "SOIL", (4)) and Mualem/Van Genuchten (used in "RETC", (5)).

Based on the results of comparative studies, the Mualem/Van Genuchten model is found to predict the partially-saturated properties of soils with reasonable accuracy (6-9). Thus, unless specific experimental data are available for these properties, the Mualem and Van Genuchten techniques are used to determine the input to UNSAT2 from the laboratory tests results for saturated conditions.

2. **Disposal Cell Simulation Profile** - For simulation purposes the disposal cell can be approximated by either a one- or two-dimensional vertical profile. The cell side slopes are, in general, relatively gentle [5(H):1(V)]. Interfaces between individual lifts and material types are essentially horizontal (2% slopes or flatter). The profile is chosen to represent the most critical flow section through the cell such that the flow analysis is conservative.

3. **Initial Suction and Moisture Content Distribution in the Profile** - These distributions correspond as closely as possible to the field moisture contents and densities as measured immediately following placement of the tailings and buffer materials. Due to the differences in hydraulic properties between various types of soils and rocks, discontinuities of suction and moisture content are expected to occur at the interfaces between materials.

4. **Boundary Conditions** - A no-flow boundary condition is imposed on the top of the tailings to simulate conditions during the transient period of post-construction moisture drainage during which precipitation flux has not penetrated through the upper cover.

The bottom boundary condition is established by prescribing a constant suction at the base of the buffer layer corresponding to a negative pressure head equal to the height of the buffer above the groundwater table. This bottom suction is varied during the sensitivity analyses to determine its impact on the flow. These sensitivity analyses are necessary because of the uncertainties in the foundation material properties and the depth to ground water. The results of the analyses provide guidance on the selection of a bottom suction for the design simulation runs.

As water infiltrates into and percolates through the profile, moisture content and flux at a given location tend to reach a steady state condition with constant boundary conditions. The hydraulic gradient i is expected to decrease below 1.0 as time progresses. The flux through the profile is computed, using Darcy's law as follows:

$$Q = (K_u)\,(i)\,(A)$$

where:

A = cross-sectional area of the material normal to the flow, and K_u and i are as defined above.

For a unit cross-sectional area, Darcy's flux is numerically equal to the flux velocity, (K_u) x (i). The specific K_u used in the equation is derived from the K_u vs. moisture content curve corresponding to the long term moisture content of the buffer layer.

The time for the seepage front to traverse the buffer layer can be calculated by summing incremental travel times over each time step or by a simplified approach. Incremental travel times can be estimated from the average properties of the buffer element in which the seepage front is located for each time step. The simplified approach is based on the greatest seepage velocity in any element of the buffer layer. The travel time is derived from the following equations:

$$\textit{Seepage velocity} = \frac{\textit{flux velocity}}{\textit{volumetric moisture content}}$$

$$\textit{Travel Time} = \frac{\textit{thickness of buffer layer}}{\textit{seepage velocity}}$$

Riprap Quality Requirements for 200- to 1,000-Year Design Life

As stated in the introduction, controls are to be designed to be effective for 200 to 1,000 years. This includes control of erosion of the radon barrier placed over the tailings as well as erosion of the tailings themselves (Fig. 1). Erosion resistance is provided by riprap, based on the combined effect of rock weight and size. Weight is accounted for by the specific gravity of the rock; size by the 50% size, D_{50}, and maximum and minimum sizes, which are a function of D_{50}.

The normal procedure for selecting a source for riprap is to perform petrographic analyses and some of the "durability" tests, which are recognized indicators of resistance to weathering - specific gravity, absorption, sulfate soundness, and LA abrasion. The petrographic analyses normally consist of inspection by the use of a hand lens and microscope, possibly supplemented by X-ray diffraction techniques. If the petrographic geologist rates the rock as at least "fair", and the

indicators confirm this pronouncement (see Table I for typical standards), the rock may be used for erosion protection of dams, channels, etc. A typical design life for this type of project is of the order of 40 to 50 years.

TABLE I

U.S. Bureau of Reclamation Standards for RIPRAP Durability (Ref. 11)

Test	Quality (Score) Poor	Fair	Good
Bulk Specific Gravity (SSD)	<2.5	2.5 to 2.65	>2.65
Absorption (% weight gain)	>1.0	0.5 to 1.0	<0.5
Freeze-Thaw Weight Loss (% after 250 cyles)	>5.0	0.5 to 5.0	<5.0
$Na_2 S0_4$ Weight Loss (% after 5 cycles)	>10.0	5.0 to 10.0	<5.0
L.A. Abrasion Weight Loss (% after 100 revolutions)	>10.0	5.0 to 10.0	<5.0

Judgement indicates that better quality rock must be used for a design life of 200 to 1,000 years. However, unless there is some geologic or other historic evidence that a particular rock has been resisting weather of the type expected at the site for periods of this order of magnitude*, further development will be necessary to extend this approach. As a goal the Table I requirements for "good" quality rock have been selected. To allow for extra excellence in one property compensating for a lesser result in another, and to include the relative importance of the various tests to different rock types,** Table II was developed as a joint effort of the DOE, the NRC and the DOE subcontractors Jacobs Engineering and Morrison-Knudsen.

To use this table for final design it is recommended that testing include at least six of the seven types of tests shown. Interpolation for results falling between the values shown and weighting of the score for each test results in a weighted total score as shown in Table III. This value is divided by the total possible weighted score to produce the overall quality ratio. If this ratio exceeds 80% the rock can be used with the D_{50} value as calculated from riprap sizing calculations.

If the overall quality ratio is less than 80% it is necessary to assess whether the use of the riprap will be in an area of the facility that is frequently saturated or only occasionally saturated as follows:

RIPRAP OVERSIZING PROCEDURE

Frequently Saturated Areas: Channels, Poorly-Drained Toes and Aprons.

Score

65-100: Oversizing factor = (80-score)%.

Less than 65: Reject.

Occasionally Saturated Area: Top Slopes, Side Slopes, Well-Drained Toes and Aprons.

Score

50-80: Oversizing factor = (80-score)%.

Less than 50: Reject.

As indicated above, if the ratio is less than 65% the rock cannot be used in frequently saturated areas; if less than 50% it cannot be used at all. And in either case rock having a ratio of less than 80% can only be used if oversized (increase D_{50} by the given %) by the factor computed as shown above. This oversizing factor is then applied to the minimum D_{50} value computed for erosion resistance to give:

Minimum specified D_{50} = Minimum design D_{50} (1 + Oversizing Factor).

For example:

Oversizing Factor = 80 - 50 = 30,

Minimum specified D_{50} = Minimum design D_{50} (1 + 0.30)

SUMMARY

Environmental remediation of approximately 40 million cubic yards of uranium tailings is resulting in the following significant technology developments:

1. Prediction of the rate of drainage of water included in the tailings at the time of compaction using the Mualem and Van Genuchten techniques to generate functions for the suction - moisture content - K_u relationships of the materials involved and using the computer program UNSAT2 for analyses of partially-saturated flow.
2. Establishment of a rational basis for using durability parameters in selecting riprap for a 200- to 1,000-year design life, including increasing size requirements to allow for weathering, based on a scoring system accounting for higher quality in one property compensating for a lesser result in another characteristic.

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* For example the Loyalhanna limestone near Pittsburgh, Pennsylvania, has remained essentially unweathered in 80- to 90-year old exposed home foundations and cobblestone streets.

** For example specific gravity is much more important to limestone than to sandstone.

TABLE II

UMTRA Project
Rock Quality Scoring Criteria (Ref. 10)

	Weighting Factor			Score										
	Lime Stone	Sand Stone	Igenous	10	9	8	7	6	5	4	3	2	1	0
Specific Gravity	12	5	9	2.75	2.70	2.65	2.60	2.55	2.50	2.45	2.40	2.35	2.30	<2.3
Absorption (%)	13	5	2	0.1	0.3	0.5	0.67	0.83	1.0	1.5	2.0	2.5	3.0	>3.0
Sodium Sulfate (%)*	4	3	11	1	3	5	6.7	8.3	10	12.5	15	20	25	>25
Abrasion (%)**	1	8	1	1	3	5	6.7	8.3	10	12.5	15	20	25	>25
Schmidt Hammer	11	13	3	70	65	60	54	47	40	32	24	16	8	<8
Tensile Strength (psi)	5	4	10	1400	1200	1000	833	666	500	400	300	200	100	<100

1. Scores derived from Tables 6.2 and 6.7 by Lindsey, Long and Begij (Ref. 11).
2. Any rock to be used must be qualitatively rated at least "fair" in a petrographic examination conducted by a geologist experienced in petrographic analysis.
3. Weighting Factors derived from Table 7 by de Puy (Ref. 12), based on inverse of ranking of test methods for each rock type. Other tests may be used; weighting factors for these tests may be derived using Table 7.
4. Test methods should be standardized (ASTM, e.g.) and should be those used in study by de Puy (Ref. 12).

* 5 cycles.
**100 revolutions.

TABLE III

Sample Calculation - UMTRA Rock Quality Scoring
(Igneous Rock)

Type of Test	Test Result	Raw Score	Weighting Factor	Weighted Score	Maximum Raw Score	Maximum Weighted Score
Specific Gravity	2.63	7	9	63	10	90
Absorption (%)	2.6	1	2	2	10	20
Sodium Sulfate Loss (%)	1.2	9	11	99	10	110
L.A. Abrasion Loss (%)	4.2	8	1	8	10	10
Totals				172		230

Overall Quality Ratio: $= \frac{\textit{Total Weighted Score}}{\textit{Maximum Weighted Score}} \times 100 = \frac{172}{230} \times 100 = 75\%$

Oversizing Factor = 80% - 75% = 5%.
Specified D_{50} = (1.05) X Design D_{50}.

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APPLICATION OF A STRUCTURED LIGHT SOURCE TO WASTE SURFACE MAPPING IN WASTE STORAGE SILOS AT FERNALD, OHIO

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ABSTRACT

Surface contours inside the large waste storage tanks typical of the Department of Energy (DOE) complex are, in general, highly irregular. In addition to pipes and other pieces of equipment in the tanks, the surfaces may have features such as mounds, fissures, crystalline structures, and mixed solid and liquid forms. Prior to remediation activities, it will be necessary to characterize the waste to determine the most effective remediation approaches. Surface contour data will be required both prior to and during remediation. In this presentation, the authors will describe the use of a structured light source to generate three-dimensional (3-D) surface contour maps of the interior of waste storage silos at the Fernald Environmental Management Project at Fernald, Ohio. The landscape in these large waste storage tanks bears a strong resemblance to some of the landscapes that might be encountered during lunar or planetary exploration. Hence, these terrestrial 3-D mapping techniques may be directly applicable to extraterrestrial exploration. In further development, it will be demonstrated that these 3-D data can be used for robotic task planning just as 3-D surface contour data of a satellite could be used to plan maintenance tasks for a space-based servicing robot.

INTRODUCTION

One of the highest priority remedial activities within the Department of Energy (DOE) complex is the remediation of the K-65 Silos at the Fernald Environmental Management Project (FEMP), Fernald, Ohio. The K-65 Silos are above ground and bermed, domed, steel reinforced concrete structures that were built in the early 1950s to store uranium raffinate residues from uranium. Two of the four silos, Nos. 1 and 2, contain a waste material that is rich in Radium 226 and, hence, generates unacceptable amounts of radon gas during the decay process. Silo No. 3 contains primarily dry metal oxide wastes. Silo No. 4 is empty and is being used as a cold test site for demonstrating newly developed technologies. Test results are to be integrated with storage tank remediation activities throughout the DOE complex.

During the later part of 1991, a layer of bentonite clay is scheduled to be deposited over the waste surfaces in Silos 1 and 2 to act as a radon containment. It is anticipated that this bentonite cap will mitigate the emitted radon gas by reducing the speed of migration until the radiation has dissipated as a result of the relatively short half-life of radon, 3.8 days. The Environmental Protection Agency (EPA), DOE, and Westinghouse Environmental Management Company of Ohio (WEMCO) have analyzed the Radon emission rates from the K-65 Silos, considered the mitigation properties of the bentonite, and concluded that a 30 centimeter minimum thickness will be required to attenuate the radon emissions to desired levels.

Since the waste surface is not flat but has large mounds and other surface features, the thickness of bentonite must be measured at points throughout the waste surface to ensure adequate coverage. The 24 meter diameter silos have limited access manways and moderately high radioactivity, therefore, the measurements must be made remotely and use techniques that are applicable with the instrumentation at distances up to 12 meters from a surface to be measured.

In this presentation, we describe the application of a Structured Light Source to obtain waste surface contour data prior to bentonite deposition as a baseline measurement, then subsequently obtain bentonite surface contour data after deposition. Therefore, the thickness of bentonite at any point along the waste surface will be determined by the difference of surface contour data. Development, demonstration, and in-field deployment of this technology was co-sponsored by the DOE Office of Technology Development and the DOE Environmental Restoration (ER) through the FEMP. The lead coordinator of the project was WEMCO with the proof-of-principle developed by Sandia National Laboratory (SNL) and with the Oak Ridge National Laboratory (ORNL) as the software developer and system integrator.

SYSTEM DESCRIPTION

Experimenters at ORNL have been generating three dimensional range and surface contour data since 1987 using a laser rangefinder purchased from the Odetics Corporation. This device yielded range resolution of approximately 2 cm for distances up to 10 m in experiments at ORNL's Center for Engineering Systems Advanced Research (CESAR). In April 1990, SNL presented a demonstration of a Structured Light Source application to map simulated waste surfaces(1). This demonstration used a sandy, surrogate waste material and consisted of a laser line projector and a calibrated black and white charge coupled device (CCD) video camera

* Westinghouse Environmental Management Company of Ohio with the U. S. Department of Energy under Contract No. DE-AC-05-860R21600.

mounted on a gantry robot (Cimcorp XR6100) at a fixed separation and orientation typically about the waste surface. This Structured Light Source System yielded range resolutions of < 5mm. Personnel from SNL continued to improve the system capabilities in 1991 to function at greater distances (> 10 m) and develop software which would generate maps in an automated fashion and group the maps to represent a single presentation of a large surface. Contour maps were generated from a surface to system reflective angle of 10° to simulate geometries to those anticipated in Fernald's Silos 1 and 2. Bentonite was also used to investigate any problems in its reflective properties. ORNL augmented the approach by designing three combination structured light/camera assemblies to increase system robustness and reduce the number of instrument locations required. Overall project coordination and site preparation was provided by WEMCO to communicate customer (ER) requirements and maintain technical focus.

The silos at Fernald are 24.4 m in diameter with 8.2 m high vertical walls, and a domed top rising to 11.0 m at the center. The walls are 20.3 cm thick concrete, while the dome tapers from 20 cm thick at the edges to 10 cm thick at the center. Five 0.5 m diameter manways are available on the dome tops, one at the center, and one each at 90° spacing, 7.6 m from the center of the dome. An array of 5 cm sounding ports are also located on the dome tops, typically spaced 4.6 m apart. Various other penetrations exist on some, but not all, of the silos. Constraints included use of existing penetrations only, load limits of not more than 311 kg on the outer part of the dome, and no net loading on the center of the dome. This later constraint implied that the surface mapping apparatus should weigh no more than the existing center manway covers they would replace. Installation from a suspended platform is necessary to access the center manway without loading the dome center and to limit physical activity on the dome.

The basic principle of operation with the Structured Light Source is that a laser line is projected on a surface to be mapped and an image of that projection is captured by a calibrated camera. If the orientations and distance separations of the camera and laser source are known precisely, and the transformations relating pixels in an image to spacial directions have been determined, then the image can analyzed to determine the spacial location of the surface reflecting the laser line. By moving the laser over points throughout the silos, multiple images are obtained and a data set generated for the entire surface. The geometric constraints inside the K-65 Silos dictate measurements as far as 12 m from both camera and the laser source. Angles of incidence range down to about 10°. The target accuracy of measurements at Fernald are +/- 5 cm, or about 0.4% at the worst case surface points. Because of the accuracy needed, careful camera calibration and alignment is required.

One of the most challenging requirements was the determination of relative orientations and distance separations of the three surface mapping measurement units (MUs). The MUs were moved twice on Silo 4 to get the necessary coverage of the silo's floor. However, several equipment deployment arrays utilizing all five manways will be needed in Silos 1 and 2 to reduce lost data caused by waste mound shadowing. In order to accurately determine the relative orientations and separations of the three MUs and maintain accurate measurements after an MU is moved from one manway to another, three fixed light sources were mounted in 5 cm sounding ports near the perimeter of Silo 4. These light sources formed a reference frame for measurements and were mounted in a manner that permits them to be left in place throughout the measurement campaign and bentonite application in Silos 1 and 2. By determining the pixel width of the light source using a camera of known focal length, calibration of the camera can be made. By knowing the distance between each of the three light sources, their relative elevation with respect to the silo, and the kinematics of the MU assemblies, orientation calibration on the MU is obtained.

Rather than have a single camera and a single laser source, three identical MUs were fabricated. Each MU included a high resolution black and white CCD video camera, a 250 watt light source, a 30 milliwatt laser light source with a 20° fan width, and a pair of high-precision rotary stages for pan and tilt position control. Redundancy of the MUs provided more flexibility during the mapping process and reduced the frequency of moving them from manway to manway. A Sun workstation was used as the operator interface, while motor control for each device was provided via a VME computer system. Image acquisition and processing was accomplished using Datacube VME modules. A system schematic is shown in Fig. 1 illustrating the location of the various components.

At this writing, the system has been cold tested in Fernald's Silo 4 and is scheduled for field deployment, Silos 1 and 2, in September 1991. Figure 2 is a sample of a surface contour map using simulated data showing representation of the surfaces in Silos 1 and 2.

During the cold test in August 1991, the equipment capability verification within Silo 4 identified height measurement accuracy to better than 7.0 mm, height measurement repeatability to better than 2.5 mm, and X-Y measurement accuracy and repeatability to 2.5 cm. Graphic presentation of the data was done with PV-Wave software providing isometric and top views, solid and wire frame presentations.

As currently developed, operation of the system required hands-on attention of a skilled programming engineer. Due to the 17° offset encountered at the silo manway mount, the MUs rested at a 17° angle from true vertical. The offset caused the system kinematics to be a problem in developing automated scan plans. As a result, highly automated scanning plans were not available for the demonstration in Silo 4. Three days were required to obtain a surface map of 50% of the silo floor. Additional development of automated scan plans will occur prior to field deployment in Silos 1 and 2 to reduce mapping time and maintain the integrated schedule encompassing all activities associated with the K-65 Silos.

The demonstration in Silo 4 was deemed successful. All criteria prescribed by the Fernald K-65 Program was met or exceeded. Accuracies, system performance, and reliability provided the confidence needed to continue preparation towards the field deployment in Silos 1 and 2. However, a more detailed scanning plan for Silos 1 and 2 are needed due to the in-silo geometry differences. More software development to automate the scanning process is necessary. The window for on-silo mapping time was predetermined and the mapping system must conform to that schedule to meet the EPA Consent Agreement.

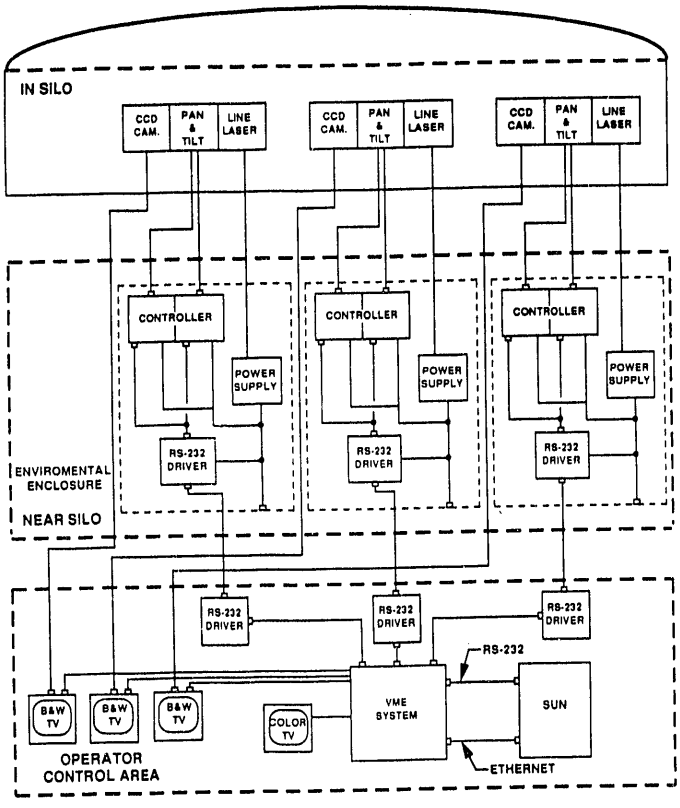


Fig. 1. Surface mapping system schematic.

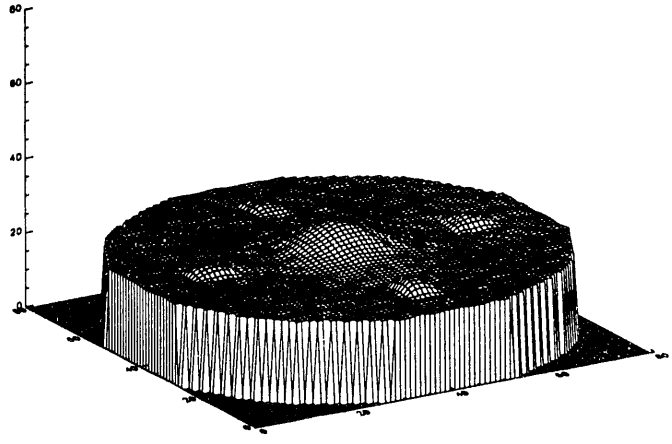


Fig. 2. Simulated surface data of Fernald K-65 silos.

ACKNOWLEDGEMENTS

The authors wish to express their appreciation to the project team members who contributed to the successful completion of the work described supporting the Fernald technology demonstration, in particular, R. A. Markus of WEMCO; M. A. Dinkins, H. M. Costello, G. T. Appleton, and G. A. Armstrong of ORNL; B. K. Christensen and M. McDonald of SNL.

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UTILIZATION OF THE MAGNETIC INDUCED POLARIZATION TECHNIQUE IN ENVIRONMENTAL REMEDIATION PROBLEMS

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ABSTRACT

The magnetic induced polarization (MIP) method can provide much greater resolving power than the conventional electric induced polarization (EIP) method. The MIP method can be much more effective than the EIP method in areas where there is a highly conductive overburden. This paper reviews the MIP method and examines the applicability of the method to environmental remediation (ER) problems. Two identified areas of application of the method in ER problems are (1) monitoring leakage of heavy metals from recovery or treatment ponds of industrial waste water, and (2) detection of faults in a proposed site for a hazardous-waste repository or nuclear power plant. Further research is needed to study the effect of various nonmetallic contaminants on the membrane polarization effect of soil or rocks. Results of such a study will determine the applicability of the MIP technique to broad ER problems.

INTRODUCTION

The magnetic induced polarization (MIP) method derives information relating to the induced polarization characteristics of the subsurface through measurements of the magnetic field, in contrast to the electric field in the case of the conventional induced polarization (IP) method. To eliminate any possible confusion between the magnetic induced polarization and the conventional induced polarization method, the latter will be referred to as the electric induced polarization (EIP) method. The MIP technique is related to the magnetometric resistivity (MMR) method (1-5) in much the same way as the EIP method is related to the resistivity method. In other words, the MIP and MMR methods make observations of the magnetic field, whereas the EIP and resistivity methods make observations of the electric field. The MIP and EIP methods make use of observations of the secondary (induced polarization) fields, whereas the MMR and resistivity methods make use of observations of the primary fields.

Some geophysicists (e.g., 6,7) claim that (1) the MIP method provides much greater resolving power than the conventional EIP method and (2) the MIP method is much more effective than the EIP method in areas where a highly conductive overburden exists or where the surface conditions render contact difficult between electrodes and ground (6-8). These desirable attributes of the MIP technique are relevant to the solution of ER problems. A review of the literature and the fundamental concepts of MIP led to the identification of two areas of possible application of the method and to the recognition of an area requiring further research.

The main purpose of this paper is to provide a concise but easy-to-understand summary of the somewhat complex and peculiar concepts of the MIP technique to those who are engaged in ER tasks but are not familiar with the method and to draw their attention to the conclusion that the method is applicable to ER problems.

MIP METHOD AND ITS COMPARISON WITH EIP METHOD

The EIP method was developed to take advantage of the polarizing property of certain earth materials and has been used successfully in many applications. A good example is its application to prospecting for disseminated minerals, for example, in porphyry copper deposits, for which other geophysical methods are largely ineffective. However, some weaknesses of the EIP method have been recognized. Probably the most critical weakness of the EIP method is its inability to provide useful information through a highly conductive overburden.

The basic difference between the MIP and EIP methods is in the mode of measurement. The MIP method measures magnetic field, in contrast to the EIP method that measures electric field, both due to the induced polarization current in the earth. Consequently, MIP measurements are expressed in terms of the same parameters as in EIP measurements, except that the electric field is replaced by the magnetic field.

In the EIP method, the action of the primary electric field is to create a volume distribution of current dipoles antiparallel to the field at each point in the polarization medium, with volume current moment strength $\vec{M} = -m\vec{J}_p$, where $\vec{J}_p$ is the primary (ohmic) current density in A/m^2 and m is the chargeability of the medium and is assumed to be constant within the polarizable medium. The total secondary potential in V at a field point at a distance r in m from the volume dipole element dv of current strength $\vec{M}$dv in an external medium of conductivity σ in S/m is(9)

$$\Phi_s = \frac{1}{4\pi} \iiint \frac{\vec{M}}{\sigma} \cdot \nabla\left(\frac{1}{r}\right) dV \qquad \text{(Eq. 1)}$$

The magnetic field in A/m due to the induced polarization current is [8]

$$\vec{H}_s = \frac{1}{4\pi} \iiint \frac{\vec{J}_s \times \vec{r}}{r^3} dV \qquad \text{(Eq. 2)}$$

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where $\vec{J}_s$ is the induced polarization current density in A/m^2. Eqs. (1) and (2) represent the fundamental equations of the two methods. Starting from these two equations, the investigators of the MIP method have shown the following aspects of the MIP method that distinguish it from the EIP method. Although the following two paragraphs are not word-for-word quotations, they are in content direct quotations from previous works. Thus, they are presented within quotation marks with references shown at appropriate points.

"The primary magnetic field due to a current passing through an electrode embedded on the surface of a horizontally stratified medium, whose layers have conductivities which are uniform within a layer but different from layer to layer, is equivalent to the magnetic field of a cable extending vertically downward from the surface to infinity (6-8, also 8 refers to 10). Hence, the primary magnetic field produced by current from a vertically emplaced current electrode on a horizontally stratified earth has only a horizontal component, which is perpendicular to the line joining the electrode with the observation point on the surface. Moreover, the current through the horizontal cable on a flat ground surface produces only a vertical magnetic field component when observations are made on the surface. Therefore, by measuring the horizontal magnetic field, one observes primarily the effects of subsurface conduction (6,7).

"Also, because the primary magnetic field of a horizontally stratified medium, whose layers have conductivities which are uniform within a layer but different from layer to layer, is independent of the conductivities of the layers (1,4,6,8), such a medium can produce no IP effect. The MIP method is therefore sensitive only to lateral inhomogeneities in polarization and is a true lateral anomaly detection method [6-8]. Howland-Rose et al. (6) also show that a medium of constant IP characteristics but variable conductivity cannot give rise to an MIP response."

Seigel (8) shows that the magnetic field, immediately over its axis, due to a horizontal dipolar current source decreases as the inverse square of its depth, as compared with the inverse cube of the depth in the case of the electric field. A similar contrast of inverse square versus inverse cube relationship applies to the MIP and EIP responses, directly over the body, due to induced polarization current flow in a spherical body. He also observes that the MIP response from horizontal cylinders follows an inverse first power law, whereas the EIP response follows an inverse square law. Consequently, the attenuation of the signal strength with depth will be slower in the MIP than in the EIP method. Of course, the detection of an anomaly depends on its being above the noise level. The effect of the depth of a source on the signal strength is that as the depth increases, the EIP signal approaches the noise level faster than the MIP signal.

The masking effect of a conductive overburden on the electric field responses of targets below is a serious problem in EIP measurements (6,7,11-13). The conductive overburden may be at the surface of the earth or may be buried but lie above the target. To determine the relative effects of an overlying conductive layer on the EIP and MIP responses due to a buried source, Howland-Rose et al. (6) conducted model studies. The model consisted of a buried line current terminated by a source at one end and a sink at the other, both of equal current amplitude. For MIP responses, the horizontal magnetic field was measured at the surface perpendicular to the current line, traversing the middle of the current line. For EIP responses, the electric field at the surface parallel to the current line was measured. The model and results are shown in Figs. 1 and 2 for EIP and MIP, respectively. These figures depict the results obtained in three different geologic situations: homogeneous half-space, a conductive layer at the surface, and a buried conductive layer. The resistivity of the conductive layer in the models was 65 times greater than that of the rest of the medium.

Figure 1 shows that the conductive layer (whether at the surface or buried) reduces the electric field so drastically that the surface EIP response becomes negligible. On the other hand, Fig. 2 shows that the magnetic field is essentially unaffected by the conductive layer. This result demonstrates the ability of the MIP method to detect a target even through a highly conductive overlying layer. This result, however, shows only how the polarization signals from the body are affected by a conductive overlying layer. Another problem of conductive overlying layers is attenuation of the primary current. However, since the attenuation of the primary current will be the same for both the EIP and MIP methods, the result described here is sufficient in demonstrating the *relative* responses of EIP and MIP, at the surface, of a buried target. Various authors (6,7) have reported numerous field examples supporting this result.

Magnetic induced polarization measurements are essentially point measurements because the physical dimensions of the magnetic sensors are less than 0.6 m (6). Electric induced polarization measurements, on the other hand, are usually made by two poles with an extended distance between them (typically 3 to 100 m). Thus, the spatial resolving power of MIP measurements is expected to be much greater than that of EIP measurements. Comparable EIP resolution may be obtainable by reducing the potential electrode spacing, but this will be at the expense of a proportionate reduction in signal strength. Fig. 3 shows an *available* example of greater resolving power of MIP relative to that of EIP.

Figure 3, which is reproduced from Seigel and Howland-Rose (14), shows results of field surveys conducted in Widgimooltha, Western Australia. At the bottom is shown the geological section constructed based on the results of drilling. The target consists of two easterly dipping lenses of nickeliferous sulfides with 1 to 3 percent nickel. The two lenses are approximately 30 m apart and their average thicknesses are 4 and 8 m, respectively. These targets are overlain by a highly conductive (3 to 10 Ω-m) overburden of 45--m thick weathered zone.

Time-domain MIP results are shown at the top of Fig. 3. The current electrodes were 360 m apart. The plotted quantity, H_{s3}, is $\mu_0\vec{H}_s/I$ in pT/A (mγ/A) where μ_0 is the magnetic permeability of free space in Wb/A--m and I is the primary current in A. The second subscript 3 represents the third time gate (1170-1690 ms) integrated employing a 2--s on/off timing. Also shown is the primary magnetic field normalized by division by the theoretical field due to a uniform earth, expressed in percent (H_N).

Time-domain EIP results are shown in the middle of the figure. A dipole-dipole array with electrode spacing (a) of 60 m and n = 1 to 4 was used, where n is the distance, in number of a's, between nearest current and potential electrodes. Resistivity and chargeability are shown in a pseudo-section form. The same integration time gate as in MIP was used.

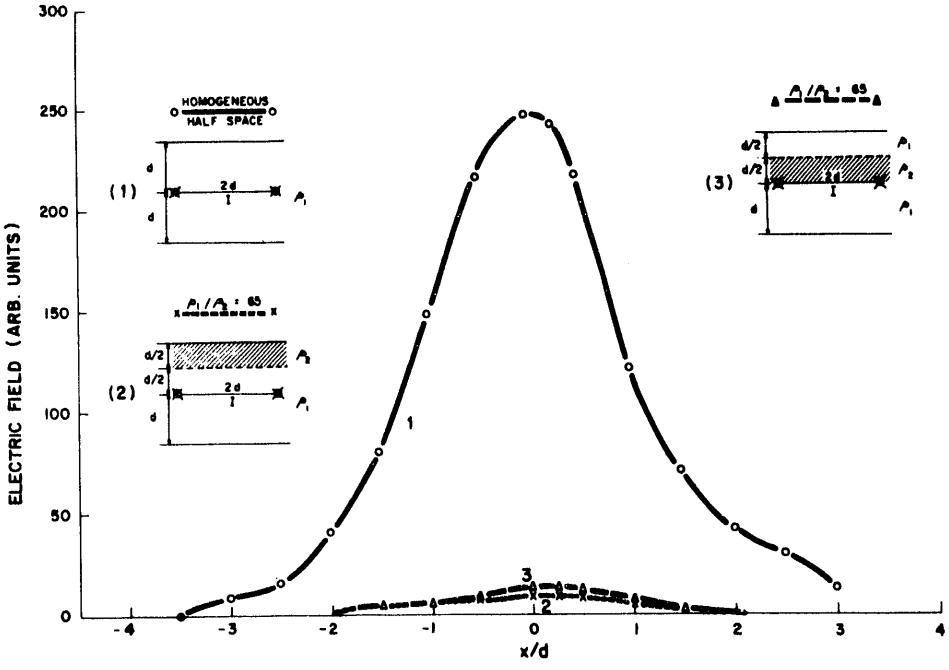


Fig. 1. Effect of a conductive layer on EIP: (1) homogeneous half-space; (2) conductive layer at the surface; (3) conductive layer in the subsurface [after Seigel and Howland-Rose (7)].

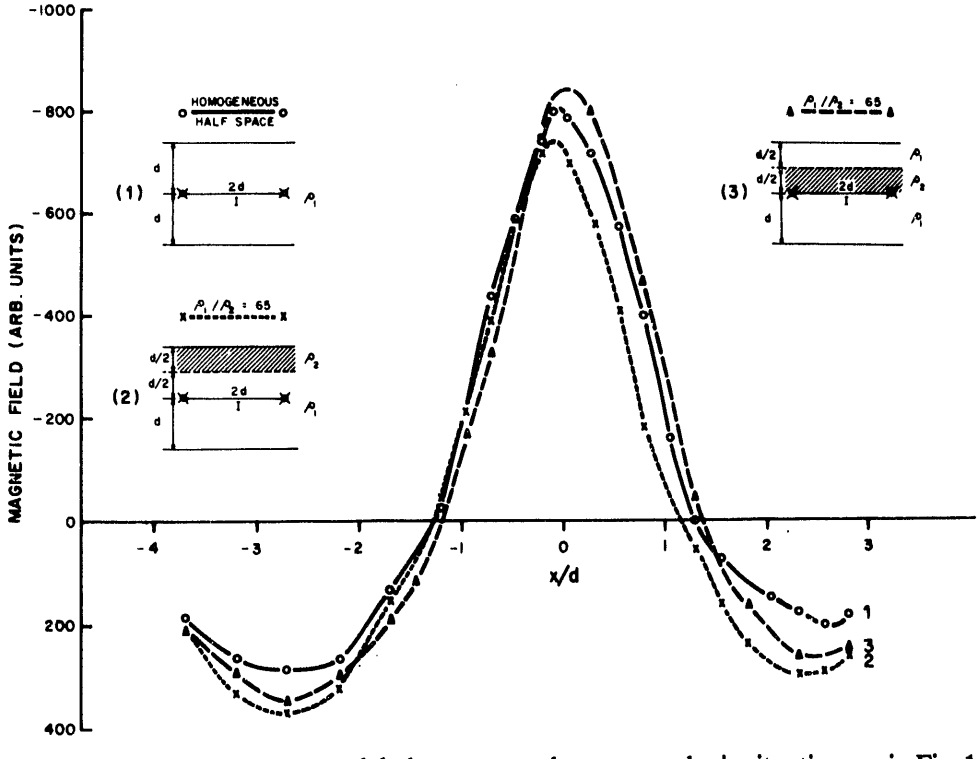


Fig. 2. Effect of a conductive layer on MIP: curve labels represent the same geologic situations as in Fig. 1 [after Seigel and Howland-Rose (7)].

As can be seen from the figure, the two separate targets are easily resolved as two separate peaks on MIP curves even though their separation is less than their depth, whereas they are hardly resolved from EIP measurements.

Two possible sources of noise in EIP measurements are (12) capacitive coupling, which is due to leakage currents between current electrodes and potential wires or between current and potential wires, and electromagnetic coupling, which results from mutual inductance between current and potential wires. The absence of potential electrodes and wires eliminates these sources of noise in MIP measurements.

The MIP method provides a detection of areas of anomalous polarizability rather than a measurement of a physical property. Since EIP measurements require apparent resistivity information and also it is a common practice to conduct a resistivity survey in parallel with an EIP survey, the true resistivity of the earth can be deduced when EIP surveys are done. Similarly, an MMR survey may be conducted in parallel

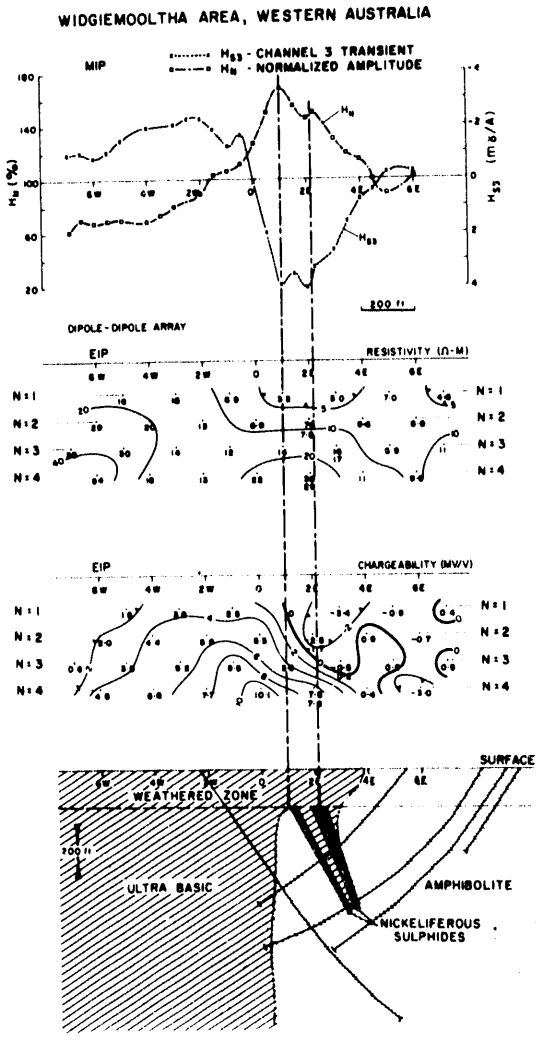


Fig. 3. Comparison in resolving power between MIP and EIP [after Seigel and Howland-Rose (14)].

with an MIP survey. However, absolute values of resistivity cannot be determined by the MMR method. Rather, only resistivity contrasts or reflection coefficients can be deduced by comparing observed MMR anomaly with theoretical values. Thus, although the interpretation of both MIP and EIP data is largely qualitative, a physical property of the earth can be deduced from the EIP method but not from the MIP method. This is a disadvantage of the MIP compared with EIP method.

FIELD PROCEDURES AND EQUIPMENT REQUIREMENTS FOR MIP MEASUREMENTS

Because the horizontal component of the magnetic field is measured in the MIP technique, whereas the horizontal electric potential gradient is measured in the EIP method, any of the electrode array configurations used in EIP measurements can be used in MIP measurements with potential electrodes replaced by a vector magnetometer.

In MIP surveys, the current electrodes are set up parallel to the probable strike direction of the target. The target will resemble a set of resistors in parallel, each of which will conduct a different current and will produce a perturbation in the magnetic field. This is in contrast to the standard practice in EIP measurements, in which the current electrodes are set up perpendicular to the probable strike direction of the target so that the target resembles a set of resistors in series, each with different potential drops.

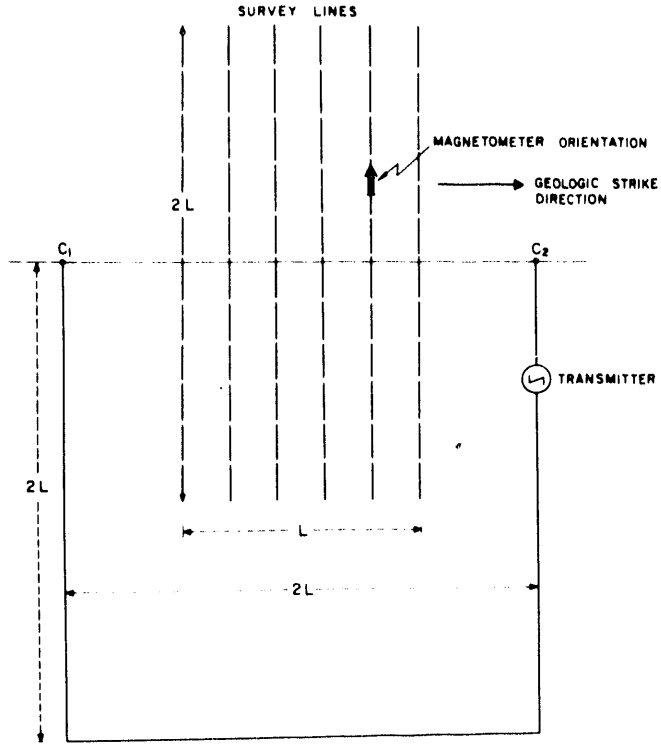


Fig. 4. Typical field layout for MIP production surveys [after Seigel and Howland-Rose (14)].

Seigel and Howland-Rose (7) describe a typical and most commonly used field layout of equipment and measurement points for production surveys as follows (see Fig. 4). The current electrodes C_1 and C_2, a distance 2L apart, are connected by a U-shaped loop of cable that is approximately 2L long on a side. A rectangular area, about L wide and 2L long, may usually be surveyed from one specific current electrode setup. The horizontal magnetic field is measured along the survey line direction, which is orthogonal to the line joining the current electrodes. The station interval, in general, should not exceed one-half of the mean depth of burial of anticipated targets; the line spacing should not greatly exceed the average expected strike length of anticipated targets.

The maximum value of L is normally determined by the mean strike length of targets expected to occur in the area. As a rule of thumb, to maintain adequate signal level, L should not greatly exceed this mean strike length for best detectability. However, L should be no less than the expected depth to the targets so that the current density at the depths at which the targets may occur may be comparable in magnitude to those near the surface.

The secondary magnetic field strength commonly measured is several picoteslas. Hence, a high- sensitivity vector magnetometer is required for MIP measurements. General requirements for such a magnetometer are (7): (1) noise level: less than 1 $pT/\sqrt{Hz}$; (2) resolution: better than 1 pT; and (3) frequency response: essentially flat for 0-1000 Hz.

Two currently available sensors that satisfy these requirements are, to the best of the author's knowledge, the Scintrex MFM-3 High Sensitivity Vector Fluxgate Magnetometer (noncryogenic) and the Superconducting Quantum Interference Device (SQUID) magnetometer (cryogenic) (15).

APPLICABILITY OF THE MIP METHOD TO ENVIRONMENTAL REMEDIATION PROBLEMS

As discussed in this paper and in the referenced documents, the MIP method has been successfully applied to resource exploration. The method, however, has not been applied to ER problems. An examination of the method regarding its applicability to ER resulted in the conclusion that there is no reason why the method should not be applicable to the following two areas of ER problems.

One area is monitoring leakage of heavy metals from collection ponds constructed for recovery or treatment of heavy metals from sludge. Scientists at some laboratories (e.g., at the Idaho National Engineering Laboratory) are looking at ways to recycle valuable metals from industrial waste water and, at the same time, to reduce the discharge of heavy metals into the environment. At some stage during the process of recovery, the waste water must be stored somewhere [currently in landfills in most cases (16)]. Waste water leaked from the storage areas will migrate through the earth. As the waste water travels through the earth, heavy metals may precipitate and remain in the earth while the rest of water travels further or transpires. The heavy metals precipitated in this manner will likely be in a form similar to naturally occurring mineral grains disseminated in the earth for which the induced polarization methods are most effective in their detection. In situations where waste water migrates through earth overlain by conductive earth material, the MIP method should be the most effective tool in detecting the disseminated heavy metals precipitated from the waste water. Metal-bearing waste streams are one of the largest sources of pollution in the United States (16) and very likely in many other industrialized countries (17). Considering the magnitude of this problem, the MIP method may be a useful and practical tool in waste management efforts.

The second application is detection of faults in a proposed site for a hazardous waste repository or nuclear power plant where a conductive overburden exists. Crushed rock or fine fissures in a fault zone can produce high polarization effect [11]. Howland-Rose et al. (6) demonstrated by model studies that the MIP method is capable of delineating a fault that defines a contact between two different blocks of earth.

These applicabilities are conceptually acceptable but, to some extent, conjectural in that the method has never been applied to ER field problems. To verify the applicabilities, tests of the method in the field are planned and funding for the tests is being sought.

CONCLUSIONS AND RECOMMENDATIONS

The following conclusions and recommendations are made based on the examination of the status of the art of the MIP method.

The most important asset of the MIP method that has been theoretically demonstrated and practically useful is its ability to provide information on buried targets in areas with a highly conductive overburden, which may be at the surface or buried in the earth. Therefore, if the target of a geophysical survey is expected to possess polarizing properties and is located below a highly conductive section of the earth, this method should be the first one used.

Supposedly, the MIP method is expected to possess higher spatial resolving power than the EIP method, although its superior resolution is difficult to determine quantitatively. Better resolution of the method relative to that of the EIP method is observed in some field examples (6,7). However, there are other examples where the resolution of the MIP method is not superior to that of the EIP method (18). Therefore, it seems fair to say that a greater resolving power of the MIP over EIP method is case specific.

Other advantages of the method are less attenuation of signal strength with depth to the target than in the EIP method; ease of field operation due to use of a magnetometer in place of two potential electrodes and accompanying cables and a receiver; absence of capacitive and electromagnetic coupling problems; and absence of the problem of ground contact of potential electrodes in dry, sandy or gravelly soil.

The application of the MIP method to ER problems is recommended for (1) monitoring leakage of heavy metals from recovery or treatment ponds of industrial waste water and (2) detection of faults in proposed sites for hazardous waste repositories or nuclear power plants.

Further research is recommended to study the effect of various nonmetallic contaminants on the membrane polarization effect of soil or rock. The results of this proposed study will determine applicability of the MIP method to broad ER problems. Olhoeft (19) shows field examples of application of the EIP method to organic contamination detection but recognizes the existence of an incomplete understanding of interactions between clays and organics. Walther et al. (20) suggest applicability of the EIP method to some of their 10 hypothetical cases of subsurface organic contamination and recommend further research on the subject. Research is needed on the effect of various nonmetallic contaminants on the membrane polarization effect in various types of soils and rocks; research results will benefit both the EIP and MIP techniques in ER efforts.

ACKNOWLEDGEMENTS

Work reported in this paper was supported by the U.S. Department of Energy Office of Environmental Restoration and Waste Management under Contract No. DE-AC07-86ID12584. The interest and support of Mr. Lawrence Ball, Laboratory Director and Manager of Special Projects of the U.S. Department of Energy Grand Junction Projects Office, and Dr. David A. Emilia, Director of Laboratory Directed Research and Development of Chem-Nuclear Geotech, Inc., were seminal in development of my expertise in the subject field. The permission to reproduce the figures used in this paper by Elsevier Applied Science Publishers Ltd. and Dr. Harold O. Seigel, president of Scintrex Limited is greatly appreciated. I thank Dr. Gary R. Olhoeft of the U.S. Geological Survey for kindly providing me with full papers numbered 19 and 20 in Refs.

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EVALUATION OF PROPOSED DESIGNS FOR STREAMFLOW MONITORING STRUCTURES AT WASTE DISPOSAL SITES

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ABSTRACT

Design of small surface water monitoring stations associated with waste sites requires an approach that balances several problems. The monitoring site must have a capacity for a wide range of flows, allow accurate measurements over the full performance range, minimize effects from accumulation of contaminated sediments, and minimize costs of construction and operation. Selecting a station design that takes these factors into consideration can be done systematically through use of formal decision analysis. The process has produced the most viable alternative designs and yielded fully documented guidelines for designing new stations as they are needed.

INTRODUCTION

Recent changes in guidance for environmental monitoring in U.S. Department of Energy (DOE) Order 5400.1 have placed much more emphasis on quantifying the flux of both water and contaminants at waste sites. This poses a challenge for many DOE facilities with small drainages in which the flow rate can vary more than three orders of magnitude. Most standard flow control structures (e.g., weirs, flumes) are not accurate over the entire desired range. Further, standard weir installations cause the accumulation of contaminated sediments, which pose a problem in waste handling and disposal. This report summarizes a formal decision-making process for the selection of best flow control structures to meet a range of objectives. The report also describes the evaluation of some technical problems that were identified during that process.

PROBLEM IDENTIFICATION

Four monitoring stations on small tributaries (Fig.1) to White Oak Creek (WOC) near the Oak Ridge National Laboratory (ORNL) were identified for upgrading, and as a preliminary step, technically justifiable performance criteria had to be developed. In so doing, two problems arose. First, the dimensions of hydraulic structures are constrained by site conditions. Due to the low topographic relief at all the sites, the maximum stage for the design of any control structure is limited (otherwise prohibitively large berms and a large stilling pool would be required), and submergence effects that occur during floods may reduce the accuracy of discharge estimates. Second, sediments at the sites are contaminated with radionuclides, thereby posing a potential health risk to workers and a waste disposal problem for excavated materials. Because a very large proportion of the sediments are expected to settle in White Oak Lake, which is restricted from public access and which has an extensive inventory of contaminated sediment that will be remediated in the future, the movement of sediments downstream from these structures is judged acceptable at the present time. Therefore, hydraulic structures that allow sediments to pass downstream are preferred, so as to reduce future accumulations.

Of the four sites located on the map in Fig. 1, the site at West Seep (site 3) was selected for the initial investigation. It is equipped with a compound, sharp-crested, V-notch weir shown in Fig. 2. The rating curve has been extended empirically to approximate flows when the weir plate and wing walls are over-topped. The observed range of flows was nearly zero to about 2500 L/s during 1989-90. The maximum head for the design of any hydraulic structure at West Seep is about 1.4 m, (4.5 ft.).

DECISION ANALYSIS

Formal decision analysis was applied to the choice of the optimal design for the hydraulic structure upgrade. The decision analysis process comprised several steps: setting a clear statement of the goal of the decision analysis; establishing criteria and objectives to be met by the solution; developing and comparing possible alternatives to arrive at an objective ranking; and evaluating the risk and possible adverse consequences of the best potential solutions to reach a final

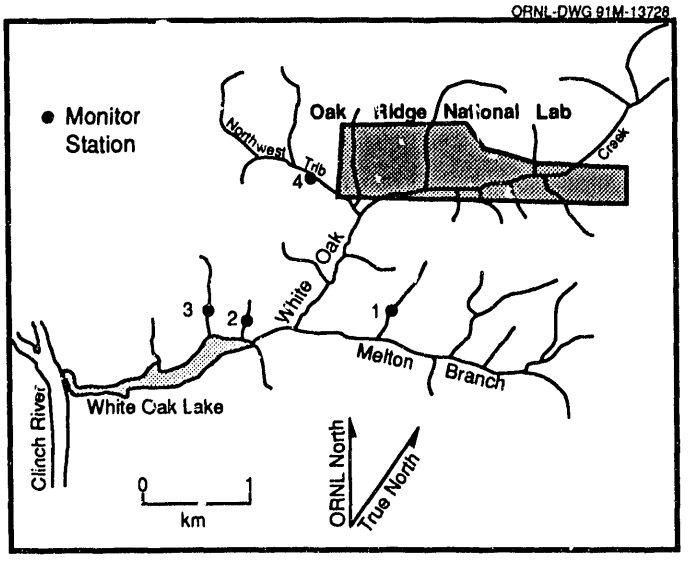


Fig. 1. Locations of surface monitoring sites at ORNL.

* Managed by Martin Marietta Energy Systems, Inc., under contract DE-AC05-84OR21400 with the U.S. Department of Energy. Publication No. 3760, Environmental Sciences Division, ORNL.



Fig. 2. Existing compound weir at West Seep.

decision. The decision analysis was conducted by an ad-hoc committee of hydrologists, engineers, and representatives of those charged with compliance monitoring of surface waters at ORNL. The decision statement that emerged was as follows:

Select the best flow control structure design, including the approach pool and tailwater section, to measure stream discharge and minimize maintenance requirements at a given location.

Once the decision statement was developed, a set of objectives to be met by the design was generated. The objectives were discussed, separated into those that MUST be satisfied if an alternative is to qualify as a viable solution and those objectives that are desirable but not mandatory (i.e., WANTs). The MUSTs were stated as follows:

Measured flows must be within 10% of true value for 95% of the expected flow range and within 25% of true value for flows up to the 25-year recurrence interval.

The submergence ratio must not exceed conventional limits for the type of control structure (i.e., for a weir, flume, etc.).

Because these MUSTs were not sufficiently defined, (e.g.; how should the expected range be defined), a series of investigations were initiated to refine them into measurable objectives. The WANTs were also identified at this time, and the most important WANT was given a weight of 10. Others were weighted on a relative scale between 10 and 1, as listed in Table I.

The alternatives that were identified as possible solutions included natural channel control, sharp-crested weirs, broad-crested weirs, H-flumes, Parshall flumes, cutthroat flumes, critical-flow flumes, rated culverts and Palmer-Bowlus flumes. Initial screening restricted the alternatives to the existing 2.67-ft compound weir, a 4.5-ft H-flume, and a 4-ft complex critical-flow flume. The design information and rating curves for the complex critical-flow flume are available in the literature (1,2).

Completion of the decision analysis involved screening alternatives to find the ones that completely satisfied the MUSTs, scoring alternatives on a relative basis for each of the WANTs, summing the product of the weights and scores over all WANTs, and finally evaluating the risks and potential adverse consequences of selecting the top alternatives. Although the final steps may appear mechanical, the systematic approach resulted in some very focused questions and development of considerable insight in the process of reaching the final decision. In the remainder of this paper, some of the most important issues that surfaced are presented.

TABLE I

List of WANTs

Rank	Issue	Weight
1.	Measure flow range to the best accuracy beyond the MUSTs criteria	10
2.	Minimize the bias in head measurements	9
3.	Maximize the responsiveness of the stilling well	9
4.	Maximize the ease and reliability of calibration	8
5.	Minimize routine maintenance requirements for the structure	8
6.	Minimize excavation and waste generation	7
7.	Minimize effects of biota on flow measurement accuracy	7
8.	Minimize sedimentation at the structure site	7
9.	Maximize durability of the structure (high flow, weather)	7
10.	Maximize freedom from weather effects (icing)	7
11.	Design lends itself to standardization	6
12.	Minimize cost of station installation	5
13.	Design allows flexibility for structure modification	5
14.	Minimize barrier effects on migration of biota, where needed	5

Mathematical Methods Used to Identify the Primary Range

The first step was to refine the MUSTs by specifying the required flow range where accuracy was required. Because of the large range between observed high and low flows at the site, it was known that some trade-offs would be required between the design limits and the acceptable accuracy of flow determinations. One idea was to have primary and secondary flow ranges. The primary range corresponds to 95% of the expected flow range, and the secondary range is the high-flow range up to the 25-year recurrence interval peak flow. The range and required levels of accuracy are consistent with DOE orders. It was decided that frequency analysis should be used to set the upper and lower bounds for the primary range (i.e., the expected flow range). Three methods were investigated for setting the primary range using data collected at 15-min intervals at the West Seep during 1989-90. It should be noted here that the variable actually measured for flow determination is the stage or water level of the pool upstream of the flow control structure. The relationship between stage and flow (the rating curve) depends upon the size and shape of the structure, and flow rate is typically expressed as a power function of head. In subsequent discussions, it is assumed that the reader is familiar with this concept.

Flow-Frequency Analysis

Flow-frequency analysis, often called flow-duration analysis, is a standard method for evaluating the flow regime. For flow data covering one or more years, the incremental

frequency ΔF_j for each flow increment ΔQ_j is computed by counting the occurrences of flows within the increment and dividing by the total number of observations in all increments. The cumulative frequency, through the i^{th} increment, F_i is

$$F_i = \sum_{j=1}^{i} \Delta F_j \qquad \text{.(Eq.1)}$$

Exceedance values that are normally used in flow-duration analysis are computed as 1-F_i. For this analysis, F_i defines the likelihood that the flow (Q), ≤maximum flow of the i^{th} increment (Q_i). Of prime consideration, therefore, is the definition of the range of Q values that are measurable for an acceptable fraction of the time.

Volume-Frequency Analysis

The emphasis in monitoring is on measuring the total amount of contaminant discharged (product of flow rate, time and concentration). Because for these small tributaries, high flows carry a disproportionate amount of contaminants (as shown later), it is more important to measure the flow over a large fraction of the total flow volume rather than over a large fraction of the elapsed time. The volume-frequency analysis specified below allows this approach. It is computationally simple, yet is not in widespread use for designing hydraulic structure attributes.

Let an incremental expected volume, ΔV_j, be defined as

$$\Delta V_j = \Delta F_j \overline{Q}_j \, \Delta T \qquad \text{,(Eq.2)}$$

where $\overline{Q}_j$ is a representative flow rate for the j^{th} frequency increment and ΔT is the elapsed time between flow observations. The cumulative volume fraction can be defined as

$$V_i = \frac{\sum_{j=i}^{i} \Delta V_j}{\sum_{j=1}^{m} \Delta V_j} \qquad \text{,(Eq. 3)}$$

where m is the index of the maximum volume increment. It follows that V_i defines the fraction of water volume that is expected at flows up to $\overline{Q}_i$.

Contaminant Flux-Frequency Analysis

A variable similar to V_i can be computed for contaminant fluxes for sites where a mathematical relationship between Q and the contaminant concentration, C, can be established. Where the relationship can be shown to be reliable it can be used to estimate the total contaminant load from continuous measurements of Q alone (2,3). It has been found at ORNL that a power-type relationship adequately describes observations of Q and C for many contaminants:

$$C = KQ^{-b} \qquad \text{,(Eq.4)}$$

where the constant, K, and the exponent, b, are fitted parameters. For perfect dilution at higher flows the exponent would be unity. When the exponent is less than one, storm flow is mobilizing extra contaminant beyond a fixed source input. This situation implies that high flows transport a disproportionately large portion of the total contaminant load. Because this situation occurs at buried waste sites at ORNL, it is important to monitor flows and collect samples in the higher ranges of Q in order to measure the annual contaminant load accurately. Thus, there is an incentive to ensure that the capacity of hydraulic structures is sufficient to measure the highest expected flows.

A contaminant flux fraction, J_i, can be defined in much the same way that the volume fraction was defined above. The variable is obtained by using the mass increment of the mean flux ($\overline{Q}_j C_j \Delta T$) for each flow class, substituting Eq. (4) into the expression and weighting by the observed frequency:

$$J_i = \frac{\sum_{j=i}^{i} F_j \overline{Q}_j^{1-b}}{\sum_{j=i}^{m} F_j \overline{Q}_j^{1-b}} \qquad \text{.(Eq.5)}$$

Constants K and ΔT appear in both numerator and denominator, thus have no effect. The implications of using flux-frequency analysis to the design of monitoring stations, are discussed in the application given later.

APPLICATION

The objective of the investigation reported below was to define the flow limits for the primary and secondary flow ranges needed for the MUST criteria. The limits are: $Q_l \leq$ primary range $\leq Q_m <$ secondary range $\leq Q_u$.

Primary Flow Range

As mentioned earlier, at the beginning of the analysis it was decided that the primary flow range would be measured to the highest degree of accuracy and that very low and very high flows would be measured at a reduced level of accuracy. Furthermore, it seemed reasonable that the primary range should span 95% of Q values and that the lower 2.5% and upper 2.5% of the Q values would fall outside the primary range. This specification corresponds to the 95% confidence limits routinely used in statistical tests. However, it was uncertain as to whether the 95% should be based on the frequency of flow, contaminant flux, or volume. Indeed, it was unknown how the limits produced by these different types of frequency analyses would compare.

Flow data used in the analysis were collected at 15 minute intervals over a 2-year period at West Seep using the complex weir shown in Fig. 2. For the contaminant flux-frequency analysis, no data at West Seep were available; however, Solomon and et al (3) derived the Q-C relationship shown in Eq. (4) for ^{90}Sr transported in a nearby tributary. The exponent in Eq. (4) was evaluated at 0.284; this value was judged to be applicable to this investigation, although the value depends on the specific nuclide.

The results of the frequency analysis along with the 95%-coverage limits are graphed in Fig. 3. For the primary range the lower limits for Q are 0.56, 1.4, and 2.8 L/s based on flow, flux, and volume-frequencies, respectively. The high-flow limits are 110, 560, and 850 L/s for the respective frequency analyses. The accuracy of these limits is affected by problems associated with the weir at the site and the site itself. The low-flow limits may be uncertain because precision in this range of the weir structure is decreased, and the high-flow limits may be affected by submergence. The submergence issue is important to accurate measurements and is addressed later, but for this analysis the effects are judged to be minor and conservative (i.e., the high-flow limits may be slightly overestimated).

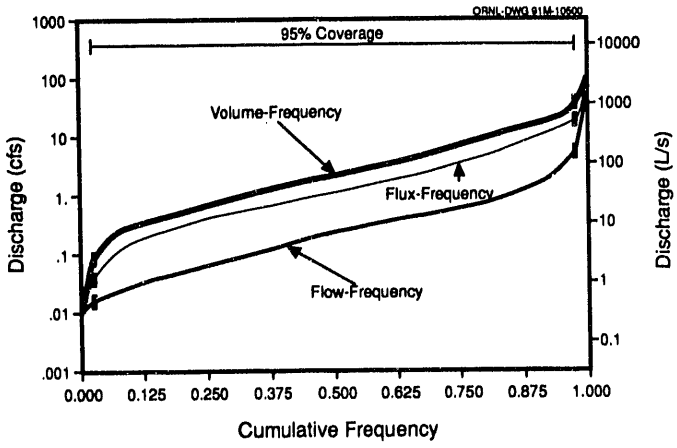


Fig. 3. Discharge-frequency relationships for West Seep based on 15-minute interval data, 1989-90.

The 95%-coverage criterion yields significantly lower range limits when based on flow-frequency than when based on volume-frequency. The difference is largest in the high-flow range limits. The range limits based on flux-frequency are intermediate, as might be expected because of the partial dilution of ^{90}Sr at increased Q.

For specification of the primary range limits it was decided to combine the results from the flux- and volume-frequency analyses. The low-flow limit, Q_l, was set at 1.4 L/s based on flux-frequency, and the high-flow limit, Q_m, was set at 850 L/s based on volume frequency. The flow-frequency analysis indicates that Q is expected to be less than Q_l about 25% of the time. It seems to be excessive to make such a large fraction of Q measurements (in time) at reduced accuracy, but this is a reasonable compromise because the low flows are not critical to measuring the total water volume or sampling the bulk of contaminants passing by the monitoring station. This flow range is thus designed to meet the DOE regulation requiring the monitoring of contaminant releases transported in the stream water.

Secondary Flow Range

Specification of the upper limit for the secondary range required the estimation of the 25-year peak flow. The empirical equation of Sheppard (5) based on analysis of discharges at 6 nearby gage sites ($0.98 < A < 62.9$ km^2) was used. The expression is

$$Q_p = (1.45)\,(9.58)\,A^{.8}\,P^2 \qquad \text{.(Eq. 6)}$$

where

Q_p = Peak Q (L/s), P = Precipitation (cm), and A = Area (km^2).

Equation 6 for peak flow is accurate to ±45% at the 97.5% confidence limit (4). The coefficient 9.58 is an empirical constant, and the factor 1.45 ensures that the Q_p estimate is within the confidence limits. The analysis of precipitation reported by Borders et al, (6) indicates that the 48-h rainfall depth with a 25-year recurrence interval is 16.0 cm. Although the 48-h storm duration is large relative to the time of concentration of small watersheds, this duration is consistent with the data used in the original regressions of Sheppard (5), and it is conservative. When this precipitation amount is used the expression above is simplified to yield a generalized expression for Q_u applicable to vegetated watersheds in the vicinity of ORNL:

$$Q_u = 3560\,A^{.8} \qquad \text{.(Eq.7)}$$

Similar expressions for limits to the primary range are also needed. For a simple approximation Q_l and Q_m obtained from the West Seep data can be linearly scaled according to watershed area. For West Seep watershed, A = 0.65 km^2, therefore:

$$Q_l = 1.4\,(A/0.65) = 2.2\,A \text{ and} \qquad \text{(Eq.8)}$$

$$Q_m = 850\,(A/0.65)^{.8} = 1200\,A^{.8} \qquad \text{.(Eq.9)}$$

The slightly nonlinear relationship between Q_p and A in Eq. (6) is used to scale Q_m. The results over the full range of flows at the West Seep are summarized in Fig. 4.

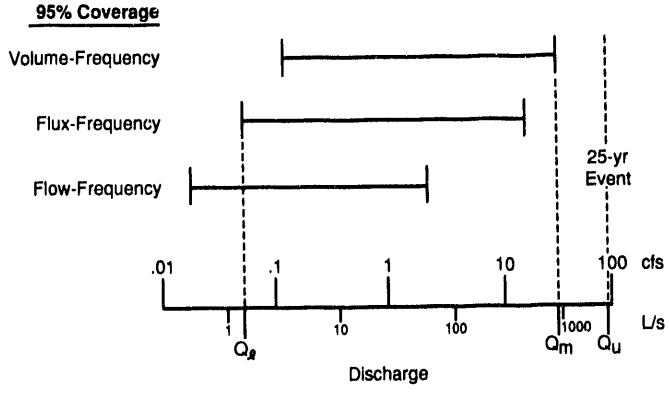
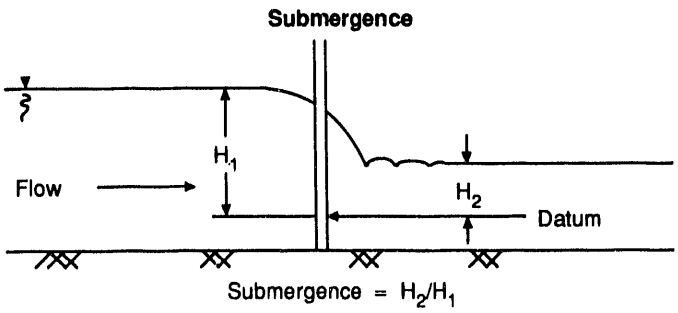


Fig. 4. Flow ranges.

Submergence Effects

The submergence ratio is defined as the quotient of tailwater head to upstream head on the structure, relative to the zero flow datum (Fig. 5). At increasing submergence ratios, flow through the structure is reduced for a given upstream head, relative to free flow (no submergence) conditions. Thus, one consideration for adequate design is to assure that submergence ratios are small enough that the stage-discharge rating is not affected beyond acceptable accuracy limits. Submergence ratios less than 0.35 for sharp-crested weirs, 0.5 for H-flumes, and 0.7 for compound, critical-flow flumes are deemed to be acceptable.

To determine submergence ratios to be expected for proposed monitoring station designs, it was necessary to have ratings for both the upstream control structure and the downstream section (tailwater). From these ratings, values of the submergence ratio could be determined for representative discharge values in the design flow range. Rating curves for the structures were available from the literature. The tailwater rating was computed with the use of the Water Surface Profiles Model developed by the U.S. Army Corps of Engineers (7). The results were used to generate Fig. 6, which shows the expected submergence for each of three structures that were studied over the range of design flows. At the upper limit of the primary range the submergence ratios were about 0.27, 0.30, and 0.37 for the evaluated structures: the existing compound weir, 4.5 ft H-flume, and the complex critical-flow flume. For the upper limit of the secondary flow range, the computed submergence ratio for the weir was greater than 0.30 (marginally acceptable), and the computed ratio was acceptable for both flumes. For the primary range, none of the



Structure	Acceptible Limit* (H_2/H_1)
Sharp-crested Weir	.35
Critical-flow Flume	0.7
4.5' H-Flume	0.5

*Allows up to 5% error from rating

Fig. 5. The submergence ratio is defined by tailwater and headwater depths.

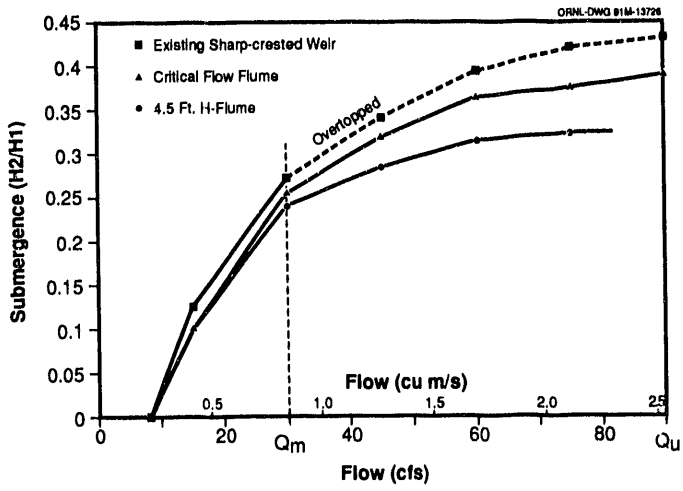


Fig. 6 Submergence versus flow at West Seep calculated from H_1.

evaluated structures are expected to experience as much as 5% error from submergence effects.

Uncertainty in Flow Evaluation Resulting from Error in Stage Measurement

The MUST criteria include a required ±10% accuracy over the primary range. However, since the variable actually measured is stage height, the accuracy criterion must be translated into these terms. The uncertainty (ε) related to stage measurement can be written as

$$\varepsilon = \frac{\Delta h \left(\frac{dQ}{dh}\right)}{Q} X\ 100\% \qquad \text{(Eq. 10)}$$

The value of Δh corresponds to measurement error at head h, and dQ/dh is the slope of the rating curve at a given flow rate Q. In practice, it is difficult to measure Δh to closer than 3mm (.01 ft). The equation is most sensitive at low values of Q; hence, the key consideration is the slope of the rating curve at the minimum design flow. This is the point where the structure will be constrained. For the three alternatives considered at the West Seep location, assuming a value of 3mm for Δh and using corresponding rating curves, the calculated uncertainties were 11%, 10.5%, and 7%, respectively, for the compound weir, the H-flume and the complex critical-flow flume. Given the approximate character of Δh, all of these designs were considered to have met the performance criterion sufficiently well.

Evaluation of the MUSTs

The investigation of flow frequencies allowed the flow ranges to be defined explicitly and in a manner consistent with the goal of sampling the bulk of the contaminants at the monitoring station. The investigations of submergence and errors expected at low flows showed that all the alternative stuctures meet the MUST criteria shown in Table II. However, some of the calculated submergence ratios and errors related to stage measurement are marginally acceptable with allowance for uncertainty in the calculations. Beyond the MUST criteria it is evident that the stuctures can be rated relative to acceptable submergence limits and low-flow accuracy, and from best to worst (but acceptable) the order is: proposed critical-flow flume, H-flume and complex weir.

FINAL DECISION ANALYSIS

Although space does not permit discussion of all the considerations used to score the list of wants, Table III shows a condensed listing of the evaluation scores derived for all of the WANTs considered. The average overall scores suggest that the flumes have a distinct advantage over the existing weir. Evaluation of adverse consequences points out the difficulty of constructing a complex critical-flow flume in the field but also notes that it will provide better capability to measure high flows. Complex, critical-flow flumes can be designed for a specific location and probably offer the best accuracy for a wide range of flows. They can be formed from concrete and can be calibrated from accurate as-built dimensions. They are an attractive option, but they are difficult to construct with high precision, and they are not free from upstream sedimentation effects. They withstand submergence quite well, and are a viable option in many applications, especially in cases in which allowing the passage of aquatic organisms is an important factor.

CONCLUSIONS

A decision analysis system was used to identify the hydraulic structure design that best fit the performance criteria and the site constraints. The complex critical-flow flume was judged to be the best design, however, the 4.5-ft H-flume was scored sufficiently close that both were retained for continued evaluation. The maximum measureable flows for the complex flume and the H-flume are (2930 and 2360 L/S, respectively) and both structures are considered to be accurate at 10% over their respective ranges. Therefore, the two-part required flow range was not necessary. That is to say, there is no need for sacrifice in accuracy in the high-flow range as was first suspected. Nevertheless, the flow analysis and the specification of 95% coverage proved to be insightful. When the objective is to sample flow for a contaminant that increases in flux at increased flow, it is important to measure the flow accurately for a large fraction of the expected volume rather than for a large fraction of the time. Some compromise in coverage is required only where the stream shows wide variations in flow and there is a constraint to the size of the hydraulic structure.

TABLE II

"MUSTs" list in Decision Analysis

Accuracy requirements:

10% of true value for $Q_l \leq Q \leq Q_m$ and 25% of true value for $Q_m < Q \leq Q_u$, where

$Q_l = 2.2\,A$;	$Q_m = 1200\,A^{.8}$	$Q_u = 3560\,A^{.8}$
Lower Limit	Middle Limit	Upper Limit

Submergence requirements:

	Sharp-crested weir	H-flume	Critical-flow flume
Max. allowable submergence ratio over primary range without tailwater correction:	0.35	0.5	0.7
Computed maximum submergence ratio at Q_m:	0.27	0.30	0.37

It was decided that costs for constructing both the complex flume and the H-flume should be estimated. The complex critical-flow flume will be selected if the cost is not considered to be prohibitive.

ACKNOWLEDGMENTS

The authors thank David R. Cunningham of the Office of Environmental Compliance and Documentation, ORNL, and Luther R. Simmons of the Office of Waste Management and Remedial Actions for their assistance, and Marlene Evans for preparation of the manuscript. Author affiliations are Roger B. Clapp and Dale D. Huff, Environmental Sciences Division; Mark F. Tardiff, Office of Environmental Compliance and Documentation; Dennis M. Borders, Department of Civil Engineering, University of Tennessee, Knoxville, subcontract to ORNL.

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TABLE III

Evaluation Scores for Decision Analysis Results

		EXISTING WEIR						4.5 FT. H-FLUME					
		Scorer						Scorer					
WANT	wt	1	2	3	4	COMP.	CUM.	1	2	3	4	COMP.	CUM.
Best accuracy and range	10	6	7	4	6	230	230	8	9	8	8	330	330
Minimize bias of head measurement	9	0	10	4	6	180	410	0	9	10	8	243	573
Max. responsiveness of still well	9	0	9	8	10	243	653	0	10	8	10	252	825
Ease & reliability of calibration	8	10	9	5	10	272	925	10	10	10	10	320	1145
Minimize routine maintenance	8	7	6	3	6	176	1101	10	10	9	10	312	1457
Minimize excavation & waste generation	7	7	5	1	6	133	1234	9	10	10	10	273	1730
Minimize effects of debris on operation	7	8	9	6	6	203	1437	10	10	8	10	266	1996
Minimize sedimentation	7	7	7	3	6	161	1598	10	10	9	10	273	2269
Maximize durability	7	9	9	3	8	203	1801	9	8	10	8	245	2514
Freedom from icing/weather effects	7	9	10	9	8	252	2053	9	10	8	8	245	2759
Uses standard design	6	10	10	8	10	228	2281	10	10	10	10	240	2999
Minimize total cost	5	6	5	2	6	95	2376	10	10	10	10	200	3199
Easy to modify for other flows	5	10	10	8	10	190	2566	9	10	10	8	185	3384
Minimize barrier to biota migration	5	1	2	2	6	55	2621	5	2	5	6	90	3474
MEAN SCORE							**655**						**868**

CRITICAL FLOW FLUME

WANT	wt	1	2	3	4	COMP.	CUM.
Best accuracy and range	10	10	10	10	10	400	400
Minimize bias of head measurement	9	0	10	7	10	243	643
Max. responsiveness of still well	9	0	10	10	8	252	895
Ease & reliability of calibration	8	7	8	7	8	240	1135
Minimize routine maintenance	8	9	9	10	10	304	1439
Minimize excavation & waste generation	7	10	10	8	10	266	1705
Minimize effects of debris on operation	7	10	10	10	10	280	1985
Minimize sedimentation	7	10	10	10	10	280	2265
Maximize durability	7	10	9	10	10	273	2538
Freedom from icing/weather effects	7	10	10	10	10	280	2818
Uses standard design	6	7	7	7	8	174	2992
Minimize total cost	5	8	8	10	8	170	3162
Easy to modify for other flows	5	6	7	6	6	125	3287
Minimize barrier to biota migration	5	10	10	10	10	200	3487
MEAN SCORE							**872**

Adverse Consequences

H-Flume:

There may be problems with flow measurements at the low end of the scale.

Setting the flume into the channel may require some excavation of contaminated sediments.

Some of the flows at the high end of the range will be lost.

Complex-Critical-Flow Flume:

Forming the shape for construction may be a problem.

The stilling well intake will be tough to access.

Field calibration of flows may be difficult, mostly at low flows.

INTEGRATED DEMONSTRATION FOR THE REMOVAL OF URANIUM SUBSTANCES FROM SOILS

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ABSTRACT

This document presents management plans and status for the Integrated Demonstration (ID) for the removal of uranium substances from soils to be conducted over approximately a three year time period at the Fernald Environmental Management Project (FEMP). The emphasis of the paper will be on the management, objectives, achievements, direction and goals.

The principal objective of this ID is to evaluate and compare the versatility, efficiency, and economics of the technology components combined into systems for the removal of various uranium substances from soils, specifically soils of a high clay silt content. Secondary waste generation reduction, cost optimization, and risk reduction are important elements in this ID. The ID will be broken into six principal tasks. These tasks are characterization, excavation, soil decontamination, waste streams disposal, regulations, and performance assessment.

The ID involves representatives from multiple DOE sites to provide a broader picture of soil remediation obstacles faced by DOE, a larger realm of technical inputs, and a greater potential that treatment technologies demonstrated will be adaptable to other sites. Technology integration activities are important to ensure the transfer of technologies to the private sector and the infusion of new technologies into the DOE system.

The Uranium Soils ID will be managed by the DOE Fernald Site Office (FSO), FEMP Technical Program Manager (TPM), DOE Oak Ridge Technical Program Officer (TPO), the Integrated Demonstration Coordinator (IDC), a Planning Review Group, and a Core Group. The Planning Review Group will be comprised of the DOE Oak Ridge TPO, DOE FSO representative, DOE Headquarters EM-55 representative, DOE Headquarters EM-54 representative, DOE Headquarters EM-40 representative and a representative from the EPA Risk Reduction Engineering Laboratory. The Planning Review Group will be responsible for reviewing the monthly and status reports, and review and concurrence of major project revisions.

The Core Group will be chaired by the Uranium Soils IDC. The leader of each task group will be a member of the Core Planning Group representing the interest of their task. A representative from Hazardous Waste Remedial Actions Program (HAZWRAP), and a representative from FEMP Environmental Remediation program will also participate on the group. The Core Group is responsible for coordinating the individual task efforts in support of the overall demonstration goals.

PROJECT DESCRIPTION

The Fernald Environmental Management Project (FEMP), previously known as the Feed Materials Production Center (FMPC), is a contractor-operated federal facility for the remediation of a site which produced high purity uranium metal for the U. S. Department of Energy (DOE). The FEMP is located on 425 hectares in a rural area approximately 29 kilometers northwest of downtown Cincinnati, Ohio. On July 18, 1986, a Federal Facilities Compliance Agreement (FFCA) was jointly signed by the U.S. Environmental Protection Agency (U.S. EPA) and DOE to ensure that human health and environmental impacts associated with past and present activities at the FEMP are thoroughly investigated so that appropriate remedial actions can be assessed and implemented. A Remedial Investigation/Feasibility Study (RI/FS) has been initiated to develop these remedial actions.

In order to help meet the cleanup goals of the DOE's nuclear waste sites such as the FEMP, the Director of Environmental Restoration and Waste Management for the DOE initiated the Office of Technology Development (OTD). One program initiated by OTD is the Integrated Demonstration (ID) program. The ID program focuses on improving/validating technologies by demonstrating effectiveness, cost savings, risk reduction potential, site applicability, and regulatory and public acceptance.

The results of the ID will be transferred for implementation throughout the DOE and the Private sector. Technology transfer involves the transfer of technological information outside the Department of Energy (DOE) system (ie: the private sector, EPA, DOD, etc.). The DOE strategy for technology transfer, as noted in SEN-30-91, is to increase DOE and industrial participation in an accelerated process. OTD headquarters (EM-55) will administer directives to ensure that technological data, reported in weekly and monthly internal reports, is distributed and disseminated outside the DOE system. Vehicles for the transfer of information include, but are not limited to, publications, presentations, and information exchange conferences.

The FEMP will host an ID for the remediation of uranium contaminated soil. The ID will address the issues from "cradle to grave" surrounding the remediation of uranium contaminated soils, specifically soils of a high clay/silt content. Reduction of contaminated soil quantity, through the coupling of real time analysis and precise excavation, along with

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decontamination techniques applicable in high clay/silt soils will be the major technology areas. Secondary waste generation reduction, cost optimization, risk reduction, and user applicability are important elements in this ID.

Innovative technologies applicable to remediation of uranium contaminated soils will be investigated throughout the DOE National Laboratory network, private industry, and universities. The ID is expected to be conducted throughout approximately three years with results feeding directly into the FEMP remediation program. Community relations activities shall be conducted as part of the ID in conjunction with the community relation activities currently ongoing under the FEMP CERCLA program. Information on treatability studies conducted within the ID will be conveyed to the public through community meetings and publications.

HOST SITE DESCRIPTION

The Atomic Energy Commission (AEC), predecessor to the U.S. DOE, established a production complex in the early 1950's for processing uranium and its compounds from natural uranium ore concentrates. This complex, known as the Fernald Environmental Management Project (FEMP), is located on 425 hectares in a rural area approximately 29 kilometers northwest of downtown Cincinnati, Ohio. The villages of Fernald, New Baltimore, Ross, Shandon, and New Haven are all located within a few miles of the plant.

The production area covers approximately 55 hectares near the center of the FEMP. The production area consists of several processing plants and waste storage areas. The Pilot Plant was completed in 1951 and was the first operational facility at the FMPC. The Pilot Plant was utilized to house many different processes including thorium metal production, uranium metal production, and uranium hexafluoride reduction. Following the completion of the Pilot Plant, the metals fabrication plant, Plant 6 began operations in 1952. The metal production plant, Plant 5; the greensalt plant, Plant 4; the recovery plant, Plant 8; the sampling plant, Plant 1; and the refinery (Plant 2/3) began operation in 1953. A uranium hexafluoride reduction plant, Plant 7, and the special products plant, Plant 9, were operational in 1954.

Production peaked in 1960 at approximately 10,000 metric tons of uranium (mtu) per year. A product decline began in 1964, to a low in 1975 of about 1230 mtu. During the 1970's, consideration was given to closing the FEMP, therefore, capital improvements and staffing were minimized. In 1981, the FEMP began to accommodate increased production requirements. Production levels significantly increased and there was a rapid staff buildup for several years. Implementation of a major facilities restoration program followed. Production ceased in the summer of 1989 to focus plant resources on the environmental restoration program.

On July 18, 1986, a FFCA pertaining to environmental impacts associated with operation of the FEMP was jointly signed by DOE and the U.S. EPA. The FFCA was entered into pursuant to Executive Order 12088 (43CFR47707) to ensure compliance with existing environmental Statutes and implementing regulations such as the Clean Air Act (CAA); Resource Conservation and Recovery Act (RCRA); and Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA). In particular, the FFCA was intended to ensure that environmental impacts associated with past and present activities at the FEMP are thoroughly and adequately investigated so that appropriate remedial response actions can be formulated, assessed, and implemented. The 1986 FFCA was amended by a Consent Agreement under section 120 and 106(a) of CERCLA. The Consent Agreement became effective on June 29, 1990 and is currently being renegotiated.

In response to the FFCA, a RI/FS is in progress pursuant to CERCLA, as amended by the Superfund Amendments and Reauthorization Act (SARA). The technical strategy adopted by the CERCLA program is to divide the site into five distinct operable units. The components of the operable units (OU's) are:

OU 1 - Waste Pits 1-6, Clearwell, and Burn Pit
OU 2 - Other Waste Units (fly ash pile and Solid waste landfill)
OU 3 - Production Area
OU 4 - Silos 1, 2, 3, and 4
OU 5 - Environmental Media

Contaminated soil exists to some degree in the majority of the Operable Units. Operable Unit 1 has contaminated soil surrounding the pits as well as lining the pit and Operable Unit 4 has contaminated soil surrounding the silos. Operable Unit 2 has contaminated soil surrounding the fly ash pile and solid waste landfill. The bulk of the contaminated soil is located in the production area, Operable Unit 3. Although contaminated soil is present in all the Operable Units, all contaminated soil is being managed under Operable Unit 5.

Soils in the region of the FEMP were formed from source materials that were deposited by the action of Wisconsin and Illinoisan glaciers. These materials consist mainly of glacial till but include sand, gravel, glacial lake clays and silt clays.

Uranium is the principle contaminant of concern at the FEMP. The acceptable concentration level for uranium in soils has not been established. For planning purposes, the preliminary remedial action objective adopted under the FEMP RI/FS, 35 pCi/g, will be utilized. The majority of soils containing uranium exceeding 35 pCi/g are located in the top .46 meter of surficial material. With respect to surface area, approximately 50 percent of the production area soils contain contamination exceeding 35 pCi/g.

TECHNOLOGY AREAS

The ID has been broken into six principal tasks. These tasks are: characterization, excavation, soil decontamination, secondary waste stream treatment/disposal, regulations, and performance assessment. Teams comprised of experts from multiple DOE sites have been formed to address each of the tasks. Representation from multiple sites provides a broader picture of soil remediation obstacles faced by DOE, a larger realm of technical inputs, and a greater potential that treatment technologies demonstrated will be adaptable to other sites.

Characterization

The soil remediation effort would benefit by utilizing a device or method which conducts close to real time uranium analysis accurately and has been proven in a field demonstration.

The current approach is to either remediate a sufficient amount of media to ensure remaining media is within specification or to delay the remediation effort while awaiting laboratory analysis results. Remediation of excess material not

only results in an increase to the remediation cost but does not apply the principles of waste minimization. A method for conducting field characterizations to determine when the specification has been met would reduce project cost and duration. The final level may require independent verification to eliminate conflict of interest concerns.

The principal role of the characterization task group is to identify field characterization and monitoring technologies that are available for demonstration which may be applied to optimize the remediation effort and to support the demonstration and optimization of technology. A secondary role of the task group is to provide support to the program in areas such as: establishing baseline contamination levels, determining important physical/chemical properties of the soil, development of sampling plans and determining QA/QC requirements.

Excavation

The typical excavation techniques for soil remediation utilize and bucket excavators. This type of equipment is excellent when a large quantity of material requires removal. However, when remediation depths of .30 meter or less are involved, bucket excavators may result in the removal of more material than necessary and allow backmixing. Reducing the quantity of material being processed results in a cost reduction. A more precise method of excavation coupled with real-time analysis during excavation will provide a method of minimizing the amount of soil remediated.

Due to the high contamination levels at some of the DOE sites, it may be necessary to reduce personnel exposure through the use of remote excavation techniques. The need for remote excavation across the DOE will be investigated and considered for inclusion into the program.

Soil Decontamination

In the past, solidification/stabilization was the primary approach to soil remediation. Decontamination technologies were not efficient or cost effective. Recent technological advances have been made in decontaminating soil which through demonstration may be proven efficient and cost effective. In order to accomplish the decontamination of the soil, it may be necessary to link several technologies together. Each of the technology components as well as the remediation system must be optimized.

The principal role of the soil decontamination task is to identify decontamination technologies that are available for demonstration and to support the optimization of soil decontamination in terms of effectiveness for uranium substance removal, cost savings, timeliness, nature of waste streams, applicability at other DOE sites, waste minimization and risk reduction.

Secondary Waste Disposal

Application of soil decontamination technologies will result in various secondary waste streams which may require further processing and/or disposal. The waste treatment/disposal technologies must address such issues as: disposal waste acceptance, cost savings, waste minimization, regulatory issues, and risk reduction. As with soil decontamination, several technologies may be linked together to form a secondary waste treatment/disposal system.

The principal role of this task is to investigate various technologies and disposal options for application to the decontamination waste streams, identifying Research and Development needs and to support the testing and evaluation of the field demonstration.

Regulations

The FEMP has been classified as a National Priorities List (NPL) Superfund Site and is governed by a FFCA to ensure compliance with regulations such as CERCLA, RCRA, and CAA. It is imperative that environmental regulations/DOE Orders are thoroughly reviewed to ensure that the demonstration operates within all applicable regulations. Compliance with environmental issues and DOE Orders at the FEMP and all subsequent technology user sites has the potential to impact remediation cost and schedules. Complete evaluation of the demonstration requires total understanding of regulatory/DOE requirements and their effects on cost. The determination of requirements and development of compliance schedules during the technology demonstration will benefit subsequent users when applying the technology in remediation efforts.

The principal roles of the regulation task group are to review the environmental regulations and DOE Orders, identify regulatory constraints of the field demonstration, identify and examine regulatory requirements for implementation at the FEMP and other sites, identify policies/regulation requiring enhancement, and develop an implementation schedule.

Performance Assessment

The principal responsibility of the Performance Assessment Task group is to oversee the ID to ensure that technology evaluations meet the technology validation requirements under CERCLA to ensure the transfer of technologies and systems into remediation implementation. The group will complete cost analysis and risk assessments for the individual technology components and the technology systems and assist/support the other task groups in performance evaluations.

In order to compare the technologies demonstrated, the technologies must be evaluated against base line criteria. The establishment of a task group focused on evaluating the technologies will provide for a detailed assessment of all options to support decision-making for future applications and establish whether the technologies are successful.

It is also important to explore the risk tradeoffs resulting from the possible air and/or water emissions from application of the remediation system.

MANAGEMENT STRUCTURE

A conceptual organizational chart for the ID is shown in Fig. 1. The principal parties include: DOE-Headquarters, DOE-Oak Ridge Technical Program Officer (TPO), DOE-Fernald Site Office (FSO), Planning Review Group, FEMP Technical Program Manager (TPM), Integrated Demonstration Coordinator (IDC), and Core Group.

The Planning Review Group will be comprised of the Oak Ridge TPO, DOE-FSO representative, DOE Headquarters EM-55 representative, DOE HQ EM-54 representative, DOE Headquarters EM-40 representative and a representative from EPA Risk Reduction Engineering Laboratory.

The Core Group will be chaired by the Uranium Soils IDC. The leader of each task team will be a member of the Core Group representing the interest of their task. A representative from HAZWRAP and a representative from the FEMP ER program will also participate on the group.

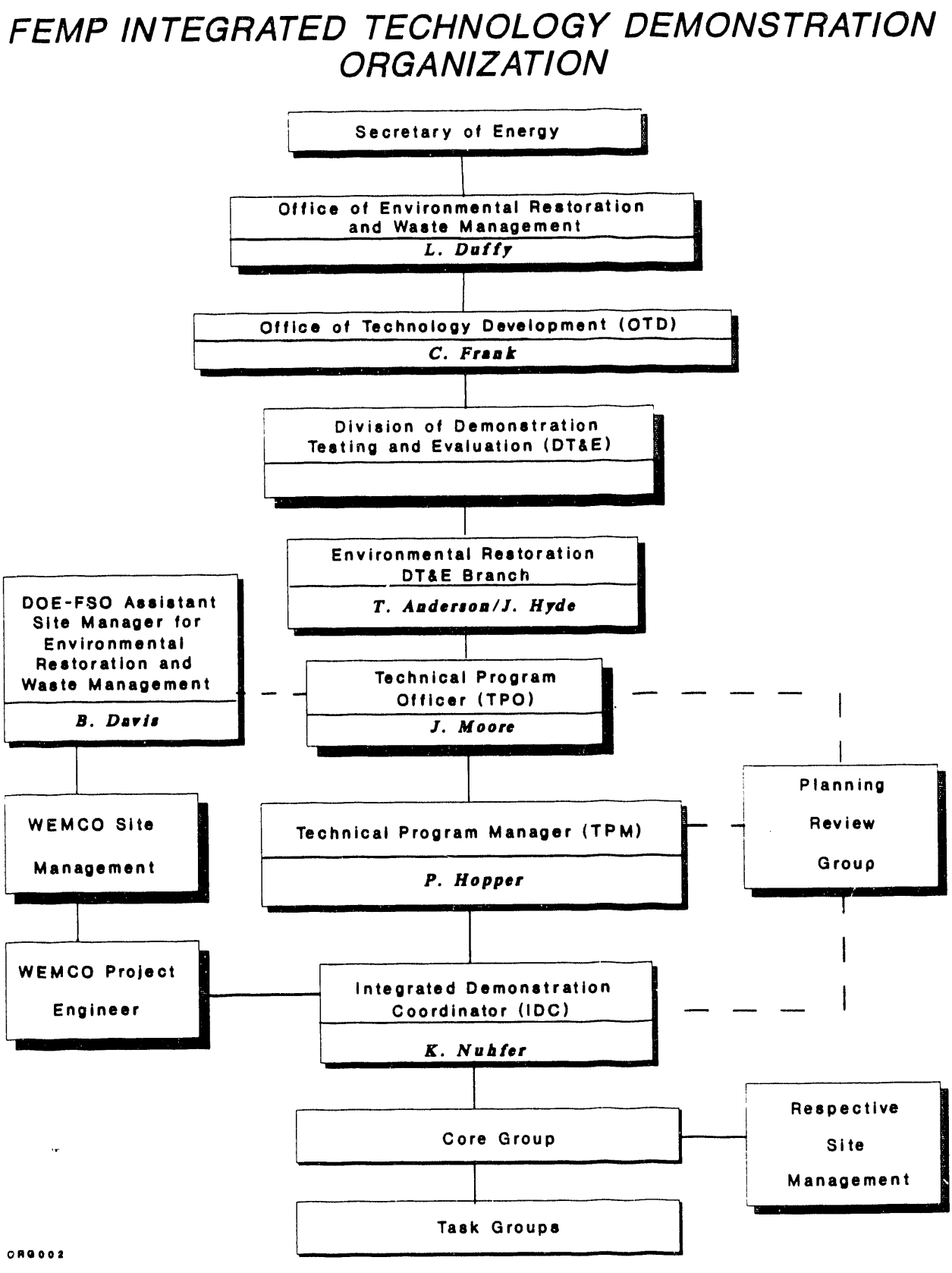


Fig. 1. FEMP integrated technology demonstration organization.

SCHEDULE

Reduction of contaminated soil quantity through coupling of real time analysis and precise excavation along with decontamination techniques applicable in high clay/silt soils will be the major technology areas for FY 92 and FY 93. A secondary focus will be in the development of a conceptual model that relates process history and soil characteristics to the physical and chemical properties of the uranium waste form found in the Fernald soils. Such information will help in the screening of separation technologies and help guide site characterization activities. The focus on secondary waste treatment and disposal will begin to increase in mid to late FY 92 after potential remediation technologies have been identified and secondary waste streams have been determined. Figure 2 depicts the current schedule for the ID.

APPROACH/STATUS

The applicable/potential technologies for removing the uranium from the soil will depend on the current physical/chemical form of the uranium in the soil. The wide variety of uranium compounds utilized at the FEMP gives rise to a number of potential sources which may generate unique uranium waste forms in the environment. Three characteristic waste forms have been identified for use in this phase of sampling:

- aqueous uranium waste (solubilized and absorbed)
- solid uranium product particulate (as released through spills), and
- air borne uranium waste particulate (dust, aerosols).

In June 1991, screening samples were obtained from five locations representing the three characteristic waste forms. The samples were obtained to determine some specific chemical/physical data on the soil and uranium waste forms. The screening samples were obtained in accordance with the revised RI/FS QAAP and the analysis is currently being completed at Oak Ridge National Laboratory.

The ID treatability samples will be obtained from two or more of the five sample locations on which screening data was collected. The areas selected will be based on the characterization results from the previous screening sampling and the RCRA determination completed for the potential locations. The locations selected must be classified as non-RCRA areas.

A sufficient amount of material will be collected at each area to conduct treatability tests on multiple technologies throughout the ID. It is important that the same material be used for all treatability tests so that the results will be comparable. The material drums from each area will be blended to obtain twelve "equal" homogeneous samples from each location.

The treatability samples will be collected by the end of September, 1991 and treatability tests will be initiated in October, 1991. Some potential technologies to be evaluated through treatability test include: physical size fraction separation, chemical extraction/leaching, application of chelators, and electrokinetics.

Based on laboratory and bench scale treatability tests, technologies will be selected for further development and evaluation. These selected technologies will be compared and evaluated on site in a field demonstration. Field demonstrations will be conducted in spring to fall (demo season) of each year.

In the 1992 demo season, characterization will be the predominant technology demonstrated. Real Time analysis technologies to be pursued in 1992 include: gamma ray spectroscopy analysis, inductively coupled plasma optical emission spectrometry, and any additional technologies discovered through industrial and university solicitation.

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ACRONYMS

AEC	Atomic Energy Commission
ARAR	Applicable or Relevant and Appropriate Requirement
CAA	Clean Air Act
CBD	Commerce Business Daily
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
DOE	Department of Energy
EPA	Environmental Protection Agency
FFCA	Federal Facilities Compliance Agreement
FMPC	Feed Material Production Center
IDC	Integrated Demonstration Coordinator
ID	Integrated Demonstration
mtu	metric tons of uranium
NEPA	National Environmental Policy Act
NPL	National Priorities List
OR	Oak Ridge
OTD	Office of Technology Development
OU	Operable Unit
ppm	parts per million
pCi/g	picoCuries per gram
QA	Quality Assurance
QAPP	Quality Assurance Project Plan
RCRA	Resource Conservation and Recovery Act
RFP	Request For Proposal
RI/FS	Remedial Investigation and Feasibility Study
SARA	Superfund Amendments and Reauthorization Act
TPM	Technical Program Manager
TPO	Technical Program Officer
WBS	Work Breakdown Structure
WEMCO	Westinghouse Environmental Management Company of Ohio

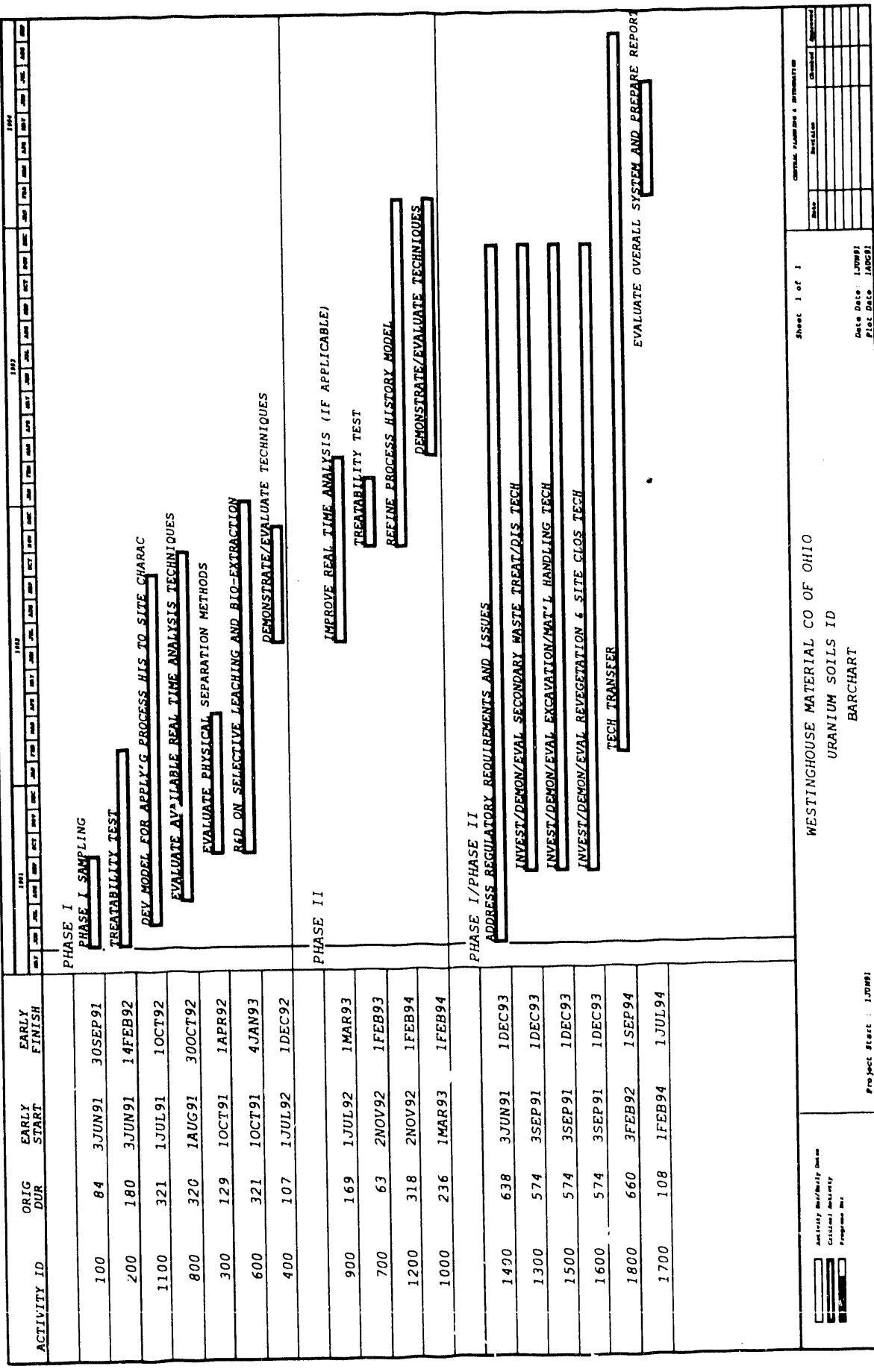
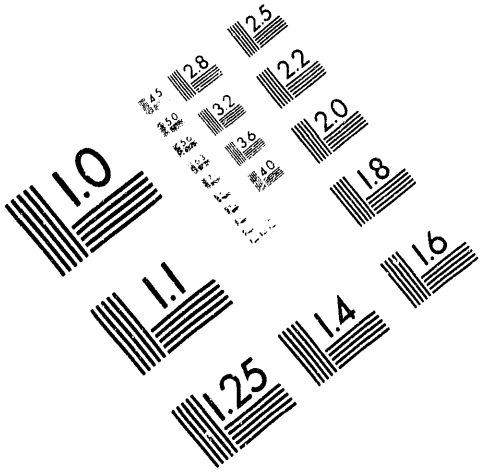
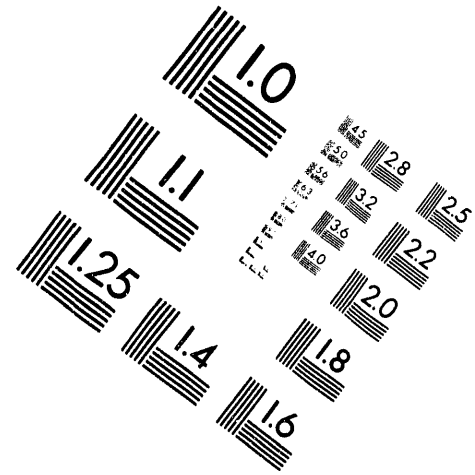


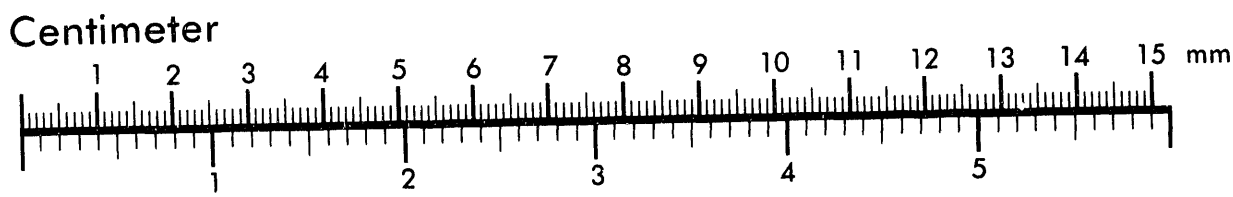
Fig. 2. Uranium soils ID schedule.

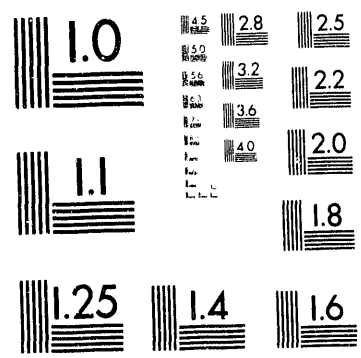


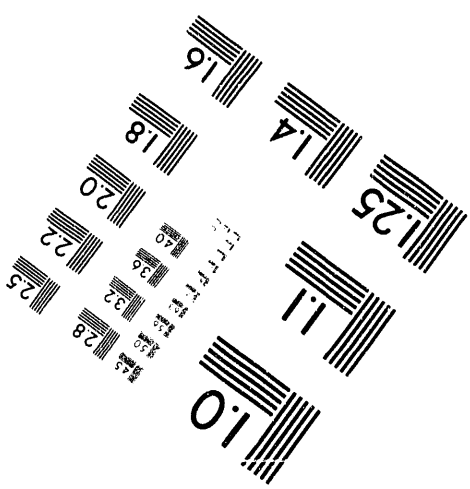


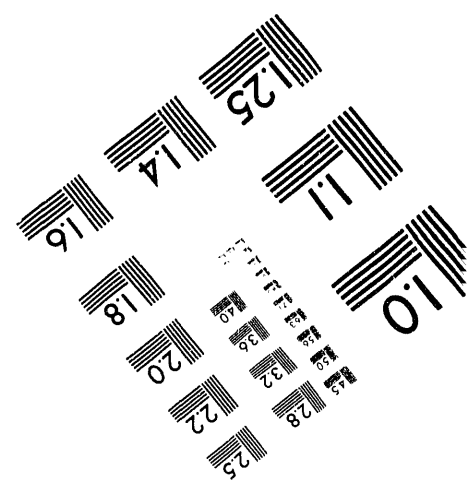
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THE BURIED WASTE INTEGRATED DEMONSTRATION

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ABSTRACT

There are numerous locations throughout the Department of Energy (DOE) Complex where wastes have been buried in the ground or stored for future disposal. Much of this buried waste is contaminated with hazardous and radioactive materials. An extensive research program has been initiated at the Idaho National Engineering Laboratory (INEL) to develop and demonstrate advanced remediation techniques for DOE Complex buried waste.

The purpose of the Buried Waste Integrated Demonstration (BWID), is to develop a scientifically sound and deployable remediation system consisting of advanced technologies which address the buried waste characteristics of the DOE Complex. This comprehensive remediation system will include technologies for the entire remediation cycle (cradle-to-grave).

Technologies developed and demonstrated within the BWID will be transferred to the DOE Complex sites with buried waste, to private industry, and to universities. Multidirectional technology transfer is encouraged by the BWID.

Identification and evaluation of plausible technological solutions are an ongoing activity of the BWID. A number of technologies are currently under development throughout the DOE Complex, private industry, and universities. Technology integration mechanisms have been established by BWID to facilitate collaborative research and demonstration of applicable remedial technologies for buried waste.

Successful completion of the BWID will result in the development of a proven and deployable system at the INEL and other DOE Complex buried waste sites, thereby supporting the DOE Complex's environmental restoration objectives.

INTRODUCTION

The Department of Energy (DOE) and its predecessor agencies have operated numerous facilities throughout the United States for a wide range of purposes including nuclear weapons research, development, and production, as well as the peaceful use of nuclear energy. As a result of these and other operations, there are numerous locations throughout the DOE Complex where wastes have been buried in the ground or stored for future disposal. These locations include the Idaho National Engineering Laboratory, the Hanford Site, Oak Ridge National Laboratory, Savannah River Site, Los Alamos National Laboratory, Lawrence Livermore National Laboratory, Sandia National Laboratory, and the Nevada Test Site.

As a result of prior practices, which allowed the commingling of various types of waste, much of the buried waste throughout the DOE Complex is contaminated with hazardous and radioactive materials. This buried waste includes transuranic (TRU) waste, low-level radioactive waste (LLW), Greater-than-Class-C waste (GTCC), hazardous waste per 40 CFR 261, mixed TRU waste, and mixed LLW.

The Idaho National Engineering Laboratory (INEL) contains a significant volume of the DOE Complex's buried waste. The majority of buried waste at the INEL is located within the Radioactive Waste Management Complex (RWMC). Over 700,000 cubic yards of buried waste are located at the INEL's RWMC. This broad spectrum of buried waste includes LLW, TRU waste, GTCC waste, and mixed waste.

The waste and site characteristics of the RWMC are such that it is a reasonably representative DOE buried waste site. Therefore, the demonstration of remediation technologies at the INEL's RWMC should provide a high degree of confidence that demonstration results will be useful for applications at other DOE buried waste sites.

INTEGRATED DEMONSTRATIONS

The DOE Office of Technology Development (OTD) has initiated an extensive program (integrated demonstrations) to develop and demonstrate advanced remediation techniques that will support DOE's environmental restoration objectives. Due to the unique nature of buried waste, technologies do not currently exist for the in-situ treatment of waste, nor do technologies exist for the comprehensive treatment of waste after it has been exhumed. In order to address these issues as well as identify other technological deficiencies, OTD has initiated the Buried Waste Integrated Demonstration (BWID) at the INEL.

The BWID is coordinated for the DOE by the Waste Technology Development Department (WTDD) of EG&G Idaho, Inc at the INEL. Although hosted at the INEL, BWID will involve engineers and scientific experts from throughout the DOE Complex to advance the understanding of potential technologies for remediation of buried wastes.

PURPOSE

The BWID will support, evaluate, demonstrate, and validate a suite of technologies (i.e. a comprehensive remediation system) for the effective and efficient remediation of buried waste. Proven technologies will be transferred to the various DOE Complex sites with buried waste problems, to private industry, and to universities. Industrial, academic, and DOE Complex-wide participation is encouraged to enhance multidirectional technology transfer.

It is the ultimate goal of BWID to improve remediation capabilities in the DOE Complex while maintaining a vigorous schedule as defined by ERP.

SCOPE

The comprehensive remediation system developed by the BWID will include technologies for the entire remediation cycle (cradle to grave). Specifically, BWID will address the following technology categories:

- site and waste characterization;
- retrieval;
- treatment;
- packaging;
- transportation;
- storage;
- disposal;
- analysis and evaluation;

The complexity and heterogeneity of DOE Complex buried waste requires considerable effort to identify an appropriate and representative demonstration site for effective remediation of buried waste. As a result, BWID will review and screen technologies in terms of waste characteristics, site characteristics, DOE Complex applicability, and technological maturity.

BWID is needs-driven, and supports the development of technologies which support ERP needs and schedules.

OBJECTIVES

The programmatic objectives of BWID include identification of technological deficiencies and advancing technologies in the area of environmental remediation of buried waste. BWID will then demonstrate a suite of environmental restoration technologies to satisfy the identified deficiencies. Advanced technologies will also be demonstrated and evaluated whether they are faster, better, cheaper, and safer than their conventional counterpart technologies.

Specific BWID programmatic objectives include:

FASTER- accelerate DOE buried waste remediation schedules;

BETTER - minimize estimates of waste generated by buried waste remediation by 50%;

CHEAPER - reduce buried waste remediation costs of presently available technologies (10:1 cost savings);

SAFER - achieve and maintain compliance with all Federal, State, and local regulations; improve environmental monitoring and assessment;

COLLABORATION

The BWID is the focal point for facilitating needs-driven corroborative research and demonstration of remedial technologies for buried waste throughout the DOE Complex. As the functional program for the OTD for buried waste remediation, BWID maintains mechanisms for interfacing with DOE-Headquarters (DOE-HQ), DOE-Idaho (DOE-ID), other DOE Field Offices, DOE contractors, private industry, and universities.

Collaboration between the DOE Complex will be enhanced through the BWID Core Support Group (CSG) and the BWID Technical Advisory Groups (TAG). Members of the CSG will represent the environmental restoration needs of their respective DOE sites. This will maintain the national perspective of BWID for addressing DOE Complex-wide needs. Similarly, the TAGs will consist of technology development experts from throughout the DOE Complex, private industry, and the academic community. These TAGs will provide the technical expertise to screen and evaluate technological solutions to the various environmental remediation problems identified by ERP.

SYSTEMS APPROACH

A systems approach will be employed to provide the technical justification for determining which emerging remediation technologies are needed to help solve the environmental restoration problems resulting from buried waste. The entire remediation process (cradle to grave) will be evaluated. Candidate technologies for characterization, retrieval, treatment, containment, stabilization, packaging, storage, transportation, and disposal will be evaluated. This systems evaluation will identify technological gaps in the system as well as identify promising new technologies that will reduce the time and cost of remediation. This information will permit OTD to better support DOE-Complex ERP Buried Waste Programs by focusing its resources on select technologies.

SCHEDULE

BWID is currently sponsoring technology development to support milestones identified by the INEL Buried Waste Program. Several short-term milestones for the BWID include: initiation of intrusive and non-intrusive characterization demonstrations (FY92), completion of DOE Complex Needs Assessment (FY92), initiation of cold test retrieval technology demonstrations (FY92/FY93).

As the DOE Complex needs assessment becomes more clearly defined, BWID will initiate additional technology development to support the critical path for buried waste remediation efforts of the DOE Complex.

SUMMARY

BWID will address the complex problem of buried waste by initially focusing on a specific buried waste location at the INEL which is representative of buried waste throughout the DOE Complex. Specific demonstrations may be conducted at various sites throughout the DOE Complex when appropriate.

Successful completion of BWID will result in scientifically sound, demonstrated technologies being transferred for deployment to various ERP throughout the DOE Complex with buried waste, to private industry, and to universities.

CERCLA INTEGRATION WITH SITE OPERATIONS THE FERNALD EXPERIENCE

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ABSTRACT

A major transition in the Fernald Environmental Management Project (FEMP) site mission has occurred over the past few years. The production capabilities formally provided by the FEMP are being transferred to private industry through a vendor qualification program. Environmental compliance and site cleanup are now the primary focus. In line with this program, the production of uranium products at the site was suspended in July 1989 in order to concentrate resources on the environmental mission. Formal termination of the FEMP production mission was accomplished on June 19, 1991. Environmental issues such as stored inventories of process residues materials and equipment are being addressed under the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA). The diversity of these hazards complicates the strategic planning for an integrated site cleanup program.

The FEMP is one of the first Department of Energy (DOE) facilities to transition from an active production mission guided by Defense Programs (DP) to an environmental mission guided by Environmental Management (EM) under Leo Duffy. Westinghouse Environmental Management Company of Ohio (WEMCO) has been charged with integrating all site activities to carry out the cleanup. A new management structure has been formulated, and an integration approach initiated. Analyses are under way to evaluate all site activities such as waste management, safe shutdown, product material disposition and routine environmental monitoring in view of CERCLA requirements. Site activities are being broken down into three categories: (a) CERCLA driven - restoration work required under CERCLA, (b) CERCLA covered - other environmental requirements which must be integrated with CERCLA, and (c) CERCLA exempt (if any). The approach to comply with these categorized activities must be negotiated with state and federal regulatory agencies. A site-wide work breakdown structure and management plans to implement a "first-of-a-kind" total site Major Systems Acquisition program are being implemented.

This paper will discuss the programmatic approach which is being implemented to ensure activities such as waste management, site utility and support services, health and safety programs, and Resource Conservation and Recovery Act (RCRA) programs are being integrated with CERCLA.

FEMP SITE HISTORY

A key facility in the DOE's nuclear production capability was the FEMP (See Fig. 1). The facility located northwest of Cincinnati, Ohio in the town of Fernald, Ohio, produced uranium metal and uranium compounds for use in production reactors and other defense facilities. An integral part of this mission is the safe operation of defense program production facilities and the effective management of derived waste materials.

The FEMP was built by the United States Atomic Energy Commission and began operations in the early 1950s. The property covers 425 hectares and the production area itself is approximately 55 hectares. The site was constructed to establish an in-house integrated production facility for processing uranium from uranium ore concentrates. A variety of chemical and metallurgical processes were employed at the FEMP to support the production of high-purity uranium metal (See Fig. 2). These production processes generated a significant quantity of waste materials containing low levels of radioactive and hazardous constituents. Increased national emphasis on environmental enhancement has resulted in the evolution of new regulatory requirements for the management of these wastes.

REGULATORY OVERVIEW

Remediating a Superfund site that continued process operations after 1980 and thus is subject to RCRA as is the case with the FEMP is a task that requires environmental managers to fully understand and be able to balance both CERCLA and RCRA regulations in addition to TSCA,

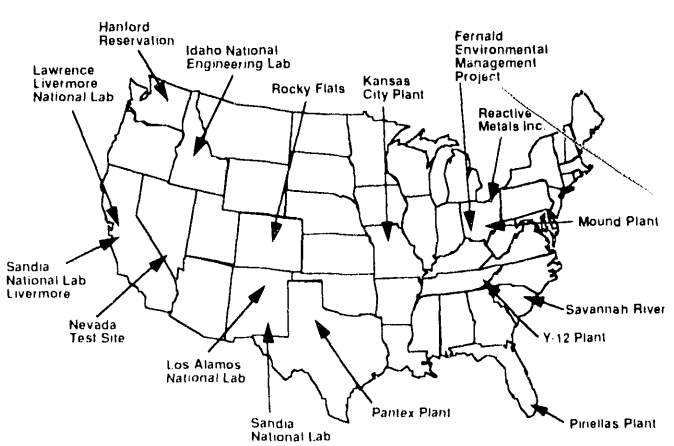


Fig. 1. FEMP location.

* Westinghouse Environmental Management Company of Ohio with the U.S. Department of Energy under Contract No. DE-AC-05-86OR21600

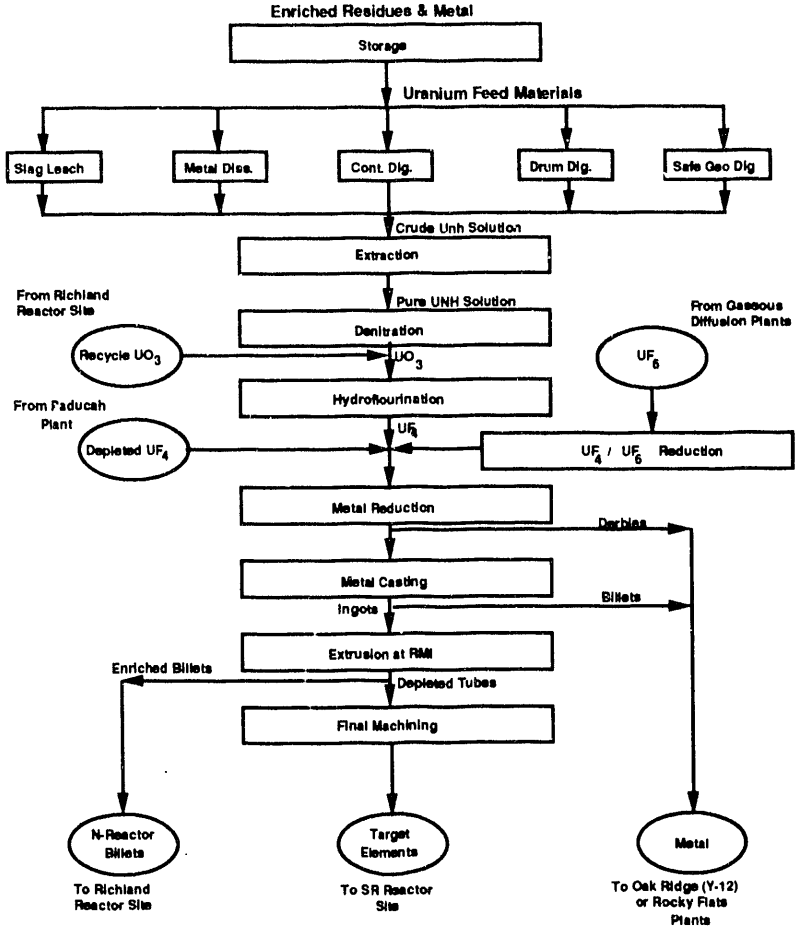


Fig. 2. FEMP process flow chart.

asbestos abatement, and other environmental and health and safety requirements.

Beginning with the basic premise that the primary driving regulation is CERCLA and then ensuring regulatory concerns for RCRA, solid and hazardous wastes; TSCA; Clean Air Act; Clean Water Act; and a host of other regulations are part of the compliance strategy. Table I is a matrix of primary environmental regulations which form the foundation of this strategy. In addition to regulation under the multitude of environmental laws, FEMP managers must also deal with the mixed waste issue. The United States Environmental Protection Agency (U.S. EPA) recently began regulating those wastes which have both a hazardous waste by definition and have radioactive levels that pose a threat to health and safety. The State of Ohio is now authorized to regulate mixed wastes as part of their RCRA Program. These mixed wastes are also subject to DOE authority and are another major factor in this complex integration management arena. By far, the area with the largest scope in this integration process is CERCLA/RCRA with its applicable or relevant and appropriate requirements (ARARs). Finally, all site Environmental Management activities must be consistent with DOE Order 5400.4, CERCLA Requirements, and other pertinent DOE Orders.

RCRA and CERCLA have two separate and distinct sets of regulations to which no uniform set of standards can be applied. CERCLA bases control on risk and does not include hazardous waste management practices. RCRA is based on managing hazardous wastes and preventing future releases. Additionally, two separate regulatory agencies in the vast majority of States are responsible for enforcement of these regulations. CERCLA is generally a federal program administered by one of the U.S. EPA regions. Nearly all States including Ohio are authorized by Congress through the U.S. EPA to regulate and enforce the RCRA regulations. Each authorized State must have environmental laws in place which are equal to or more stringent than the federal program.

One of the most challenging areas of integration involves finding a common ground in site characterization including sampling, cleanup levels, and groundwater monitoring. Sampling of soils and groundwater for contamination is a key factor requiring integration. CERCLA, being risk-based, requires sampling and analyses consistent with the Hazardous Substance List (HSL). This list in some cases includes different constituents and levels of analysis than those required by RCRA. Since the end result for both RCRA and CERCLA is site remediation, lowering the risk for CERCLA and removing and managing the source of hazardous waste for RCRA is a balancing act, finding a sampling regime that satisfies both regulations.

Similarly, the cleanup levels for soils and groundwater become an issue with both State and Federal regulators. RCRA has specific contamination levels for ground water and proposed levels for soils while, in most cases, cleanup levels are negotiated based on the treatment option selected under CERCLA.

TABLE I

Regulatory Oversite at Fernald

PROGRAM	DESCRIPTION	REGULATED BY
CERCLA	"Super-fund" regulates disposal of past hazardous wastes.	U.S. EPA/OEPA
RCRA	Resource Conservation Recovery Act. Regulates current hazardous waste since 1980.	U.S. EPA/OEPA
TSCA	Toxic Substance Control Act. Act regulating PCB use and disposal.	U.S. EPA/OEPA
CWA	Clean Water Act. Regulates all navigable bodies of water.	OEPA
CAA	Clean Air Act. Regulates air emissions.	OEPA/SWOAPCA
NEPA	National Environmental Policy Act Document. Deals with environmental impact statements for federaly funded actions.	DOE
DOE	Department of Energy. Regulation of disposal of radioactive materials.	DOE
OSHA	Hazardous Waste workers health and safety (29-CFR)	OSHA
UST	(Hazardous) 40-CFR 264 subpart J and state regulations for underground storage of hazardous waste.	OEPA
UST	Oil and gas regulated by 40 CFR 280 and state regulations.	OEPA
State Fire Marshal	Regulates removal of underground storage tanks containing oil/gas. From state regulations and 40 CFR 280.	State Fire Marshal
Title III SARA Reporting	Requires industries to report all known releases of hazardous materials.	OEPA/EPA
Mixed Waste	Waste that is both hazardous by definition and radioactive.	DOE/OEPA/EPA
NESHAP	National Emission Standard for Hazardous Air Pollutants. Regulates the emission of radionuclides.	U.S. EPA
NPDES	National Pollution Discharge Elimination System. Regulates the chemical concentrations in liquid effluents.	OEPA

Monitoring well placement and construction is yet another area where agreement must be reached between Federal and State regulators. In RCRA, it is a requirement to fully characterize groundwater contamination for the site both horizontally and vertically. At some sites, this means going through bedrock to reach a second aquifer. The wells must be sampled and monitored regularly through closure, and in most cases, for many years after during the post closure phase. There are specific requirements in the State and Federal RCRA regulations for groundwater monitoring. To ensure these regulations are satisfied by the groundwater monitoring and sampling used to develop a risk-based Record of Decision (ROD) for CERCLA requires a complete knowledge of the scope and limits of both programs.

CURRENT CLEANUP AND WASTE MANAGEMENT PROGRAMS

Consistent with national emphasis, the U.S. EPA issued a Notice of Noncompliance on March 9, 1985, to the DOE identifying their major concerns over potential environmental impacts associated with FEMP operations. In accordance with Executive Order 12088 on July 18, 1986, the DOE entered into a cooperative agreement with the U.S. EPA, entitled the Federal Facilities Compliance Agreement (FFCA). The intent of the FFCA was to ensure compliance with existing regulations and to guarantee that environmental impacts associated with past, present, and future activities at the FEMP are adequately investigated so that appropriate remedial actions can be implemented.

On November 21, 1989, the FEMP was placed on the CERCLA National Priorities List (NPL). In accordance with Section 120 of CERCLA pertaining to NPL facilities, a Consent Agreement (CA) governing the completion of the

Remedial Investigation/Feasibility Study (RI/FS) and the implementation of remedial and removal actions was entered into by the U.S. EPA and DOE in June 1990. This agreement establishes responsibilities and authorities between the U.S. EPA and DOE and is currently being renegotiated.

A key focus of the CA is the completion of a sitewide RI/FS (See Fig. 3). The RI/FS will assess existing and potential environmental impacts and evaluate remedial action alternatives to mitigate these impacts pursuant to CERCLA and U.S. EPA guidance. Consistent with DOE draft Notice 5400.4, negotiations are under way to integrate the RI/FS and the National Environmental Policy Act (NEPA).

The progressive findings of the RI/FS are identifying potential FEMP facilities requiring remedial action. To support the timely initiation of remedial actions, the RI/FS has been segregated into operable units. These operable units represent discrete facilities or concerns comprising the total scope of the RI/FS process. The selection of these operable units was based on the type of facilities and similarities in the types of remedial action alternatives. Currently, five operable units have been defined:

Operable Unit 1: Waste Pit Area. Waste Pits 1-6, clearwell, burnpit, berms, liners and soil.

Operable Unit 2: Other Waste Units. Fly ash piles, other south field disposal areas, lime sludge ponds, solid waste landfill, berms, liners, and soil.

Operable Unit 3: Production Area. Production area and production-associated facilities and equipment including, but not limited to, all structures, equipments, utilities, drums, tanks, solid waste, waste, product, thorium, effluent lines, K-65 transfer line, wastewater treatment facilities, fire training facilities, scrap metals piles, feedstocks, and coal pile.

Operable Unit 4: Silos 1-4. Silos 1, 2, 3, and 4, berms, decant tank system, and soil.

Operable Unit 5: Environmental Media. Groundwater surface water, soil not included in the definitions of Operable Units 1-4 sediments, flora, and fauna.

This operable unit concept will result in five Records of Decision (RODs). Pursuant to the CA, DOE is required to implement the selected alternatives identified in the ROD of the RI/FS. The Environmental Remedial Action (ERA) Project provides the necessary resources to implement the remedial action alternatives identified in the RODs in a cost-effective and timely manner.

A second major agreement between the DOE and a regulatory agency is the Consent Decree (CD). The CD issued by the State of Ohio in December 1988 provided specific milestones for achieving compliance with requirements governing the management of hazardous wastes, stormwater, and wastewater discharges. The original agreement is in the process of being amended to provide additional commitments and milestones regarding completion of waste evaluations, upgrading of waste storage facilities, overpacking of thorium, and resubmittal of hazardous waste permits. Site efforts to address the commitment/milestones stipulated by the CD are being addressed by the Waste Management Program and the Clean Air and Clean Water Programs. Table II presents a listing of current FEMP RCRA Hazardous Work Management Units (HMMUs) by Operable Unit.

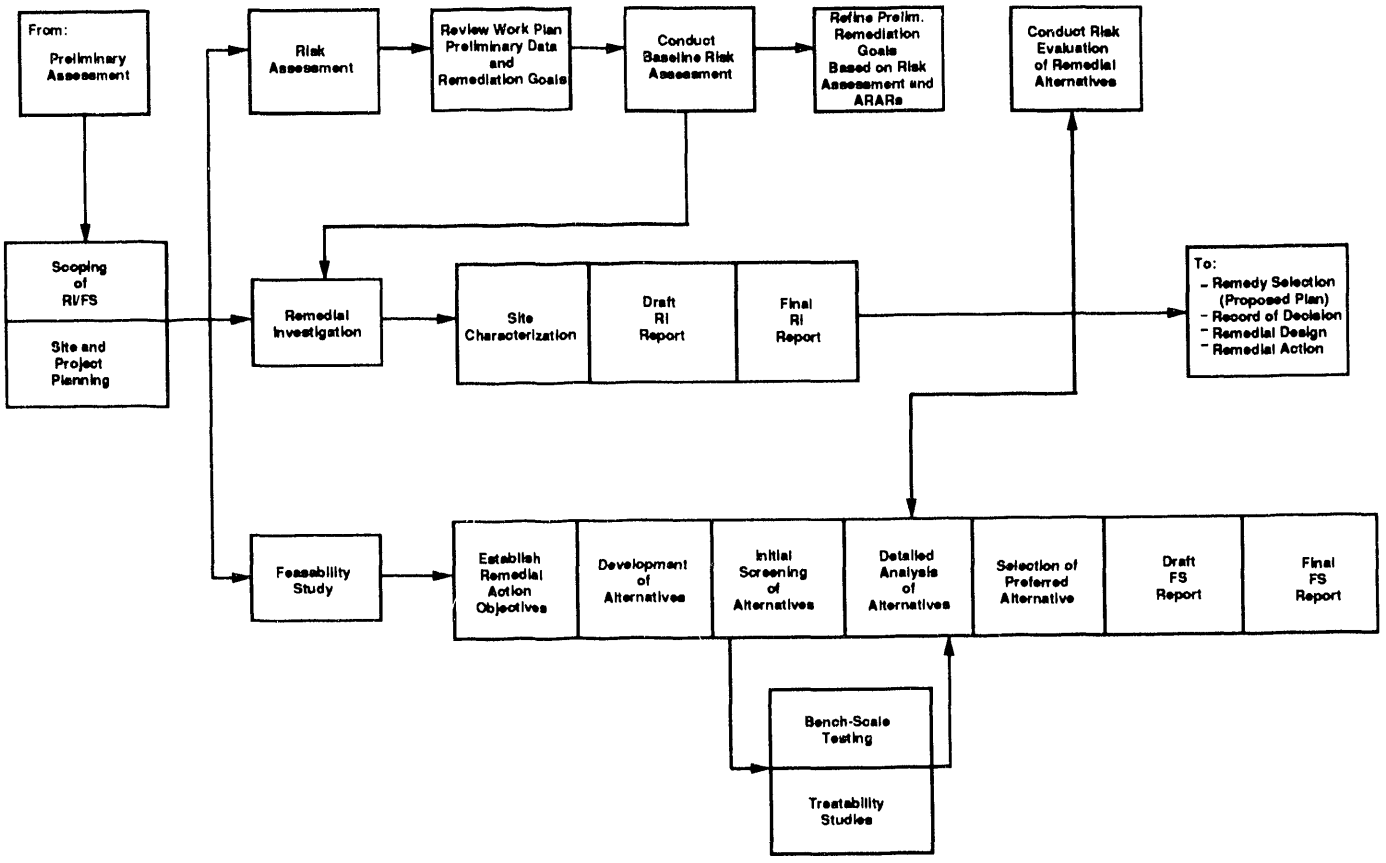


Fig. 3. Remedial investigation/feasibility study flow chart.

TABLE II

Hazardous Waste Management Units by Operable Unit

OPERABLE UNIT 1

Waste Pit 4
Waste Pit 5
Clearwell

OPERABLE UNIT 2

Lime Sludge Ponds

OPERABLE UNIT 3

Parts Cleaner - Welding Shop
Waste Oil Storage - Garage
Drummed HF Residue - Plant 4
Drummed HF Residue - NW of Plant 4
Nitric Acid Rail Car
NAR System
Wheelabrator - Building 66
Wheelabrator Dust Collector - Building 66
Box Furnace
Oxidation Furnace 1
Primary Calciner
Solvent Storage - Tank T-6
KC2 Warehouse - Building 63
Plant 9 Warehouse - Building 81
Storage Pad - North of Plant 6
Underground Storage Tank 5
Plant 8 East Drum Storage Pad
Plant 8 West Drum Storage Pad
CP Warehouse - Building 56
Plant 1 Pad
Hilco Oil Recovery Unit
Sump - West of Pilot Plant
Plant 1 Storage - Building 67
Detrex Still
Trane Thermal Liquid Incinerator
Plant 8 Warehouse - Building 80
Barium Chloride Salt Treatment Facility
Solvent Storage - Tank T-5
Pilot Plant Warehouse Storage Pad
Plant 6 Warehouse
HF Tank Car

OPERABLE UNIT 5

Coal Pile Runoff Basin
Sludge Drying Bed
Biodenifrification Surge Lagoon
Drummed HF Residue - South of Cooling Tower
Tank Farm Sump
Fire Training Facility
Drum Storage Area - South of Lab Building
Drum Storage Area - Lab Building Loading Dock
Well Drilling Storage Area
Equipment Storage Area

In addition to providing the major programmatic oversight of the CD deliverables, the Waste Management Program also is responsible for the management and disposal of low-level radioactive waste residues and scrap metal under DOE Orders.

Other programs such as the Clean Water Program and Clean Air Program deal with capital improvements and operating enhancements to ensure the FEMP remains in compliance with National Pollution Discharge Elimination System (NPDES) limits, National Emission Standards for Hazardous Air Pollutants (NESHAP) and other emission standards and with programs such as asbestos abatement.

Another major effort is implementing the safe shutdown of all process facilities. This program's major emphasis is on the removal and disposition of inventory which was "in process" when production activities were curtailed in July 1989 and on the disposition of final and intermediate product material still in inventory.

The implementation of these major programs requires that innovative approaches be developed to ensure all negotiated agreements and milestones are met with minimal inter-agreement interference. These innovative approaches were driven by regulatory differences between CERCLA, RCRA, other laws/regulations and DOE Orders. DOE Order 5400.4 provides the roadmap for the FEMP programs. By utilizing this DOE Order and regulations and statues, environmental and project management expertise was given the task of developing an integration strategy for FEMP environmental management programs. The remaining sections discuss the program's development and implementation. Figure 4 presents the FEMP Work Breakdown Structure being utilized to guide site activities and indicating how integration is being accomplished.

INTEGRATION STRATEGY

CERCLA Integration Committee

To effectively pursue the goal of total programmatic CERCLA integration, the need was identified for a centralized project management function. Accordingly, the CERCLA Integration Committee was formed in January 1991, consisting of WEMCO management and technical personnel. This committee reports to a team comprised of DOE and contractor upper management. The CERCLA

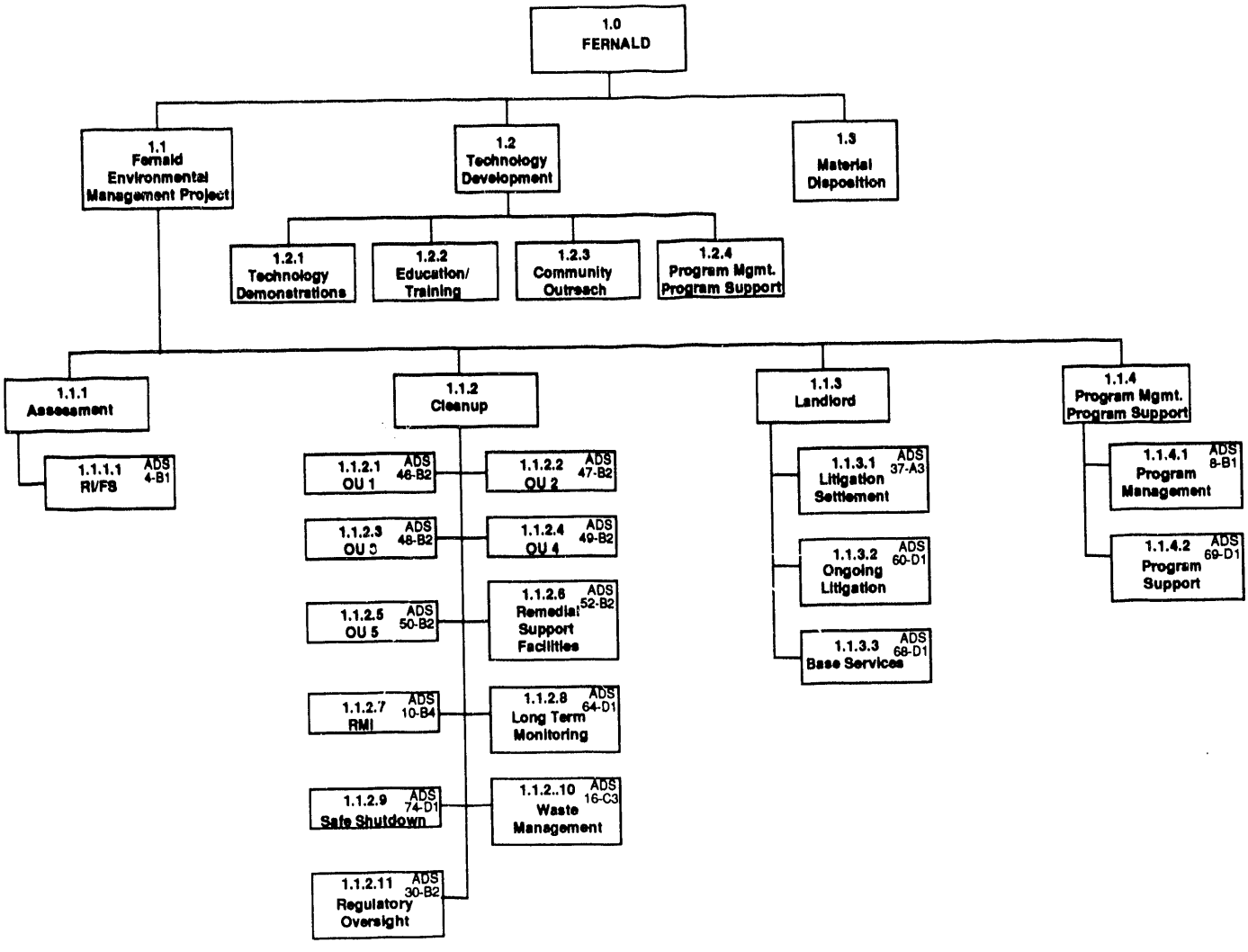


Fig. 4. FEMP work breakdown structure.

Integration Committee has been tasked with formulation of a plan to bring all activities into compliance with the various requirements of CERCLA. The group is developing an overall integration schedule; defining critical interfaces between U.S. EPA, OEPA, U.S. DOE, the Ohio State Fire Marshal, and other regulatory agencies; determining the impact on mandated schedules and resource allocation of the integration effort; and overseeing the activities of various task specific groups and sub-groups. Figures 5 and 6 show the management structures employed.

QAPjP Group

The Quality Assurance Project Plan (QAPjP) group, which reports to the CERCLA Integration Committee is responsible for the development of a new site wide QAPjP. The QAPjP group has several sub-groups working on specific segments of the QAPjP development process. One sub-group has compiled a list of all sampling activities on site and prepared Data Quality Objectives (DQOs) for these activities. Another sub-group is writing the body of the QAPjP and the required appendices, and coordinating review by WEMCO, DOE, and the U.S. EPA. A third group is coordinating the development of U.S. EPA Contract Laboratory Program (CLP) equivalent radionuclide analysis protocols. The final sub-group is overseeing the implementation of a comprehensive environmental database to allow easy access to the analytical results by a wide range of users.

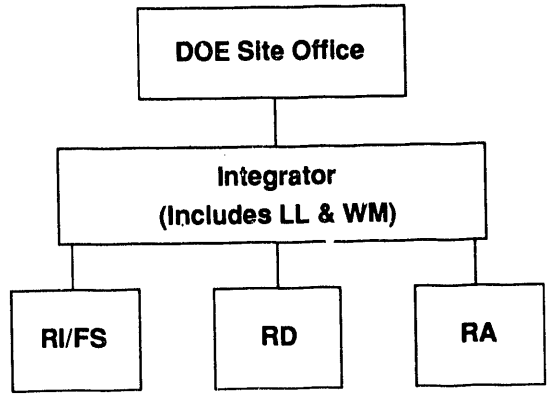


Fig. 5. Integration strategy organizational chart.

In the QAPjP planning stages, it was recognized that U.S. EPA participation early in the development process would facilitate approval of the final product. Accordingly, technical meetings with U.S. EPA Region V, DOE, and WEMCO have allowed the early identification of areas of contention, which may then be resolved prior to a formal submittal of the QAPjP.

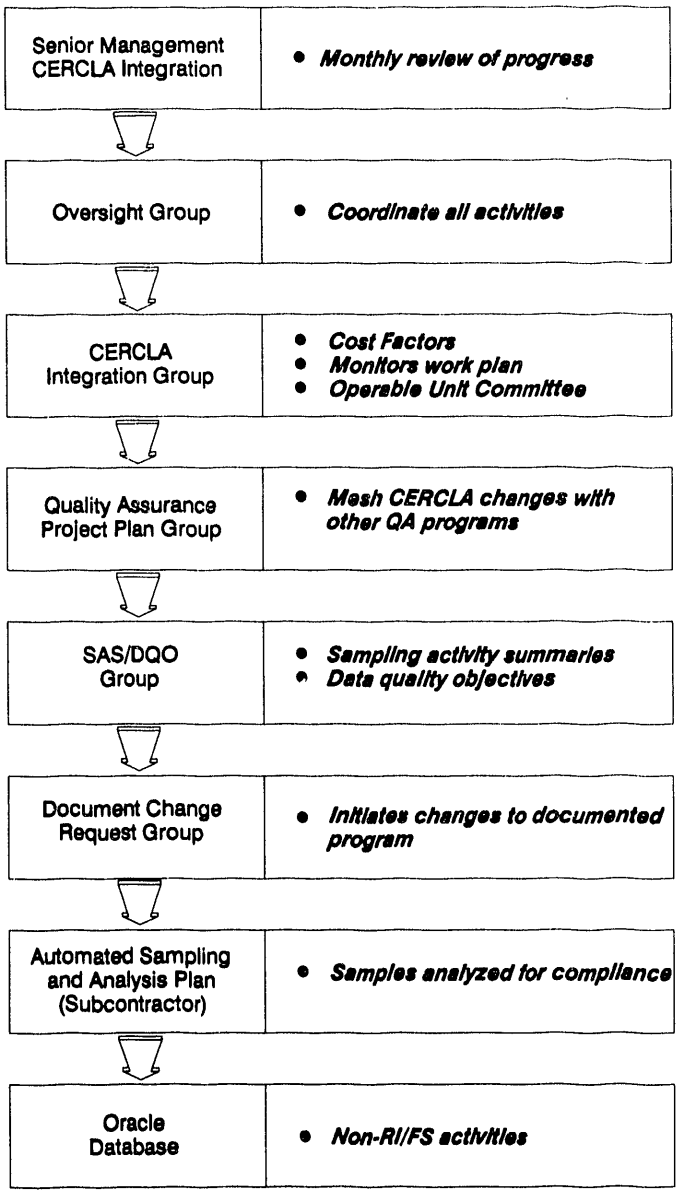


Fig. 6. Integration strategy subgroup organizational chart.

Underground Storage Tanks

One significant integration issue involves Underground Storage Tanks (USTs). Ten abandoned petroleum USTs were removed from seven excavations during the 1990 calendar year. The method of handling USTs involves the execution of the following activities to satisfy Ohio UST regulations and fully integrate CERCLA protocols and requirements: 1) characterize the accumulated water 2) dispose of the water based on characterization 3) excavate any contaminated soils 4) perform certification sampling 5) evaluate the sampling data and perform cleanup to Ohio State Fire Marshal standards 6) generate a report for the Administrative Record. The sites will be fully remediated for any CERCLA contamination under the ERA Project.

Removal Actions

The CERCLA Integration Committee proposed that all ongoing cleanup activities be conducted as removal actions under the terms of the CA. In order to minimize repetitious paperwork, it was additionally recommended that a relatively small number of broad removal actions be chartered enveloping essentially all ongoing site cleanup activities. A proposed categorization of these removal actions is presented in Table III.

Consistent with the CA, removal actions will have Work Plans prepared and submitted to the U.S. EPA and OEPA for review. For the ongoing cleanup activities, the documentation would primarily consist of procedures and plans which demonstrate compliance with applicable regulatory requirements. Review comments received from regulatory agencies would be appropriately addressed and a response issued. Consistent with the CA, final approval of the Work Plans would rest with DOE to the extent practical. The Removal Action Work Plans would be completed including the following:

- A reference to ongoing and near term planned activities, with a discussion of the need for transition planning.
- A description of parallel regulatory or CD requirements identifying the intent to integrate regulatory programs.
- A description of the proposed activities referencing existing procedures, DOE Orders, and plans which control these activities.

TABLE III

FEMP Generic Removal Actions

Safe Shutdown Removal Action

- Lock/Tag
- Purge Lines and Equipment
- Removal Gross Contamination
- Product Disposition

LLW/Sanitary/Hazardous/Scrap Waste Management

- Inventory Management
- Treatment
- Disposal

Mixed Waste/PCB/Co-Contaminated*/Mixed Scrap Waste Management

- Inventory Management
- Treatment
- Disposal

Thorium Management
Asbestos Management

- Inventory Management/Disposal
- Abatement Projects

Excavation/Demolition Activities

- Maintenance
- Construction

*Co-Contaminated waste is defined as Uranium contaminated PCBs

- A discussion of integration of the removal activities with the ongoing RI/FS and projected response actions including a description of investigations, analysis and documentation.
- Current schedules for accomplishing work activities and the mechanism for modifying these schedules.
- Reference to the site health and safety plan and an identification of the safety requirements which will be imposed.

RCRA Closures

The Hazardous Waste Management Review conducted as part of the CD and its proposed amendments identified additional (HWMUs). The HWMUs fall into two categories: a) those units which the FEMP will include in the Part B Permit Application; and b) those units which the FEMP will not seek to permit.

In addition to the ongoing RCRA activities, the FEMP is undergoing a RI/FS and various CERCLA response actions. In order to meet the Ohio Hazardous Waste requirements and to continue to progress on remediation activities, a Closure Plan Strategy is being developed. This plan will be submitted for review and concurrence by both the U.S. EPA and OEPA.

The FEMP will utilize the third option described in the "OEPA Closure Plan Review Guidance which involves risk assessment cleanups. The "Risk based or health based cleanups" are based on CERCLA guidance and all relevant hazardous constituents are expected to be in the risk assessment. For example, FEMP would need to include constituents of concern based on the hazardous waste activity rather than only radionuclides, which the State of Ohio does not regulate. In this, the FEMP would proactively be preparing schedules which reflect response activities and requesting extensions to meet CERCLA cleanup dates when the plan is submitted. The FEMP would not be submitting schedules which indicate the closure would be completed within 180 days, if that is not consistent with the proposed cleanup approach.

Site Wide Quality Assurance Project Plan

An important part of the CERCLA Integration process is the sitewide QAPjP preparation. A QAPjP defines the quality assurance requirements for all sampling and analysis activities performed on a Superfund site. The original RI/FS QAPjP covered narrow scope of activities to be performed only in direct support of the RI/FS process. Under the new philosophy that virtually all FEMP activities are either directly covered by CERCLA or by ARARs, the need for a unified QAPjP became apparent. Simply put, since almost any sample taken can potentially be used in the decision making process, the results must be legally and technically defensible, accurate, and comparable.

The quality assurance requirements for a given sample are based upon the anticipated end use of the data generated. DQOs are management tools developed to determine what quality and type of data is required, how the data is defensible, and how the level of risk is minimized. A DQO is prepared for each task, specifying such things as the analytes, instrumentation, sampling procedures, and quality control sample analysis requirements. The DQO assures that all samples are uniformly acquired and analyzed, resulting in data with an appropriate level of confidence and reproducibility.

Closely tied to DQOs are the concept of Data Quality Levels. Data Quality Levels are specified in the U.S. EPA CLP protocols. They range from level one (primarily field measurements) to level four (highly accurate laboratory procedures), with level five reserved for experimental or one time analysis procedures. Unfortunately, the CLP protocols were developed for a constituent list which did not include radioactive parameters. Any radioanalytical procedure performed under the standard CLP protocols is, therefore, a level five analysis and subject to burdensome requirements. An important part of the QAPjP preparation at the FEMP is the development of CLP equivalent protocols for radioanalytical procedures. The protocols will utilize levels A through E, which mirror the standard CLP levels with radioanalytes included. These protocols will streamline the sample analysis process, will serve as a model to many other DOE sites, and provide standard analytical methods for both radiometric and non-radiometric analysis.

CONCLUSION

In consideration of the overlapping and some conflicting regulatory requirements guiding FEMP activities, key site resources were focused upon developing an appropriate strategy. The purpose of this integration strategy was to establish a framework for the effective management of environmental programs while ensuring continued compliance with all existing statues, regulations, decrees, and agreements. The following fundamental objectives were established to provide the foundation for the integration strategy:

- Ensure compliance with the terms of the CA and CD
- Maintain consistency with applicable DOE Orders including required project management concepts for Major System Acquisitions (per DOE 4700.1)
- Ensure collated site data is fully consistent with the data quality objectives of the RI/FS
- Ensure changes to site existing conditions resulting from ongoing site operations are fully integrated into the RI/FS and Administrative Records
- Ensure Site Operations are conducted in a manner which is consistent to extent practical with the anticipated final Remedial Actions
- Minimum production of unnecessary or duplicative documentation
- Avoid application of unneeded constraints on cleanup progress and planning
- Ensure strategy can be effectively integrated into ongoing site cleanup operations without adversely impacting progress

To effectively achieve these objectives, a range of basic integration approaches included:

A. Business as Usual, including the conduct of discrete cleanup actions driven by separate regulatory requirements and/or agreements

B. Business as Usual, as defined as one coupled with the additional requirement that the discrete cleanup actions be evaluated individually for the need to be implemented as removal actions

C. Reconfigure existing site programs into broad-based categories of Removal Actions to be implemented under the terms of the CA

In consideration of a range of criteria including cost, implementability and regulatory and community acceptance, Alternative C is being pursued for implementation at the FEMP.

In conclusion, FEMP experiences have shown that the plethora of broad environmental regulations/statutes, DOE Orders and compliance agreements can be effectively integrated. This integration requires that the Environmental Management program be conceptualized and developed utilizing CERCLA as the foundation.

Finally, and most importantly, successful integration requires open and frequent communication among all participants.

DISCLAIMER

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SUCCESSFUL INTEGRATION OF THE CERCLA AND NEPA COMPLIANCE PROCESSES IN THE WELDON SPRING SITE REMEDIAL ACTION PROJECT: A CASE STUDY

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ABSTRACT

Special problems are posed for Department of Energy projects by the need to satisfy the environmental compliance documentation requirements of both the National Environmental Policy Act (NEPA) and the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA). For the Weldon Spring Site Remedial Action Project, a two-part process was employed for the production of CERCLA documents that would also satisfy NEPA. One partinvolved determination of the proper level of documentation and integrating the information requirements of both Acts. The second part involved managing the Headquarters review, approval and issuance activities. The first full application of this process was completed during 1990 for two interrelated actions; removal of the bulk waste from the Weldon Spring Quarry(an Operable Unit requiring a Remedial Investigation/Feasibility Study),and construction of a water treatment plant for the Weldon Spring ChemicalPlant (a non-time-critical removal requiring an Engineering Evaluation/Cost Analysis).

INTRODUCTION

The requirement that all Department of Energy (DOE) sites and projects comply with the National Environmental Policy Act (NEPA) is a well-established policy and compliance procedures have long been in place. A more recent, but equally important, requirement is the imposition of the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA). Within DOE, special problems are posed by the concomitant requirement to produce environmental compliance documentation that will satisfy the requirements of both CERCLA and NEPA without duplication of effort. For the Weldon Spring Site Remedial Action Project (WSSRAP), a two-part process was developed that took into account both the unique and overlapping requirements of the two Acts (especially as evidenced by their regulations), and the flow of activities involved in review, approval and issuance of the compliance documents.

The first full-scale application of this process was completed during 1990 through the compliance documentation that was produced for two distinct, but interrelated actions at the Weldon Spring Site. These actions are (1) the removal of a large volume of contaminated bulk wastes from the Weldon Spring Quarry, and (2) the construction of a comprehensive water treatment plant at the Weldon Spring Chemical Plant.

SITE BACKGROUND

The WSSRAP encompasses two non-contiguous properties situated about 4 miles apart along Highway 94 a few miles south of the community of Weldon Spring, Missouri (Fig. 1). One is an old 9-acre limestone quarry; the other is an abandoned 217-acre chemical plant. The quarry was placed on the NPL in 1987 and the chemical plant in 1989; for NPL/CERCLA compliance purposes, however, they are treated as a single site. The chemical plant area was originally the site of the Weldon Spring Ordnance Works, which was built by the U.S. Army in 1942 to produce explosives, and was shut down in 1946. The site was subsequently taken over by the Atomic Energy Commission (AEC) in 1955, which built the chemical plant for production of uranium and thorium. Those operations continued until the plant was shut down in 1966.

During the plant's operating periods, the quarry was used as a dump for various solid wastes (e.g., soils, building rubble, and equipment debris) generated at the chemical plant area. These bulk wastes total some 95,000 cubic yards that will have to be removed in order to allow final characterization (and ultimate remediation) of the quarry. Space limitations preclude storing or disposing of the bulk wastes in the vicinity of the quarry when they are removed, and it was determined that they should be hauled to the chemical plant area and held in an engineered temporary storage area (TSA) until a final site remediation decision is made.

At the chemical plant area, the key component of the wastes is an estimated 220,000 cubic yards of raffinates (sludges) from the AEC operations stored in four pits covering about 26 acres. These pits also impound an estimated 57,000,000 gallons of contaminated water. Before the sludges can be remediated, the capability is required to draw down, treat, and discharge the contaminated water. This requirement created the need for the chemical plant area water treatment plant (known simply as the site water treatment plant). The TSA will cover about 13 acres and will be equipped with a comprehensive leachate collection and runoff control system. Management of the water from this system will also require a reliable water treatment system; hence, the dependency relationship between the quarry bulk waste removal and the site water treatment plant.

COMPLIANCE DOCUMENTATION

Removal of the quarry bulk waste was planned as a Separate Operable Unit within the project that required full Remedial Investigation/Feasibility Study (RI/FS) documentation under CERCLA. The site water treatment plant was planned as a non-time-critical expedited response action. Therefore, the appropriate CERCLA compliance documentation was an Engineering Evaluation/Cost Analysis (EE/CA).

Preparation of the Feasibility Study and the EE/CA was the responsibility of the Environmental Assessment and Information Sciences Division of the Argonne National Laboratory (ANL). Since all are CERCLA documents it was necessary in their development to devote special attention to

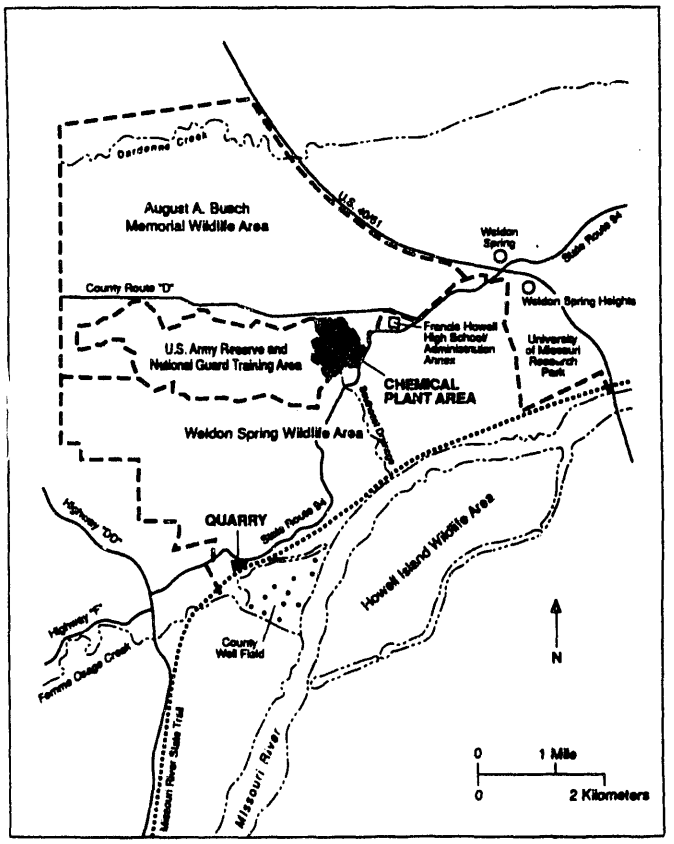


Fig. 1. Weldon Spring site and vicinty.

assuring that all NEPA requirements would be accommodated.

The two-part process of integration mentioned earlier actually consists of two distinct processes or functions that need to be performed in carrying out the integration of CERCLA and NEPA. One involves the "front-end" planning and subsequent execution of the mechanics of integrating the CERCLA and NEPA information requirements as the compliance documents are developed. The other involves the "back-end" management activities that are necessary to shepherd the completed documents through the Headquarters review and approval chain so that they can be formally issued. The front-end process is the responsibility of the field, i.e., the Project Office, while the back-end is the responsibility of the Headquarters Program Office.

While help is available to assist performance of the front-end process, in the form of NEPA and CERCLA regulations and guidance documents, there is no similar guidance for the actual integration of the information requirements. Thus, the integration mechanics had to be worked out on an ad hoc basis. No guidance exists at all for the back-end process, and historically it has been created anew for each integrated document.

Figures 2 and 3 illustrate the front-end process of integrating CERCLA and NEPA. Figure 2 indicates the process developed by ANL for determining the primacy of CERCLA or NEPA and for determining which type of documentation should be prepared. Figure 3 is a representation of the process of integrating CERCLA and NEPA according to information and evaluation requirements, once the decision had been made regarding the appropriate levels of documentation. (An additional requirement not shown by either of these illustrations is public participation, which is quite extensive at Weldon Spring.)

Both the quarry bulk waste removal and the site water treatment plant were conceived to be accomplished in ways that would produce little, if any, adverse environmental impact. Therefore, it was determined early in planning for the documentation process that the appropriate level of NEPA documentation would be the Environmental Assessment (EA). It was also decided that because of the dependency relationship between the two actions, the CERCLA documents for both actions should ultimately be packaged together to serve as the functional equivalent of an EA.

Although the process of managing the document review and approval activities must necessarily follow behind the front-end process, there is one important point where they meet prior to completion of the front-end process. That point is the informal review of the documents by the cognizant Headquarters elements, especially those in the Office of Environment, Safety and Health (EH). The importance of this point will be indicated later.

Creating CERCLA documents that will satisfy the NEPA is not overly difficult, if careful consideration is given to the information requirements of the regulations under the two Acts in planning and executing the documentation process. In both a Feasibility Study and an EE/CA, for example, thorough evaluation of proposed alternatives against CERCLA's nine criteria will essentially guarantee that NEPA's technical evaluation requirements are satisfied.

Since interim actions were being planned in this case, it was also necessary to make clear that two key NEPA requirements regarding interim actions were satisfied. These are that the actions (1) would not prejudice the decision for ultimate remediation of the site and (2) would not limit the choice of reasonable alternatives for that final remediation. All of these requirements were more than adequately met in the CERCLA documents produced by ANL.

The overall plan for issuance of the final compliance documents for the Weldon Spring quarry bulk waste removal and the site water treatment plant had established a schedule for full completion, including all necessary approvals, by September 30, 1990.

The task of bringing the CERCLA compliance documents together on a timely basis for adoption as an EA was confronted early by a scheduling problem. The Remedial Investigation/Feasibility Study (RI/FS) process for the quarry bulk waste removal was begun much earlier than the site water treatment plant EE/CA. The RI report was completed in late 1989, the FS was released for public comment in early March 1990, and the public meeting on the FS was held on March 29, 1990. At that time, the first draft of the site water treatment plant EE/CA had not yet been completed. Thus, the RI/FS process was nearing completion while the EE/CA documentation process was just beginning, a fact that did not bode well for the planned overall schedule.

In May 1990, the draft EE/CA was submitted for Headquarters review. The Project Office stressed that this was to be an informal review and indicated that it hoped to achieve some schedule compression by having this review completed and all comments incorporated in a final draft in time to release the document to the public in July 1990. In early July, the final draft was submitted to the Program Office and all

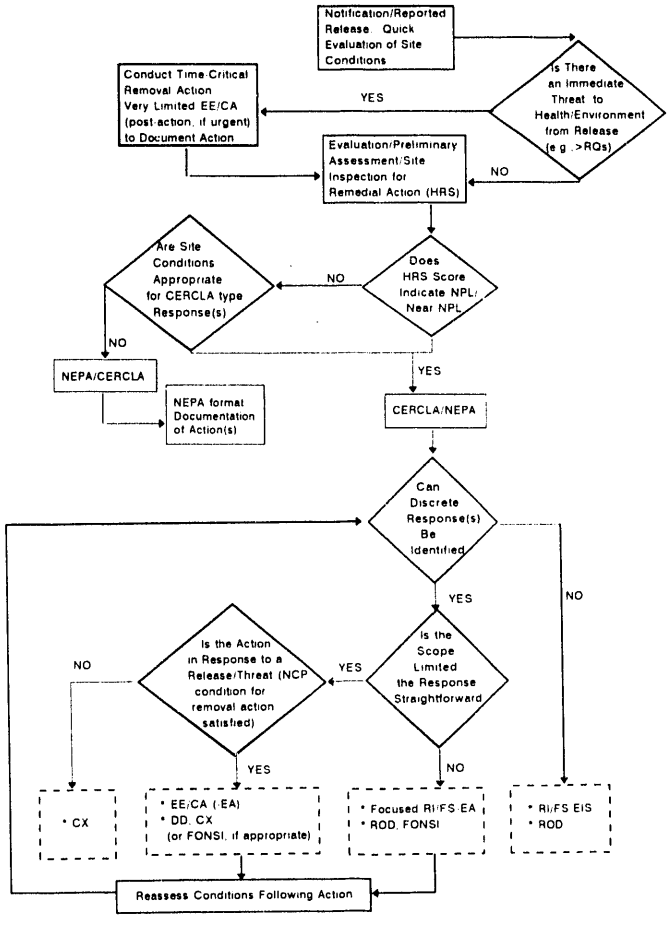


Fig. 2. Proposed strategy for compliance with NEPA & CERCLA at DOE remedial action sites.

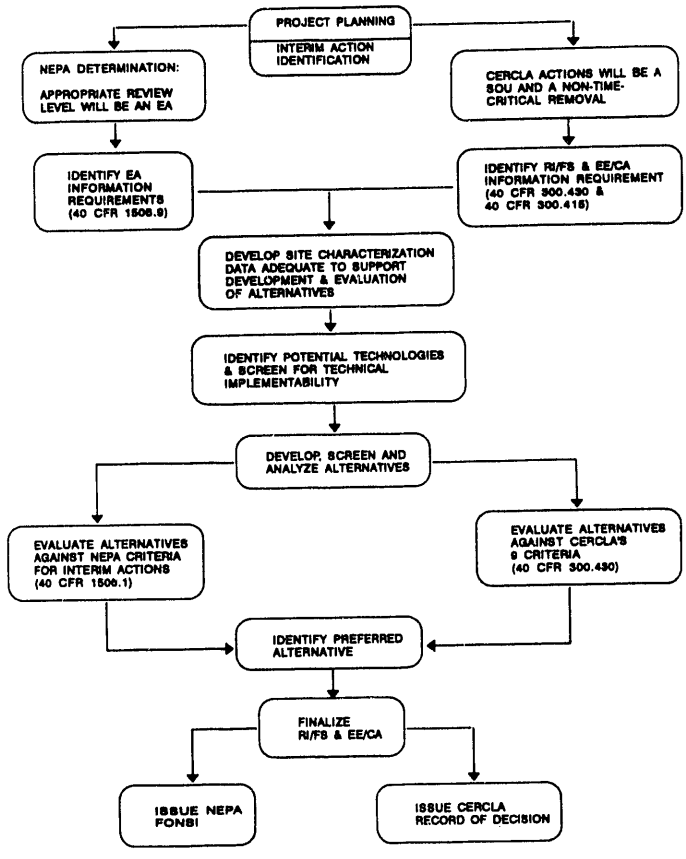


Fig. 3. Integration of CERCLA/NEPA documentation

Headquarters reviewers were requested informally to focus on the major issues in the document so that they could provide a key-item type of review within a short period. This kind of request could be accommodated because the individuals involved had all reviewed the document earlier and the Project Office gave assurance that all their comments had been incorporated, and that no other significant changes had been made. This procedure worked very well and the Project Office was able to release the EE/CA to the public on July 29, 1990. A public hearing was held on August 16, 1990.

The back-end management process consisted of the following key sequential activities under the direction of the Headquarters Program Manager.

- Activity 1 - Obtaining informal review of draft documents by the involved parties at Headquarters (e.g., Program Office, EH, Office of the General Counsel).
- Activity 2 - Obtaining quick-turnaround review of final draft documents by all involved HQ parties, to expedite release for public review.
- Activity 3 - Development of a detailed day-by-day schedule for moving the documents through the final concurrence and approval channels.
- Activity 4 - Obtaining agreement among the key Headquarters staff coordinators to work to the detailed schedule.

For the Weldon Spring documents, it was decided early-on that all cognizant Headquarters offices (i.e., Program Office and the CERCLA and NEPA staffs in EH) would be requested to provide informal review (Activity 1). This approach provided two benefits; it provided informal comments back to the field, and it substantially increased the reviewers' familiarity with the project and with the documentation. The approach worked to the project's definite advantage when the final draft of the site water treatment plant EE/CA was submitted for review prior to release for public review.

In that instance, the Project Office was able to assure the reviewers that their comments had been incorporated and that no other significant changes had been made in the document. The result was that the review turnaround time was reduced to one week (Activity 2). This substantially helped to compress the overall schedule in the moving toward the EA. Had that review taken the usual 45-60 days, the public review period would probably have extended well into October 1990, and the EA would likely have been delayed into early 1991.

The ability to expedite the site water treatment plant EE/CA schedule meant that achieving the goal of completing the entire document review and approval process by September 30, 1990, was still a possibility. This led to a focus on the next final documentation hurdle, that of obtaining concurrence and approval of the CERCLA Record of Decision (ROD) to follow the RI/FS for the quarry bulk waste removal.

While the Project Office was completing the ROD and the Decision Summary, the Program Office developed a proposed detailed schedule (Activity 3) for obtaining the necessary concurrences (EH and General Counsel). This schedule was created by holding discussions with the cognizant staff coordinators in the concerned organizations to learn what their organizations' internal procedures would be when the documents arrived there from the Program Office, and how

long those procedures would take to complete, given that the staff coordinators could provide expeditious handling. This approach to detailed schedule development assured that all key parties were solicited for input and that no schedule dates were included that the affected parties did not feel could be accommodated (Activity 4). Figure 4 shows the resultant schedule for the ROD. While not all of those dates were met, most completions were close to the target dates and, in the end, the EPA signed the ROD on September 28, 1990.

At that time, however, the complete set of documents for the quarry bulk waste removal and the site water treatment plant had not yet been adopted as an EA. Issuance of the CERCLA ROD was not impacted however, because its issuance had to be delayed for other reasons. In the ensuing six weeks, EH completed its final review of the documents, and adopted them as an EA and issued a Finding of No Significant Impact on November 15, 1990. (The set of documents consists of the quarry bulk waste removal RI, Baseline Risk Evaluation, FS, Responsiveness Summary for the FS, and Proposed Plan, along with the site water treatment plant EE/CA.) This completed the NEPA compliance portion of the documentation process. Thus, in a total CERCLA/NEPA documentation schedule that covered approximately two years, and end-date slippage of six weeks must be considered to be reasonable and acceptable performance. Some highly-focused management actions were required, however, to preclude any major slippage.

CONCLUSIONS

The key to the success of the review and approval process for the Weldon Spring quarry bulk waste removal and the site water treatment plant was in the cooperation between the Project Office and the Program Office. While it cannot be said that the path was always smooth and straight-forward, at this point both organizations have strong appreciation for what needs to be done to make the process work. This should be of great benefit as future requirements occur to integrate CERCLA and NEPA in environmental compliance documents.

RECOMMENDATIONS

Front-End Integration (By the Field)

- Ensure that CERCLA document preparers understand the NEPA requirements as well as CERCLA requirements (as the ANL-produced documents demonstrate).
- Conduct field reviews to assure that the finished documents do, in fact, cover the CERCLA and NEPA requirements before the documents are submitted to Headquarters.
- Assure that the introduction to the documents, especially the Feasibility Studies and EE/CAs, states clearly that they are intended to satisfy both CERCLA and NEPA.

Back-End Integration (By the Program Office)

- Assure that all reviewers are informed of the nature of the review (formal or informal) they are being asked to perform.
- Establish detailed review and approval schedules as necessary to enhance overall schedule performance.
- Work with staff in other Headquarters organizations in developing schedule input and to assure understanding of the detailed schedules.

Project and Program Offices

- Develop close working relationships so that misunderstanding will be minimized and compliance document review schedules can be accomplished as planned.

DATE	KEY ACTIVITY/EVENT
8/16/90	Public Meeting for the Site Water Treatment Plant EE/CA.
8/17/90	Draft FONSI informal review period ends.
8/23/90	EM-423 receives Final ROD for review and concurrence from site (copies forwarded to EH-23 and EH-25).
8/27/90	Public comment period for EE/CA ends.
9/07/90	EM-40 sends final ROD to EM-1/EH-20/GC-11 for concurrence to submit document to EPA for signature.
9/12/90	EM-1 submits requests to EH-1 to adopt the RI/FS and EE/CA as an EA and issue FONSI.
9/21/90	EH-1 adopts RI/FS and EE/CA as an EA and issues FONSI.
9/21/90	EH-20 and GC-11 concur with EM-40 decision on ROD and EM-40 submits package to EM-1 for transmittal to ORO.
9/24/90	EM-1 concurs and sends ROD to ORO Manager for transmittal to EPA Region VII with memorandum authorizing signature if EPA sign ROD without changes.
9/24/90	ORO Manager forwards ROD to EPA Region VII for signature.
9/26/90	EPA Region VII signs ROD and returns document to ORO Manager.
9/28/90	ORO Manager signs and issues ROD (assuming no changes by EPA).

Fig. 4. Detailed schedule for review, concurrence and approval of Weldon Spring site quarry bulk wastes remedial investigation/feasibility study (RI/FS) and record of decision (ROD), site water treatment plant engineering evaluation/cost analysis (EE/CA), and finding of no significant impact (FONSI).

CERCLA DOCUMENT FLOW: COMPRESSING THE SCHEDULE, SAVING COSTS, AND EXPEDITING REVIEW AT THE SAVANNAH RIVER SITE

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ABSTRACT

The purpose of this paper is to convey the logic of the CERCLA document flow including Work Plans, Characterization Studies, Risk Assessments, Remedial Investigations, Feasibility Studies, proposed plans, and Records of Decision. The intent is to show how schedules at the Savannah River Site are being formulated to accomplish work using an observational approach where carefully planned tasks can be initiated early and carried out in parallel.

This paper will share specific proactive experience in working with the EPA to expedite projects, begin removal actions, take interim actions, speed document flow, and eliminate unnecessary documents from the review cycle.

INTRODUCTION

The Savannah River Site (SRS) has 120 projects currently in the RCRA/CERCLA process. Scores of other sites are being evaluated for inclusion as Remedial Investigation projects. Compressing schedules and expediting document review have tremendous significance in terms of project time and money saving potential.

Current waste site investigations at the SRS include seepage basins, rubble pits and piles, waste tanks, and disposal sites for radioactive, hazardous, and solid wastes. Other defense nuclear sites in the Department of Energy (DOE) complex have similar remediation projects. It is hoped that sharing SRS site schedule and cost initiatives with others will be beneficial to representatives from other sites. Feedback will be useful to SRS.

This paper will represent conclusions on ways to connect CERCLA documents, plan concurrent work, and interact proactively with regulators to accomplish work toward Records of Decisions in an efficient and effective manner.

PRIMARY DOCUMENTS

The first documents written in the CERCLA Program are the workplans for individual sites, which must be approved by regulators before characterization work can begin. Risk assessments follow characterization and workplans, and the summary document is called the Remedial Investigation. Cleanup alternatives and early conceptual design work are documented in the Feasibility Study.

PRESENT SCHEDULE AND COST EFFICIENCIES

The Westinghouse Savannah River Company Environmental Restoration Assessments Program is pleased to have realized a cost savings of $2.5 million in subcontract assessment costs in Fiscal Year 1991. In addition, thousands of hours of document review time have also been saved. This effort has been made possible through a proactive relationship with the U.S. EPA as well as with DOE in expediting projects and streamlining documents in the review cycle. Monthly meetings with regulators conducted with a planned agenda have been key to generating decisions.

Specifically, a total of 23 workplans were written and submitted for regulatory review in 1991. Workplans document the necessary characterization activities required to investigate individual waste sites and define problems in those areas. Originally, EPA had prescribed phase 1 and phase 2 workplans for each site in the program. Similarly, EPA asked for both a preliminary risk assessment and a baseline risk assessment for each waste unit. This would have resulted in a total of 92 documents plus revisions due to the EPA over the next two years.

WSRC took the initiative and worked with DOE and EPA to produce a more efficient pathway resulting in 40 fewer documents and 40 fewer revisions. Double-phase workplans were eliminated at 20 to 23 waste units scheduled in 1991. Single-phase workplans were judged to be sound technically and thus met EPA standards. Each workplan plus its revision costs about $75,000. With 20 sites now qualifying for single-phase workplans, this was an FY'91 cost savings of $1.5 million.

Further initiatives with EPA resulted in agreement for SRS to eliminate double-phase risk assessments at 20 to 23 waste units. As a result, key preliminary data will now be placed in the baseline risk assessment for each of the 20 units. Ten preliminary documents would have been due in FY'91. Since each risk assessment document costs about $100,000, the cost savings represented on these documents is at least $1.0 million.

FUTURE DOCUMENT FLOW

Baseline Risk Assessments work can begin as soon as the first wave of characterization data is generated. Feasibility Study work can begin during the Risk Assessment Phase. Early identification of alternatives is advisable and will be pursued as soon as site characterization data becomes available. A Risk Evaluation of Remedial Alternatives will be compiled as a companion document parallel to the Feasibility Study. The preferred alternative decision will be reached with input from the Risk Assessment.

Early conceptual design work will be completed in the Feasibility Study Phase. Final design work will not commence until the Proposed Plans have been accepted in a record of Decision. Public acceptance must be reached before significant design work can begin.

FUTURE SCHEDULE & COST EFFICIENCIES

The observational approach of conducting blocks of work in parallel should be pursued and is reflected in the SRS

CERCLA document flow. However, the key to document flow is return flow from regulatory agencies. Because the Federal Facilities Agreement between DOE and the states is still pending, the Savannah River Site initiated an advance in funding to the regulators in South Carolina to cover document review costs in the CERCLA Program. Regulatory agencies must adhere to negotiated review times in order for programs to be successful.

Three other very important concepts should be discussed which are relevant to CERCLA schedules. The first concept is the interim action, an activity which represents a window of opportunity to begin early cleanup work. These actions are advisable since they can be performed in the assessment phase of cleanup projects. Currently, the Savannah River Site is proposing several interim actions at sites where oil drums or tanks have been buried.

A second concept to cutting schedule time and conserving costs is combining sites when possible for documentation purposes. A good example of this at SRS is a recent agreement to combine four sites into one called the Burial Ground Complex. This combined meshing now satisfies RCRA, CERCLA, and State Settlement Agreement requirements.

It should be realized that waste sites, whether they be managed separately or in combinations, may yield an interim Record of Decision when cleanup plans are finalized. A final Record of Decision amy not be granted until all groundwater plans are agreed upon in an area. At the time a final ROD would be issued for the entire Corrective Action Management Unit.

A third concept in CERCLA scheduling is the option of No Further Action (NFA). At large facilities where many small waste sites are examined, a significant number of sites will need no further action. Enough may be known about these sites to allow minor cleanup to begin immediately. This could result in an early Record of Decision. SRS has several such sites on expedited schedules where the NFA option is being pursued. All sites should not require the length of time for assessment that complex sites require.

CONCLUSION

In sum, schedule compression and cost saving may be realized a number of ways in the CERCLA Program. Single phased workplans and risk assessments are one way to get efficiency. Scheduling primary documents in a parallel fashion where possible requires coordination but is also advisable. Performing interim actions, combining sites into larger units, pursuing No Further Action alternatives, as well as expediting small site schedules are all additional ways to move to cleanup faster with less cost.

At SRS, the ER Program estimates with confidence that $2.5 million in CERCLA assessment costs were saved in FY'91. In addition, thousands of hours of personnel review time have been saved through document efficiency. Engineers and geologists have been able to move ahead with additional site characterization planning and scheduling needed in the early stages of this program. Other regulatory work has been expedited to satisfy EPA. The value of this savings in regulatory and managerial review time is surely in the millions of dollars. The future saving of such program efficiency will continue to be realized significantly in FY'92 and FY'93.

TAKING INTERIM ACTIONS: INTEGRATING CERCLA AND NEPA TO MOVE AHEAD WITH SITE CLEANUP

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ABSTRACT

The cleanup of contaminated sites can be expedited by using interim response actions in accordance with the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), as amended, and the National Oil and Hazardous Substances Pollution Contingency Plan (NCP). In fact, a major portion of some Superfund sites can be cleaned up using interim actions. For CERCLA sites being remediated by the U.S. Department of Energy (DOE), such actions must also comply with the National Environmental Policy Act (NEPA) because the DOE has established a policy for integrating CERCLA and NEPA requirements. A strategy for the integrated documentation and implementation of interim actions has been applied successfully at the Weldon Spring site, and major cleanup projects are currently underway. This paper discusses some of the issues associated with integrating CERCLA and NEPA for interim actions and summarizes those actions that have been identified for the Weldon Spring site.

INTRODUCTION

The cleanup of contaminated sites can be expedited by using interim response actions. These actions include both (1) removal actions that are conducted to respond to a release or a threat thereof, such as a leaking pit; and (2) interim or focused remedial actions that are conducted to address a separate operable unit of the site, such as a discrete source area or a specific environmental medium such as surface water or groundwater.

A major portion of some Superfund sites can be cleaned up entirely as removal actions, e.g., sites remediated by the U.S. Environmental Protection Agency (EPA) at which actions are taken solely in accordance with CERCLA and the NCP. For facilities being remediated by DOE, interim actions must also comply with NEPA, including the implementing regulations provided by the Council on Environmental Quality (CEQ). Hence, certain limitations must be addressed before interim actions can be selected to expedite cleanup at DOE Superfund sites under the integrated CERCLA/NEPA process.

SITE BACKGROUND AND INTERIM ACTION PROGRAM

The Weldon Spring site is located about 48 km (30 mi) west of St. Louis, Missouri, and consists of two noncontiguous areas: an 88-ha (217-acre) chemical plant area and a 3.6-ha (9-acre) limestone quarry. Both areas are radioactively and chemically contaminated as a result of past processing and disposal activities; the site has been inactive for more than 20 years. The chemical plant area contains about 40 buildings, several surface water impoundments (including four waste pits), and two former dump areas. The quarry was used to dispose of a variety of solid material such as process waste, building rubble, and equipment; surface water has ponded at the base of the quarry. The EPA listed the quarry on its National Priorities List in 1987, and the chemical plant was added to the listing in 1989.

An interim-action program has been successfully applied at the Weldon Spring site. That is, several compliance decisions have already been made in concert with the regional EPA office and the state of Missouri, and action is currently underway for a number of significant cleanup measures. In the meantime, preparation of the major compliance documentation that addresses the overall disposition of contaminated material from the site is continuing. This documentation consists of a CERCLA remedial investigation/feasibility study (RI/FS) integrated with an environmental impact statement (EIS) under NEPA, resulting in a hybrid RI/FS-EIS.

To scope the interim actions, the Weldon Spring site was evaluated for current and potential releases and for separately manageable problems. In this manner, a number of removal actions were identified in accordance with the CERCLA conditions listed in the NCP. These interim response actions have been targeted to help stabilize the site by addressing potential health and safety threats. The actions were also tailored to support the comprehensive cleanup effort for the site. A phased cleanup strategy that includes specific operable units and interim actions was presented in the work plan for the project.

The removal actions that have already been implemented to reduce health and safety threats to on-site personnel and/or to respond to off-site contaminant releases at the chemical plant area include the following:

- Inactive power lines and poles that were falling to the ground -- posing health and safety threats on-site -- have been taken down. Uncontaminated material has been released off-site for reuse, and contaminated material has been placed in temporary storage

on-site pending upcoming disposal decisions for the project.

- Overhead external piping that was insulated with deteriorating asbestos coverings -- posing potential threats on-site and representing a potential source for off-site releases -- has been taken down. The asbestos coverings have been removed and all material has been surveyed and classified. Uncontaminated material was disposed of off-site (including most of the piping), and contaminated material was placed in controlled storage on-site.
- Old electrical equipment on-site containing polychlorinated biphenyls (PCBs) -- representing a source of potential release and subsequent health threats -- has been removed. The PCBs have been flushed from the equipment, and both the fluids and the containers have been transported off-site to a licensed treatment and disposal facility.
- Chemicals in drums, tanks, cylinders, bottles, and other containers that were scattered among the buildings and in certain outside areas -- posing a potential health threat on-site and representing a potential source for off-site releases -- have been containerized and consolidated within an empty nonprocess building that was converted for waste storage on-site.
- A small amount of radioactively contaminated soil at a vicinity property -- which could have posed a potential health threat off-site because of planned use of the area -- has been excavated, drummed, and placed in controlled storage on-site.
- Surface runoff around a contaminated dump area -- which represented a source of contaminant release off-site (notably uranium) -- has been diverted from the area by constructing a dike and diversion system.
- A number of the deteriorating chemical plant buildings -- which posed a health and safety threat on-site -- have been decontaminated and dismantled, and the material has been placed in temporary storage on-site. The remaining structures -- which include the highly contaminated process buildings, are targeted for decontamination and dismantlement in the near term; the compliance process for this follow-on action is almost complete (i.e., the evaluation and community participation phases have been completed, but the compliance closeout under NEPA is still in the final stages).

Additional removal actions that have been documented and are in various stages of design and implementation include the following:

- A water treatment plant is being constructed at the quarry to treat water removed from the quarry pond -- which represents a source of contaminant release that is threatening a nearby drinking water supply via contaminant migration to groundwater.
- A water treatment plant is being constructed at the chemical plant area to treat water removed from the various impoundments -- which represents a source of contaminant release and exposure; this plant will also provide the capacity for treating additional water that may be generated by other response actions at the site (e.g., water collected from decontamination facilities and storage areas).

In addition, an interim remedial action was identified in accordance with the CERCLA process. This action involves removing solid waste from the quarry for consolidation with the remainder of site material at the chemical plant area. This waste represents a source of contaminant release into air (radon) and also into groundwater (both radiological and nonradiological contaminants). The migration to groundwater potentially threatens the nearby drinking water supply. As for other interim actions, the waste resulting from each of these actions is to be stored on-site pending the disposal decision for the project. These decisions will be determined from the RI/FS-EIS that is currently in preparation and will be documented in the subsequent record of decision (ROD).

ISSUES

Many issues were raised and resolved during the planning and documentation of interim actions for the project, including (1) CERCLA justification and NEPA constraints, (2) CERCLA schedule and cost limitations, (3) integration with other site activities, (4) compliance documentation and closeout, (5) cumulative impacts, (6) applicable or relevant and appropriate requirements (ARARs), and (7) community involvement. These issues are addressed individually below.

Compliance with Procedural CERCLA and NEPA Requirements

Eight factors to be considered in determining the appropriateness of a removal action under CERCLA are listed in the NCP (see 40 *Code of Federal Regulations [CFR]* 300.415). These factors address a variety of conditions that may be common at DOE Superfund sites. For example, they include (1) the actual or potential exposure of humans or biota; (2) actual or potential contamination of drinking water supplies; and (3) the presence of contaminated material in drums, tanks, or other bulk storage containers that may pose a threat of release. In addition, the "other" category -- which is the eighth factor listed and addresses "other situations or factors that may pose threats to public health or welfare or the environment" -- may be appropriate to a wide variety of problems at a specific site.

The CEQ regulations given in 40 CFR 1506.1 identify conditions under which interim actions would be limited for DOE Superfund sites. For example, when an EIS is in progress and the interim action is not covered by an existing EIS, no action can be taken that may significantly affect the quality of the human environment unless it is independently justified and would not prejudice the ultimate project decision; adequate environmental documentation must also be prepared. Because an RI/FS-EIS is currently in progress for the Weldon Spring project, these conditions apply to interim response actions at the site. For the quarry bulk waste action, this constraint focused the selection of alternatives. No disposal decisions have been made for material generated by the interim actions that would prejudice the ultimate project decision. That is, the material is generally to be placed in controlled storage on-site pending the disposal decisions that will made using information from the analyses in the RI/FS-EIS; these decisions will be presented in the ROD.

Schedule and Cost Constraints

Removal actions should comply with the schedule and cost limits identified in the NCP -- i.e., one year and $2 million -- unless one of the waiver conditions given in the NCP applies. These conditions are (1) the action is required on an emergency basis or (2) a continued response is otherwise appropriate and consistent with the remedial action for the site. Although these schedule and cost limits are identified for Superfund-financed actions, DOE also considers them in evaluating departmentally funded actions. In fact, several of the removal actions proposed for the Weldon Spring site exceed these limits (e.g., the water treatment and building decontamination and dismantlement actions). However, the actions were deemed appropriate because they met the second of the two waiver conditions identified in the NCP.

Integration with Other Site Activities

The sequencing and physical integration of interim actions can be a problem when the activities are interrelated and the site area is limited, as is the case at the Weldon Spring site. For example, to support the quarry bulk waste action, (1) a water treatment plant had to be available at the quarry; (2) a storage area and water treatment plant had to be available at the chemical plant area (to treat water collected at the storage area); and (3) several buildings and other structures had to be removed to build the storage area and treatment plant, so a staging area was also needed for the structural debris. The timing and content of appropriate documentation and decisions under both NEPA and CERCLA had to be carefully planned for each of these separate but interrelated activities in order to move forward with specific cleanup activities.

Documentation Process

The basic compliance document prepared for a DOE removal action is the CERCLA engineering evaluation/cost analysis (EE/CA) report, supplemented to meet the requirements of NEPA. For the more significant removal actions at the site, such as the water treatment and building dismantlement actions, this has been at the level of an environmental assessment (EA). Interim remedial actions are documented in an RI/FS under CERCLA, also supplemented to meet NEPA requirements. For the quarry bulk waste action, a focused RI/FS was prepared for which the NEPA analysis was at an EA level.

The determinations for compliance closeout are typically documented separately. For a removal action, a removal action decision document is prepared under CERCLA and a finding of no significant impact (FONSI) is prepared under NEPA. In many cases, a categorical exclusion rather than a FONSI may be appropriate; this should be determined by reviewing the types of activities that have been proposed for consideration as categorical exclusions by DOE Headquarters. (Certain of the early removal actions at the chemical plant area were conducted prior to SEN-15, and the memorandum-to-file was used as the NEPA decision document.) For interim remedial actions, the CERCLA decision document is a ROD and the NEPA decision document is that appropriate for the scope of the action. The CERCLA and NEPA closeout documents for the interim remedial action at the quarry were a ROD (essentially an interim ROD) and a FONSI, respectively.

As indicated in the discussion of the previous issue, certain actions depended on the components of others. This interrelationship was factored into the compliance closeout process. The on-site water treatment plant was considered integral to the quarry bulk waste action because the potential impacts associated with this action depended on the availability of treatment capacity for water collected from the temporary storage area and from the truck decontamination facility. Hence, the related EE/CA documentation was included with the RI/FS-EA in a "combined EA package" for which a single FONSI determination was made. The closeout documents for these separate removal actions under CERCLA remained separate, for inclusion in the administrative record files for each action. Similarly, EE/CA documents that were prepared to address different chemical plant structures were grouped into a combined EA package to support a second FONSI determination, while the CERCLA decision documents for each activity package remained separate.

Cumulative Impacts

Cumulative impacts are considered so the sum of impacts associated with various individual actions does not result in an unacceptable threat to human health or the environment. The potential cumulative impacts associated with the project's interim actions were presented in the compliance documents for each, rolling forward as appropriate as the actions were developed to consider all reasonable overlaps. For example, health effects associated with the surface discharges from each of the water treatment plants were combined for potential downstream users, and environmental impacts of construction activities for the treatment and storage facilities were combined to evaluate effects on nonhuman resources. In this manner, overall impacts can be maintained within acceptable levels as site cleanup progresses.

ARARs

The ARAR process can be extremely time-consuming, and a project can benefit a great deal by addressing potentially controversial regulatory requirements early in the compliance process. Although the interim-remedy waiver condition for ARAR attainment given in the NCP does apply to such actions, an attempt must be made to meet pertinent requirements to the maximum extent practicable, in accordance with the NCP.

Considerable progress was made on the project's ARAR development process by emphasizing this issue as part of the interim actions. An understanding has been reached with both the state and the regional EPA office on a variety of requirements for the project, including water quality limits for off-site surface water releases and the determination of specific waivers for the action period, e.g., the state limit for radon (relative to the quarry bulk waste action) and federal time limits for storing certain chemically contaminated material (relative to storage activities at the chemical plant area).

Community Involvement

An aggressive community involvement strategy can influence the success of an interim action program. Examples of how this strategy has been applied at the Weldon Spring project include (1) meeting with local interest groups prior to full release of the plan, in order to receive early input; (2) notifying the press with more than the newspaper notices

required for such actions, e.g., by being accessible for briefings; (3) preparing "progress report" inserts for distribution to local newspapers; (4) holding public meetings for potentially sensitive removal actions, even though this is not required; and (5) providing the opportunity for follow-up meetings with interested individuals or groups, in order to assure the continuity of effort and responsibility for the planned activity.

CONCLUSIONS

The application of an integrated interim-action program can have multiple benefits for a site. The obvious benefit is that discrete cleanup activities can begin in the field in a very timely manner, i.e., without being delayed by the schedule for comprehensive project decisions. These decisions typically address difficult issues such as the location for waste disposal and the levels of specific cleanup criteria, and they often involve policy issues that take some time to resolve.

In addition, preparing the compliance documents for interim actions affords the chance to address issues ranging from presentation and format to ARARs and regular interagency coordination; facing these issues early can greatly facilitate the subsequent compliance process for major site decisions. Finally, an interim-action program demonstrates to the public the project's commitment to move forward with cleanup, and it can improve relationships considerably. Many of the lessons learned during the development and implementation of interim actions at the Weldon Spring site may help other DOE facilities move more smoothly through the interim-action process to facilitate site cleanup.

ACKNOWLEDGMENTS

Work supported by the U.S. Department of Energy, Office of Environmental Restoration and Waste Management, under contract W-31-109-Eng-38.

AN OVERVIEW OF PUBLIC HEALTH SERVICE HEALTH-RELATED ACTIVITIES AS THEY RELATE TO THE DEPARTMENT OF ENERGY'S ENVIRONMENTAL RESTORATION PROGRAM

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ABSTRACT

The Agency for Toxic Substances and Disease Registry (ATSDR) was created by the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA) as an agency of the Public Health Service. Under the Superfund Amendments and Reauthorization Act of 1986 (SARA; CERCLA as amended), the public health responsibilities of ATSDR were greatly expanded. Among the responsibilities are (1) preparing health assessments for each site proposed for or listed on the National Priorities List (NPL) established by the U.S. Environmental Protection Agency; (2) conducting epidemiologic and other health studies around NPL sites; (3) establishing registries of exposed individuals; (4) establishing health surveillance programs; (5) developing toxicological profiles for hazardous substances; (6) performing health and emergency response consultations; and (7) performing other health-related activities (e.g., health education).

In October 1990, ATSDR signed a memorandum of understanding (MOU) with the Department of Energy (DOE) headquarters requiring that DOE operations offices sign interagency agreements (IAGs) with ATSDR for its conduct of 104(i) health activities at DOE sites. These activities include health assessments, related health studies such as surveillance programs, epidemiologic studies, and registries of exposed persons, and toxicological profiles of hazardous substances unique to DOE sites. ATSDR's studies will focus more on an assessment of the health risk to human populations residing in and around DOE sites than on an evaluation of the health risk to workers on site. Nevertheless, CERCLA, the MOU, and site-specific IAGs authorize ATSDR's access to health and environmental data concerning each site. The IAGs contemplate that ATSDR work closely with DOE operations offices in their implementation of their respective environmental restoration programs.

In addition to the agreements ATSDR has with DOE and its operations offices, the U.S. Department of Health and Human Services (HHS) last December signed an MOU with DOE for the management and conduct of energy-related analytic epidemiologic studies by HHS. The Centers for Disease Control (CDC), which maintains close ties to ATSDR, has been designated as the agency within HHS to implement this MOU. It derives its authority to manage and conduct health studies from the Public Health Service Act and the Occupational Safety and Health Act of 1970. Thus, two separate but closely allied agencies within the Public Health Service will be involved and share responsibilities with DOE in the health-related issues of its environmental restoration program.

In this paper, we will provide a brief overview of ATSDR's 104(i) activities and CDC's role at DOE sites, followed by a discussion of how these activities will impact DOE's environmental restoration program.

INTRODUCTION

As public awareness has grown over the last decade regarding the need to clean up abandoned hazardous waste sites, attention has gradually shifted to a concern about the health risks posed by both active and inactive facilities or sites owned or operated by federal agencies, including the nuclear weapons complex of the U.S. Department of Energy (DOE). The U.S. Department of Health and Human Services (HHS), and by law and delegation, the Agency for Toxic Substances and Disease Registry (ATSDR) and the Centers for Disease Control (CDC), have a significant role in assisting the public in understanding health risks at DOE sites. We begin with an introduction of ATSDR and its activities and accomplishments, and then discuss ATSDR's and CDC's relationship to DOE. We conclude with an analysis of the impact of ATSDR and CDC activities on DOE's environmental restoration program.

Creation of the Agency for Toxic Substances and Disease Registry

Strengthening its commitment to clean up hazardous waste in the aftermath of Love Canal and Valley of the Drums, Congress passed the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), or Superfund statute, in 1980[1]. The CERCLA's legislative history centered on lively debates over the creation of a trust fund or "superfund," the joint and several liability provisions, and the broad, sweeping authorities given to the Environmental

1 Comprehensive Environmental Response, Compensation, and Liability Act of 1980, Pub. L. No. 96-510 (Dec. 11, 1980), as amended by the Superfund Amendments and Reauthorization Act of 1986, Pub. L. No. 99-499 (Oct 17, 1986), codified together at 42 U.S.C. 9601, et seq.

Protection Agency (EPA) to clean up these waste sites[2]. When final passage of CERCLA came in 1980, the Agency for Toxic Substances and Disease Registry (ATSDR) was established but with no legislative history to document its creation. The ATSDR was created as a totally separate federal agency from EPA; ATSDR was placed in the U.S. Public Health Service (PHS), within HHS. It was authorized to carry out the health-related provisions of CERCLA in cooperation with EPA and a host of other federal as well as state and local health agencies[3]. Specific tasks included the establishment and management of national disease and exposure registries; an inventory of literature, research, and studies on the health effects of toxic substances; and a listing of areas closed or restricted to the public because of toxic substance contamination. In addition, ATSDR was authorized to give assistance, including medical care and testing, to exposed individuals in public health emergencies and conduct screening programs to determine relationships between exposure to toxic substances and illness.

EXPANSION OF ATSDR RESPONSIBILITIES UNDER SARA - 1986

With the passage of the Superfund Amendments and Reauthorization Act of 1986 (SARA), ATSDR's role as the Superfund public health agency was greatly expanded. ATSDR's primary responsibilities are derived from CERCLA, as amended by SARA, and thus relate to hazardous waste sites listed or proposed for listing by EPA on the National Priorities List (NPL). The Agency also has duties to conduct health assessments under the Resource Conservation and Recovery Act (RCRA), which regulates the generation, transport, and disposal of hazardous and solid waste[4].

ATSDR's responsibilities can be broken down into two categories: site specific and non-site specific. Those activities that are site specific include the following:

- provide health consultations, including emergency responses, to EPA and state and local health agencies;
- perform health assessments of all sites proposed for listing or listed by EPA on the NPL within given timeframes;[5]
- perform health assessments when petitioned to do so from outside the Agency;
- issue public health advisories recommending that measures be taken to reduce exposure to hazardous substances from a release, and eliminate or substantially mitigate the significant risk to human health;[6]
- conduct studies that evaluate the health effects from exposure to hazardous substances. Such studies include epidemiologic studies, exposure and disease registries, and health surveillance programs.[7]

ATSDR's non-site-specific responsibilities involve the following:

- prepare and regularly revise and supplement a list of "priority" hazardous substances most commonly found at NPL sites and which pose the most significant potential threat to human health;
- prepare toxicological profiles for each priority hazardous substance;
- initiate a substance-specific research program to fill priority data needs identified for the substances;
- develop and disseminate to health care providers materials and training to identify chronic disease and acute illness associated with exposure to hazardous substances.

ATSDR ACCOMPLISHMENTS

Over the last two years, ATSDR has had accomplishments in all the above-mentioned areas. In its most recent reporting period of 1989-1990, ATSDR provided close to 2,000 health consultations, 486 as emergency responses.[8] To date, it has completed approximately 1,234 health assessments, including petitioned health assessments.[9] A wide spectrum of studies have been undertaken or completed since 1989, including 17 exposure studies, 21 surveillance projects, 10 pilot studies, and 9 epidemiologic studies.[10] The Agency has established a national exposure registry consisting of subregistries for trichloroethylene (TCE), dioxin, and benzene. Since January 1989, ATSDR has issued six public health advisories, all of which resulted in EPA taking some kind of action, including the relocation of residents.[11]

Having prepared its list of priority hazardous substances, ATSDR has recently solicited input into the Agency's revised algorithm for evaluating and ranking hazardous substances at NPL sites.[12] Seventy-five toxicological profiles have been released in final. Additionally, the Agency has held meetings with interested parties to discuss its substance-specific research program.

In the area of education, ATSDR has forged ahead with a series of Case Studies in Environmental Medicine. These

2 Environment and Natural Resources Policy Division of the Congressional Research Service of the Library of Congress, A Legislative History of the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (Superfund), Pub. L. No. 96-510, Together with a Section-by-Section Index, 97th Cong. 2d Sess. (1983).
3 42 U.S.C. §9604 (i)(1).
4 See Pub. L. No. 89-272, Title II, §3019, as added Nov. 8, 1984, Pub. L. No. 98-616, Title II, §247(a), 98 stat. 3265, codified at 42 U.S.C. §6939a.
5 A health assessment is defined as the evaluation of data and information on the release of hazardous substances into the environment in order to assess any current or future impact on public health, develop health advisories or other recommendations, and identify studies or actions needed to evaluate and mitigate or prevent human health effects.
6 The term public health advisory does not appear in CERCLA. It is used, however, in the National Contingency Plan where it provides EPA with an alternative method for listing a site on the NPL. 40 C.F.R. §300.66. See also ATSDR, Health Assessments and Health Effects Studies of Hazardous Substances Releases and Facilities, 42 C.F.R. Part 90.2.
7 42 C.F.R. Part 90.2.
8 ATSDR, ATSDR Biennial Report to Congress (1989 and 1990), at 51.
9 Id. at 36.
10 Id. at 95, 106, 108, and 112.
11 Id. at 79-81.
12 56 Fed. Reg. 29485 (June 27, 1991).

self-instructional, educational case studies provide information about individual hazardous substances that will assist physicians in diagnosing, treating, and preventing hazardous substance exposure in their patients.[13]

ATSDR GOALS

Although ATSDR has accomplished a great deal in the last few years, the Agency is striving to do more. In ATSDR's recently published Goals, Objectives, Milestones, four goals are stated:

- identify adverse human health outcomes potentially related to the release of hazardous substances;
- determine relationships between identified adverse human health outcomes and hazardous substances;
- implement public health strategies to prevent or mitigate adverse human health outcomes related to hazardous substances;
- implement the infrastructure necessary to accomplish the ATSDR mission.[14]

Included in this publication are many ideas the Agency plans to implement in the future. These include, to name a very few, the development of various databases to identify environmental disease, the establishment of an applied research plan in support of health assessments, the full implementation of its substance-specific research program to fill significant data needs for priority hazardous substances, and the implementation of training and education programs in environmental medicine and in environmental epidemiology regarding hazardous substances.[15]

FEDERAL PROGRAMS

ATSDR's mandates under CERCLA and RCRA as well as its goals and objectives relating to site-specific health activities are fully applicable to sites or facilities owned or operated by federal agencies.[16] To date, most of ATSDR's efforts and achievements have centered on non-federal sites. However, with the creation of the Associate Administrator for Federal Programs position out of the Office of the Assistant Administrator two years ago, considerable emphasis has been placed on ATSDR activities at federal facilities.

Beginning with a Memorandum of Understanding (MOU) with the Department of Defense (DOD) signed October 4, 1989, ATSDR has undertaken negotiations with those federal agencies whose sites and facilities are proposed for or listed on the NPL. ATSDR presently has in place with the four DOD components (Army, Navy, Air Force, Defense Logistics Agency) separate interagency agreements (IAG) and Annual Plans of Work (APW), which essentially set forth the particular responsibilities of the agencies and provide for funding of ATSDR activities at the federal sites. Similarly, ATSDR signed an umbrella agreement on October 10, 1990, setting the framework for IAGs with separate DOE field offices. At the time of this writing, the agencies were close to signing an IAG with DOE's Savannah River Field Office that will cover all work at all DOE facilities until FY 93.

ATSDR ACTIVITIES UNDER DOE AGREEMENT

The IAG provides that ATSDR will conduct and DOE will fund a number of health-related activities at all 17 NPL DOE facilities. These activities as well as the procedures for conducting them are authorized by §104(i) of CERCLA and are consistent with ATSDR's regulations.[17] The Scope of Work states that ATSDR and the DOE field offices shall cooperate in the conduct of health assessments, consultations, and other related health activities, and in the development of toxicological profiles for hazardous substances at the DOE sites listed on the NPL and for other high priority sites to be identified.[18] The Initial Plan of Work allows ATSDR to recruit, hire, and train 60 personnel to carry out the activities at DOE sites.

ATSDR's top priority is to conduct what the Agency terms as "scoping visits" to all DOE NPL sites as a first step in the preparation of health assessments. These visits serve as a way of introducing ATSDR to DOE personnel, and provide the opportunity for the Agency to make crucial contacts with the community, collect information from local, state, and federal health and environmental agencies, record site remediation schedules, and observe on- and off-site conditions. After the scoping visits are completed within the next year, ATSDR will prepare health assessments for each site. The Agency has agreed in the IAG that these health assessments shall

> include a qualitative assessment of [each] site . . . and conclude with a statement as to the public health implications of the site, recommendations to assure the protection of the public health, as well as the identification of areas in which additional studies or public health actions are needed.[19]
>
> In addition, ATSDR shall, independent from DOE, conduct any needed surveillance activities, registries, health surveys, pilot studies, health studies, and related research that will further define the extent and impact of human exposures to hazardous substances.

In carrying out its activities, ATSDR is responsible for assuring that all relevant available data for each site are received and considered. ATSDR is also responsible for ensuring that ATSDR personnel obtain any needed security clearances. To assist ATSDR with its document receipt and review, DOE must prepare an inventory of all health and environmental data related to ATSDR's health activities at the site. DOE must also undertake "every reasonable effort" to declassify data ATSDR deems necessary for conducting its activities. In turn, ATSDR agrees to provide the DOE entity and other appropriate parties within DOE with a draft of the

13 ATSDR, ATSDR Biennial Report to Congress (1989 and 1990), at 23.
14 ATSDR, Goals, Objectives, Milestones 1991.
15 Id.
16 42 U.S.C. §9604 (i)(17).
17 42 U.S.C. §9604 (i); 42 C.F.R. Part 90.
18 DOE, Interagency Agreement Between U.S. Department of Energy, Savannah River Field Office, and the U.S. Public Health Service, the Agency for Toxic Substances and Disease Registry. DE-A109-91SR18215.
19 Id. at 8.

health assessment at the time of public comment, at least 45 days before the health assessment's final release.

At the request of DOE or other federal, state, or local health agencies, ATSDR will also provide health consultations which, where appropriate, will include a statement about the public health implications posed by the site, as well as include recommendations for protecting public health and performing follow-up health studies. Additionally, ATSDR may undertake a toxicological profile of a hazardous substance identified by and at the request of a DOE entity. The DOE entity will be provided with copies of the various stages of draft profiles; moreover, the DOE entity is entitled to review and comment of the final draft document 60 days before it is finalized.

The IAG also calls for ATSDR's assistance in the area of emergency response. If requested by a DOE entity, ATSDR will make an Emergency Response Coordinator available at all times to activate a preliminary assessment team. This group of ATSDR employees are trained to provide technical advice and assistance on a wide range of issues, some of which include worker safety and health, site safety plan development or review, medical treatment protocols, and public relations. In particular, ATSDR will assist in testing the efficacy of the entity's emergency response system.

Further, ATSDR will participate in the priority setting activities undertaken by DOE Headquarters, focusing particularly upon current ongoing releases of hazardous substances and their health implications.

Finally, ATSDR and DOE may collaborate in the preparation and dissemination of certain environmental health education materials. These may include training DOE personnel in communicating health information to the public, preparing emergency response guidelines and training for health care providers, developing case studies for medical professionals practicing in communities surrounding DOE sites, giving computer training to interested persons in the use of toxicological and medical databases, and offering training programs to on-site or local health professionals on environmental medicine and toxicology.

HEALTH AND HUMAN SERVICES MOU WITH DOE: THE SPEERA REPORT

In August 1989 the Secretary of Energy chartered an advisory committee to report to him on the state of DOE's epidemiology program. The Secretarial Panel for the Evaluation of Epidemiologic Research Activities, or SPEERA, issued its report in March 1990. One of its recommendations was that DOE enter quickly into an MOU with HHS to manage DOE's analytic epidemiologic research.[20] With DOE resources, HHS would conduct this research either in-house or by following its established procedures for conducting extramural research including peer review and open competition. The panel further recommended that DOE continue to conduct what it termed as descriptive epidemiologic studies such as its occupational health surveillance programs. The Secretary of Energy agreed with these recommendations and soon after the report was released, DOE and HHS began negotiating an MOU. The MOU was signed by the Secretary of Energy and the Secretary of HHS effective December 24, 1990.[21]

The new MOU authorizes the transfer of energy-related analytic epidemiologic health research to HHS and by delegation to CDC. Within the CDC, the National Center for Environmental Health and Injury Control (NCEHIC) and the National Institute for Occupational Safety and Health (NIOSH) will have direct control over the research programs that will include selected ongoing and future epidemiologic health studies, such as cohort, case-control, and cross-sectional mortality and morbidity studies that test hypotheses. The MOU states that dose reconstruction and exposure assessment studies are covered under the MOU because they provide data necessary for conducting the epidemiologic studies. Populations to be studied include workers at DOE facilities, residents of communities in the vicinity of DOE facilities, other persons potentially exposed to radiation, and, finally, persons exposed to potential hazards resulting from non-nuclear energy production and research. Within its Division of Environmental Hazards and Health Effects, NCEHIC has recently created a Radiation Studies Branch which will be primarily responsible for community-based radiation studies. NIOSH has recently created an Energy-Related Health Research Program in the Division of Surveillance, Hazard Evaluations and Field Studies. With its congressionally authorized mission to reduce and prevent work-related injuries, illnesses, and premature death caused by exposure to toxic chemicals, radiation, and other hazardous agents and working conditions, NIOSH will be responsible for managing and conducting analytic epidemiologic occupational studies.

A critical element to the transfer of epidemiologic research to CDC is the development of a research agenda. The MOU provides that HHS will establish an advisory committee to advise the Agency in setting the research agenda and in conducting the research program. The advisory committee, to be chartered by the Secretary of HHS, will consist of non-federal employees who are research scientists, or who represent public health offices, public interest groups, and those affected by DOE facilities such as workers and community residents. The charge to the HHS advisory committee is to review proposals and make recommendations to HHS on establishing its research agenda and developing a research plan. Under the MOU, DOE is given the opportunity to review and comment on the HHS research plan. DOE may undertake those analytic epidemiologic studies that the advisory committee has recommended be included in the research agenda but HHS has decided not to conduct, provided DOE finances such studies separately from its budget for implementing the MOU with HHS.

The MOU also provides that HHS will initially continue existing DOE grants and contracts. However, DOE and HHS agreed that HHS will review all existing grants and contracts

20 The Secretarial Panel for the Evaluation of Epidemiologic Research Activities for the U.S. Department of Energy, Report to the Secretary March 1990.

21 CDC, Memorandum of Understanding Between the Department of Energy and the Department of Health and Human Services. 56 Fed. Reg. 9701 (Mar. 7. 1991).

and determine whether to continue, expand, or cancel these studies, with the advice of the HHS advisory committee on how these studies may fit into the research agenda.

Since the MOU was signed late last year, a task force of CDC, ATSDR, and DOE officials have met on numerous occasions to implement the transfer of studies. CDC and ATSDR personnel have made site visits to all DOE facilities and have begun hiring physicists, epidemiologists, industrial hygienists, and other scientists to manage and conduct present and future studies. CDC and ATSDR have also initiated the process for chartering the HHS advisory committee. It is anticipated that the first meeting of the advisory committee will take place in spring 1992. In the meantime, CDC has already started its review of DOE studies in progress but the status quo will be maintained until the advisory committee has met to consider a research agenda.

This December CDC plans to hold a meeting to seek scientific and public input into issues of relevance to establishing a research agenda and formulating a research plan. Topics at this outside discussion may be considered by CDC and ATSDR as they formulate research ideas to bring before the HHS advisory committee.

PHS IMPACT ON DOE'S ENVIRONMENTAL RESTORATION PROGRAM

Through separate authorities and mechanisms, ATSDR and CDC have both been given a role at DOE facilities. ATSDR's statutory mandate is to assess health risks from exposure to hazardous substances, including radiation exposures. Pursuant to its MOU with DOE, the CDC will focus on radionuclide dose reconstruction and analytic epidemiologic studies involving communities and workers. Although their roles differ to some extent, as agencies headquartered in Atlanta, Georgia and directed by the same individual, ATSDR and CDC have both the opportunity and the obligation to share information about their respective activities. In fact the ATSDR MOU with DOE requires that proposed long-term, health-related ATSDR activities such as surveillance, registries, and health studies be submitted to the HHS advisory committee to be considered in developing the overall research plan.[22] The question arises as to how and to what extent ATSDR's and CDC's health-related activities will affect DOE's environmental restoration program. Several observations are in order, beginning first with ATSDR.

ATSDR's stated mission is to prevent or mitigate adverse human health effects and diminished quality of life resulting from exposure to hazardous substances in the environment.[23] Its responsibilities include detecting the presence and assessing the nature of health hazards at Superfund sites, helping prevent or reduce further human exposure to hazardous substances and diseases resulting from such exposures, and expanding and communicating the knowledge base about health effects from exposure to hazardous substances.[24] ATSDR is, therefore, focused on obtaining an assessment of the current health climate at DOE facilities. This requires identifying the hazardous substances present on- and off-site, determining whether pathways of exposure exist, characterizing any affected populations, and finally, understanding the health risks posed by the presence of hazardous substances. In effect, ATSDR's responsibility is to describe what the present and future health risks are to certain exposed populations and give recommendations about how to reduce or eliminate those risks. ATSDR satisfies this responsibility by conducting health assessments, performing a variety of health effects studies, preparing toxicological profiles, and disseminating educational materials. Because of its responsibility to identify health risks from current and future exposures, and make recommendations to prevent or mitigate those risks, ATSDR will undoubtedly influence DOE's environmental restoration program since risk to human health is a crucial consideration in environmental cleanup.

ATSDR INTERACTION WITH CLEANUP

ATSDR fully intends to allow for public input and access to its activities. This will certainly place demands on its timeframes for completing its projects. The deadlines set by CERCLA for completing ATSDR's health assessments are particularly difficult to meet. Specifically, §104(i)(6)(A) requires that the Agency complete health assessments of facilities within one year of the date the facilities are proposed to be added to the NPL. This language suggests that ATSDR is to provide an assessment of health risks near the time EPA determines that a site should be on the NPL. However, the statute also expects that same health assessment to contain a thorough analysis of the risks to human health and suggest ways of reducing or eliminating those risks, a difficult task to accomplish when so little data typically exist at this very early point in remediation.[25] Furthermore, CERCLA anticipates that the analysis and recommendations found in the health assessment will be used in completing the remedial investigation and feasibility study.[26] Currently, DOE has 17 facilities listed or proposed for listing on the NPL. With massive cleanup efforts that will extend well into the next century under way at these DOE facilities, the question remains at what point in these efforts can ATSDR be most effective and at the same time satisfy the spirit of the law to provide the public with timely information about the current risks to their health.

CDC'S ROLE

As ATSDR is preparing to conduct health assessments at DOE NPL facilities, CDC is currently reviewing the analytic epidemiologic studies transferred from DOE earlier this year, and further is initiating the process for establishing a research agenda and implementing a research plan.

A number of the studies CDC will now manage have been in existence for many years and involve a retrospective exposure assessment, that is, a study of the human health effects

22 ATSDR, Memorandum of Understanding Between the Agency for Toxic Substances and Disease Registry, U.S. Public Health Service, and the U.S. Department of Energy on the Development of Toxicological Profiles for Hazardous Substances and Health Assessments and Related Activities at DOE Facilities.
23 54 Fed. Reg. 33617 (August 15, 1989).
24 ATSDR, ATSDR Biennial Report to Congress (1989 and 1990), at 9.
25 42 U.S.C. §9605(i)(6) (F) and (G).
26 42 U.S.C. §9604 (i) (6) (D).

from radiation releases that occurred in the 1940s and 1950s. CDC's broad authority to carry out these studies is derived from the Public Health Service (PHS) Act and the Occupational Safety and Health Act (OSHA).[27] The PHS Act allows CDC to conduct and promote the coordination of research, investigation, and studies relating to the causes, diagnosis, treatment, control, and prevention of physical and mental diseases and impairments of people.[28] The OSHA authorizes NIOSH to conduct occupational safety and health research. These studies are therefore in no way tied statutorily to DOE's environmental restoration program in the manner that ATSDR activities are under CERCLA. Nevertheless, the scientific knowledge gained from these studies may influence DOE decisions about cleanup levels. Furthermore, although all of the initially transferred studies are radiation related, in the future CDC will not limit its research agenda to radiation studies, particularly when conducting studies in an occupational setting where there are likely to be other exposures to other hazardous substances.

REGULATORY IMPACT

Neither CERCLA nor the PHS Act grants ATSDR or CDC regulatory functions requiring DOE to implement any ATSDR or CDC recommendations. Of course CERCLA is fully applicable to DOE as it is to all federal agencies owning or operating NPL sites, meaning that DOE must remediate those sites and use its own resources to do so.[29] Accordingly, DOE is responsible for paying for the costs incurred by ATSDR in conducting its activities at DOE sites.[30]

Thus while neither ATSDR nor CDC has any regulatory impact on DOE's environmental restoration program, they clearly bring with them a long-standing credibility with public health institutions that will lend credence to an acceptance of their respective contributions at DOE sites. Moreover, both ATSDR and CDC have made a commitment to giving full public access and input into their activities at DOE facilities. The reason for this policy is to earn and maintain the public's trust.

CONCLUSION

The impact ATSDR and CDC will have on DOE's environmental restoration program should be viewed as a positive contribution in at least two ways. First, these PHS agencies will most certainly add to the knowledge base about the risks to human health from exposures at DOE sites. Second, they will strive to achieve public recognition and, if not total acceptance, at least respect that is possible because of the agencies' autonomy from DOE, the respect they have earned for their previous work, and endorsement of their open approach to implementing their respective responsibilities at DOE facilities.

27 42 U.S.C. §101 et seq.; 29 U.S.C. §651 et seq.
28 42 U.S.C. §241(a).
29 42 U.S.C. §9602.
30 42 U.S.C. §9607(a) (4) (D).

AN APPROACH TO REGULATORY COMPLIANCE WITH RADIOACTIVE MIXED WASTE REGULATIONS

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ABSTRACT

On May 7, 1990, radioactive mixed waste (RMW) at the West Valley Demonstration Project (WVDP) became subject to the State Of New York hazardous waste regulations. The facility was required to be in full compliance by June 6, 1990. Achievement of this goal was difficult because of the short implementation time frame. Compliance with the hazardous waste regulations also presented some potential conflicts between the hazardous waste requirements and other regulatory requirements specifically applicable to nuclear facilities. The potential conflicts involved construction, operation, and control measures.

However, the facility had been working extensively with EPA Region 2 and the New York State Department of Environmental Conservation (NYSDEC) on the application of the hazardous waste regulations to the facility. During these preliminary contacts, WVDP identified three issues that related to the potential conflicts:

- Equivalency of Design and Equipment,
- Land Disposal Restrictions (LDR), and
- The Principle of As Low As Reasonable Achievable (ALARA) Radiation Exposure

The equivalency of nuclear facility design and equipment to the hazardous waste requirements is based in part on the increased construction criteria for nuclear facilities, the use of remote radiological monitoring for leak detection, and testing of system components that are not accessible to personnel due to high levels of radiation.

Regulations governing storage limitations of LDR materials posed additional concerns. EPA has granted a two-year national capacity variance for RMS, but the presence of the California-listed metal, nickel, in its high-level waste prevents the site from utilizing the variance. Discussions were held with both state and federal agencies to resolve this dilemma. A two-fold solution was agreed on by the WVDP and the regulatory agencies. In the first place, it was recognized that the WVDP was accumulating sufficient quantities of RMS to facilitate proper treatment, which for high-level waste is vitrification. In the second place, the material was placed in storage prior to the effective date of the LDR regulations, so it is not subject to regulations until such time as the WVDP begins the vitrification process.

The ALARA principle could be violated if certain of the hazardous waste regulatory requirements were implemented in radiological areas. For example, if regular inspection of stored materials were required in areas of high radiation fields, or if dense packing used for radiological shielding were replaced with typical hazardous waste storage requirements providing space between waste containers.

Several schedule extensions were requested to allow the WVDP adequate time to bring its RMS program into compliance. For example, a 6 month extension was requested to conduct an historical and process knowledge review of stored wastes that are currently classified "low-level radioactive" to determine that these are not RMS. An additional extension was requested to accommodate appropriate sampling and analyses of the wastes.

This paper discusses in detail:

- The implementation and results of the WVDP's interaction with its regulators,
- How the regulators were helped to understand the different situations and conditions of nuclear and chemical facilities, and
- How, by working together, the result was not only mutually advantageous to the WVDP and the agencies, but it also assured that the health and safety of workers, the public, and the environment were protected.

INTRODUCTION

The West Valley facility was the first and only commercial nuclear fuel reprocessing operation in the United States. The reprocessing operation ran during the 1970's and resulted in the generation of approximately 600,000 gallons of high level waste (HLW) that is stored in underground tanks on site. Tank 8D-2 contains the majority of the waste in two phases, a sludge and a liquid supernatant. Tank 8D-4 contains a acidic thorex waste.

In 1980, Congress passed the West Valley Demonstration Project (WVDP) Act (Public Law 96-368), directing the U.S. Department of Energy (DOE) to carry out an HLW management demonstration project at the site for the purpose of demonstrating solidification techniques for preparing the HLW for disposal. On-site vitrification in borosilicate glass was selected as the preferred technology.

On May 7, 1990, New York State became authorized to regulate the hazardous waste constituents of Radioactive Mixed Waste (RMW) under it Hazardous Waste Regulations (RMW is waste with both radioactive and hazardous components). On June 4, 1990, the WVDP submitted a Resource Conservation and Recovery Act (RCRA) Part A Permit application for treatment and storage of RMW, and thus became subject to RCRA interim status standards (contained in 40 CFR 265 and 6 NYCRR 373-3).

The facility personnel have been working extensively with the Environmental Protection Agency (EPA) Region II and the New York State Department of Environmental Conservation (DEC) on the issues revolving around this new legislation since December of 1989. The purpose of this extensive work was to present to the regulatory agencies the issues revolving around the implementation of these regulations where they could be in direct conflict to other regulatory requirements that the facility had to follow. These conflicts stemmed from the differences in the construction, operation, and control measures that are present at a nuclear facility versus a non-nuclear facility.

WVDP identified specific areas of concern based on the apparent inconsistencies between nuclear facility practices versus the hazardous materials regulations. The basis of these concerns were in the area of:

- Equivalency of Design and Equipment related to secondary containment and leak detection,
- ALARA principles, related to inspection, administrative requirements and marking,
- Extensions to implement regulatory requirements, and
- Land Disposal Restrictions.

The equivalence in design and equipment is based in part to increased construction criteria, the use of remote monitoring for leak detection, and testing of system components that are not currently accessible due to very high levels of radiation, and the use of multiple engineered barriers as double containment.

The ALARA principles are violated if the regulatory requirements will require the inspection of containers on a Periodic basis (weekly or daily), as well as the concept of dense packing that allows for the materials to be used for self shielding. This is in direct opposition to the regulatory requirements of RCRA for container inspection.

The extensions required under the regulations are based on the function of when the regulations came into effect, May 7, 1990, with full compliance required by June 6, 1990. The need for a complete inventory analysis, training to local and state response personnel and changes to Emergency and Standard Operating Procedures to reflect the new regulations could not be accomplished within this time frame. Additionally, the historical and process knowledge review of the waste inventory needed to be completed as a detailed data review rather than exposure of Personnel to radiation to obtain the same information.

The issue of Land Disposal is being dealt with on the national level and is not specifically addressed in this report.

BACKGROUND

The High Level Waste Tanks (8D-1 through 8D-4) contain HLW that is now regulated as Mixed Waste. Tank 8D-2 waste meets the definition of hazardous waste by virtue of exhibiting the characteristic of toxicity (EPA hazardous waste numbers D005, D006, D007, D009, and D010). The Tank 8D-4 waste meets the definition of hazardous waste based on exhibiting the characteristics of corrosivity and toxicity (EPA hazardous waste numbers D002, D005, D006, D007, and D010).

Tanks 8D-2 and 8D-3 are used for Cesium stripping of the HLW to produce LLW and storage prior to transfer of the Supernatant for reduction through evaporation and Cement Solidification respectively.

EQUIVALENCY IN SECONDARY CONTAINMENT AND LEAK DETECTION REQUIREMENTS

The interim status standards for tank systems (6 NYCRR 373-3.10) require that:

> Secondary containment vault systems must be "designed and operated to contain 100 percent of the capacity of the largest tank or the volume of all interconnected tanks, whichever is greater, within its boundary. . designed or operated to prevent run-on or infiltration or precipitation into the secondary containment system..." (6 NYCRR 373-3.10[d] [5] [ii]).
>
> In addition, ancillary equipment "must be provided with full secondary containment (e.g., trench, jacketing, double-walled piping)..." (6 NYCRR 373-3.10[d] [6]).

- In addition, the secondary containment systems must be "capable of detecting and collecting releases and accumulated liquids until the collected material is removed" (6 NYCRR 373-3.10[d] [7] [2] [ii]).

WVDP Secondary Containment and Leak Detection Methods

This paper provides a listing of the transfer of the supernatant and the methods that the WVDP uses to provide secondary containment and leak detection for the Supernatant This includes the use of multiple engineered barriers and radiation detection instrumentation. Multiple engineered barriers and radiation monitors are standard design features in the nuclear industry for protection of personnel and the environment from exposure to radiation, and are used throughout the WVDP facilities. The use of these features and devices in conjunction with standard design -features and detection devices for non radiological systems provides secondary containment and leak detection for the supernatant transfer system.

The HLW storage tanks are in secondary containment vaults. The majority of the transfer pipe is double-containment pipe or is single containment pipe in pipe chases, which are high-density concrete or steel conduits constructed according to nuclear industry standards and serve as secondary containment structures. All other tanks, process vessels, pumps, jumper connection devices, and single containment pipes are contained within vaults or multiple engineered barriers constructed according to nuclear industry standards that serve as vaults. The multiple engineered barriers at WVDP include building walls, floors, and ceilings of concrete or steel of sufficient thickness to prevent exposure to radiation, and often with additional steel plating to further block radiation and facilitate removal of contamination.

Various types of radiation monitors and liquid level sensing devices are used at the WVDP, including:

- Continuous air monitors (CAMs). These are radiation detectors. CAMs draw a stream of ambient air and collect particulate activity on a filter mounted in front of a detector that continuously monitors for radioactivity. CAMs are equipped with chart paper on which activity rates are recorded, and alarms set to activate if the rate exceeds the background rate for the area.
- Air samplers. These are radiation detectors. Air samplers draw a stream of air through a filter paper on which dust and airborne contaminants are captured. The filter paper dust is counted for radioactivity by a technician and the paper replaced weekly. Results compared with previous data to determine any change in radiation levels.
- Liquid detectors. These are conductivity Probes consisting of two electrodes in close proximity such that the presence of sufficient moisture creates an electrical circuit that activates an alarm. The electrodes are contained within a continuous strip of moisture-sensitive material.
- Sump liquid level detectors. These are conductivity probes similar to liquid detectors. A high liquid level in the sump activates an alarm.
- Sump liquid level indicators. These are bubbler ~ type differential pressure devices. The pressure difference between the ambient air and the bottom of the sump is measured by measuring the resistance to a small stream of air "bubbled" through the tubing. A higher liquid level in the sump causes increased resistance to air flow, which is directly proportional to the liquid level

Design, construction, and operational activities at the WVDP met and continue to meet the standards of the American Society of Mechanical Engineers "Quality Assurance Requirements for Nuclear Facilities" (ASME NQA-1-1986), which specify quality assurance (QA) requirements for materials, operations, inspections, and documentation. In addition, Safety Analysis Reports (SARs) detail facility construction and activities, analyze possible accident scenarios, and list items essential to safety.

HLW Treatment Processes at the WVDP

Two treatment systems have been used and/or will be used to treat HLW at the WVDP: the Integrated Radwaste Treatment System (IRTS), and the Vitrification System. The IRTS consists of ion-exchange reduction of HLW to low level radioactive waste (LLW), followed by two RCRA treatments, volume reduction by evaporation, and cement solidification. The IRTS has been used to treat Tank 8D-2 supernatant.

The Vitrification System is not yet in operation. The process will consist of vitrification of the sludge in Tank 8D-2, the acidic waste in Tank 8D-4, and treatment residues in Tank 8D-I. The transfer and treatment of the 8D-2 sludge, the 8D-4 waste, and the treatment residues in 8D-I will use facilities currently under construction and/or the IRTS system. The facilities currently under construction are being constructed with secondary containment and leak detection, according to RCRA regulations and will meet all applicable RCRA interim status standards.

During vitrification, the IRTS will be used for transfer and treatment of sludge wash solutions and possibly other liquids that may be generated as a result of the vitrification process.

Integrated Radwaste Treatment System

The supernatant is initially contained in Tank 8D-2. It is transferred through the Supernatant Treatment System (STS) Building valve aisle/pipeway to Tank SD-I, where it is treated by means of an ion exchange technique in zeolite containing columns to remove radioactive cesium. The spent zeolite is dumped onto the tank floor for later removal and treatment. Following the ion exchange treatment, the supernatant is low level radioactive waste (LLW). The LLW is then transferred back through the STS Building valve aisle/pipeway to Tank 8D-3 for temporary storage. From Tank 8D-3, it is transferred back through the STS Building valve aisle/pipeway again to the Main Plant Process Building and the Liquid Waste Treatment System (LWTS), where it is concentrated by evaporation. Following concentration in the LWTS, it is transferred to the Cement Solidification System (CSS), where it is solidified into a cement matrix suitable for long-term storage. The end product cement matrix is no longer hazardous (or RMW), based on TCLP testing conducted on the material, per 40 CFR Parts 261, 264, 265, 268, 271, and 302, and Final Rule 3/29/90 (SWH-FRL-3601-1; EPA/OSW-FR89-026; RIN 2050-0AA78). In addition to treatment of the supernatant in Tank 8D-2, the STS will be used for transfer and treatment of sludge wash solutions and possibly other liquids that may be generated during the vitrification process.

A transfer drawing of the supernatant system is provided in Fig. 1, 1a and 1b. This transfer drawing shows the physical layout of the RMW flow through the facility. The 3-D perspective is useful for understanding the complexities, but at the same time simple straight forward pathway.

Figure 2 is a schematic showing the overall waste flow pattern in the supernatant system and showing that the system is "closed," that is, that any released material, which would be collected in sumps that are part of the system, would subsequently be re-entrained into the treatment process. This was an important feature for the regulators to understand, that is the "closed system" concept.

ALARA

As Low AS Reasonable Achievable (ALARA) is a radiation protection standard that revolves around the concepts of reducing the potential radiation exposure to individuals though the use of:

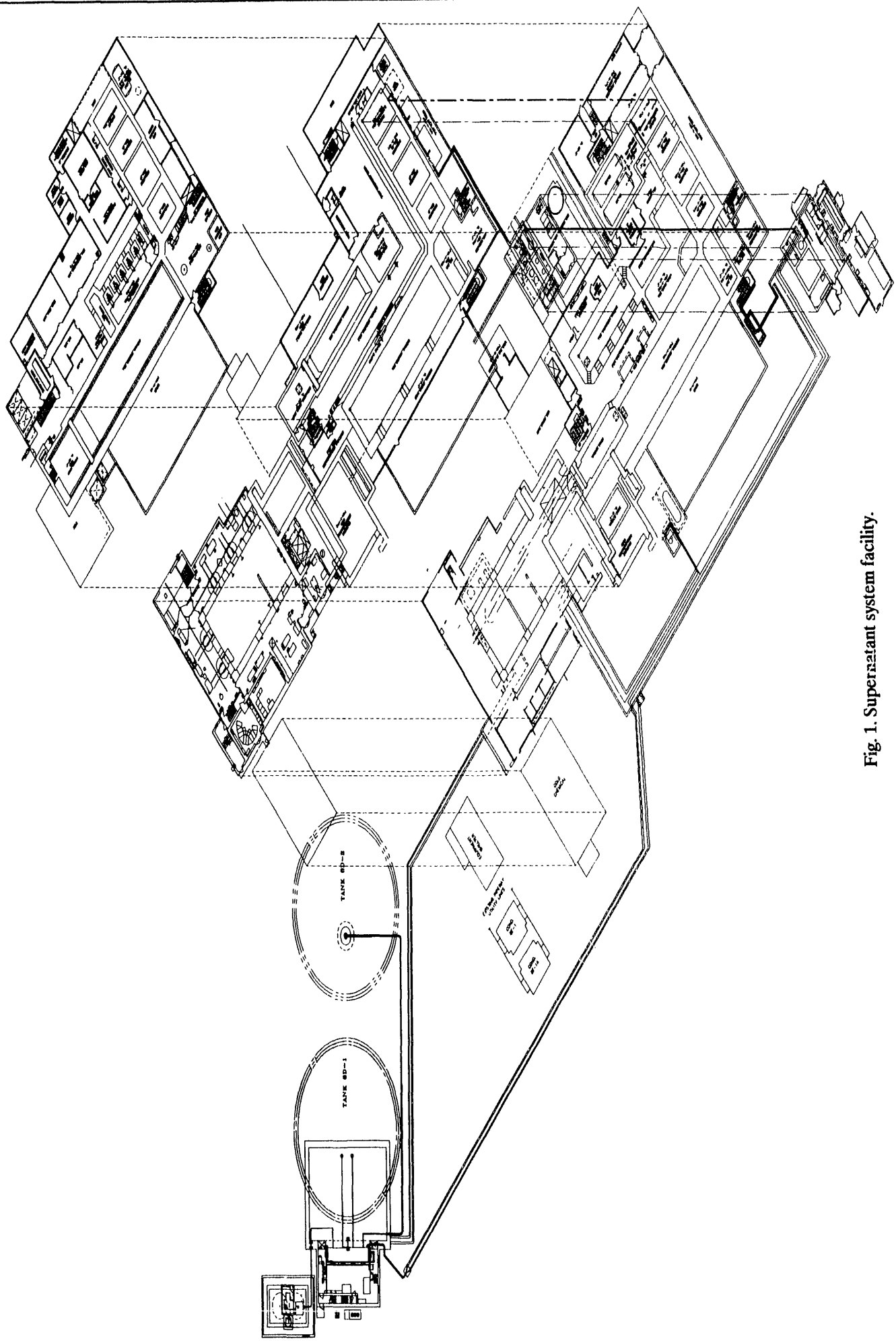


Fig. 1. Supernatant system facility.

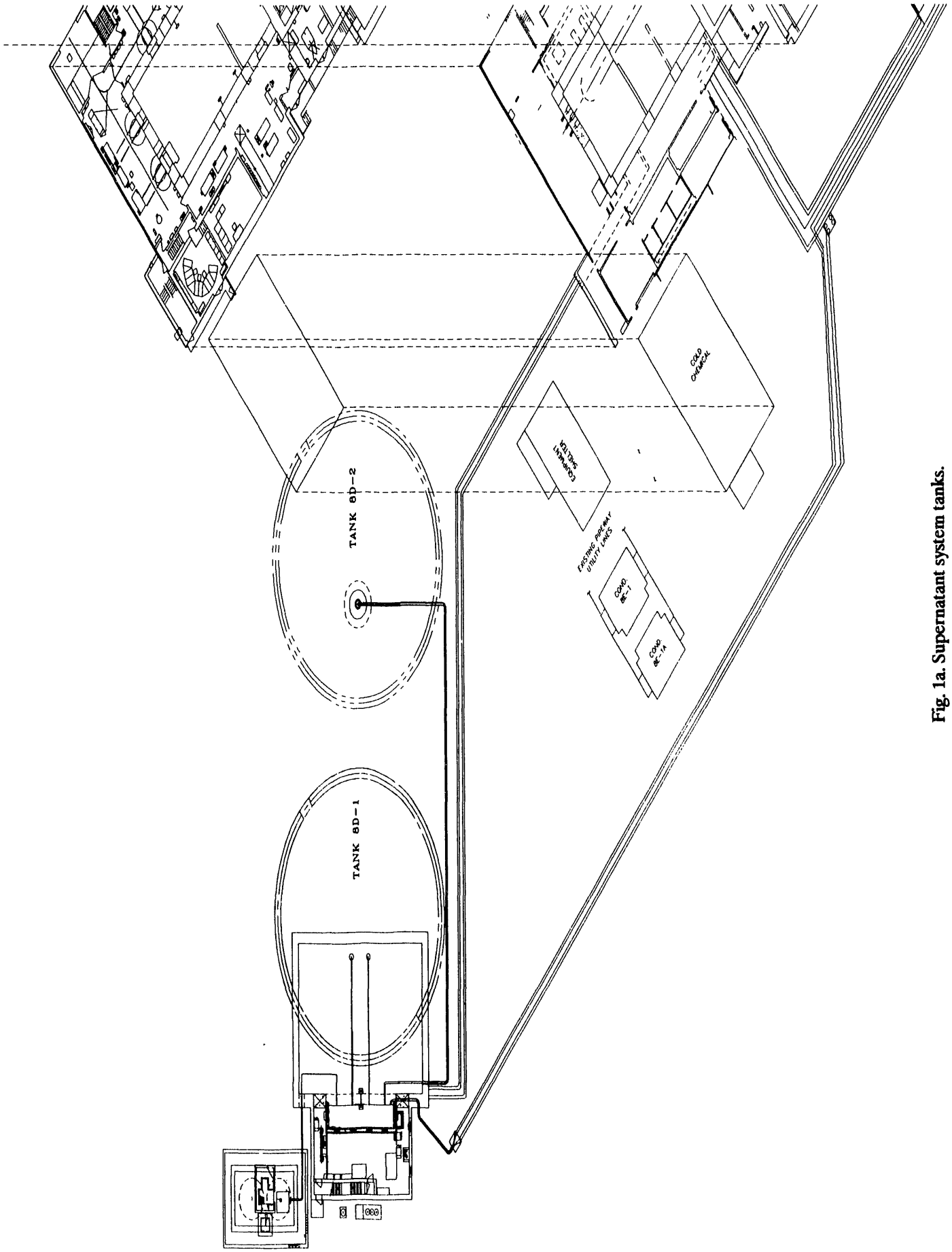


Fig. 1a. Supernatant system tanks.

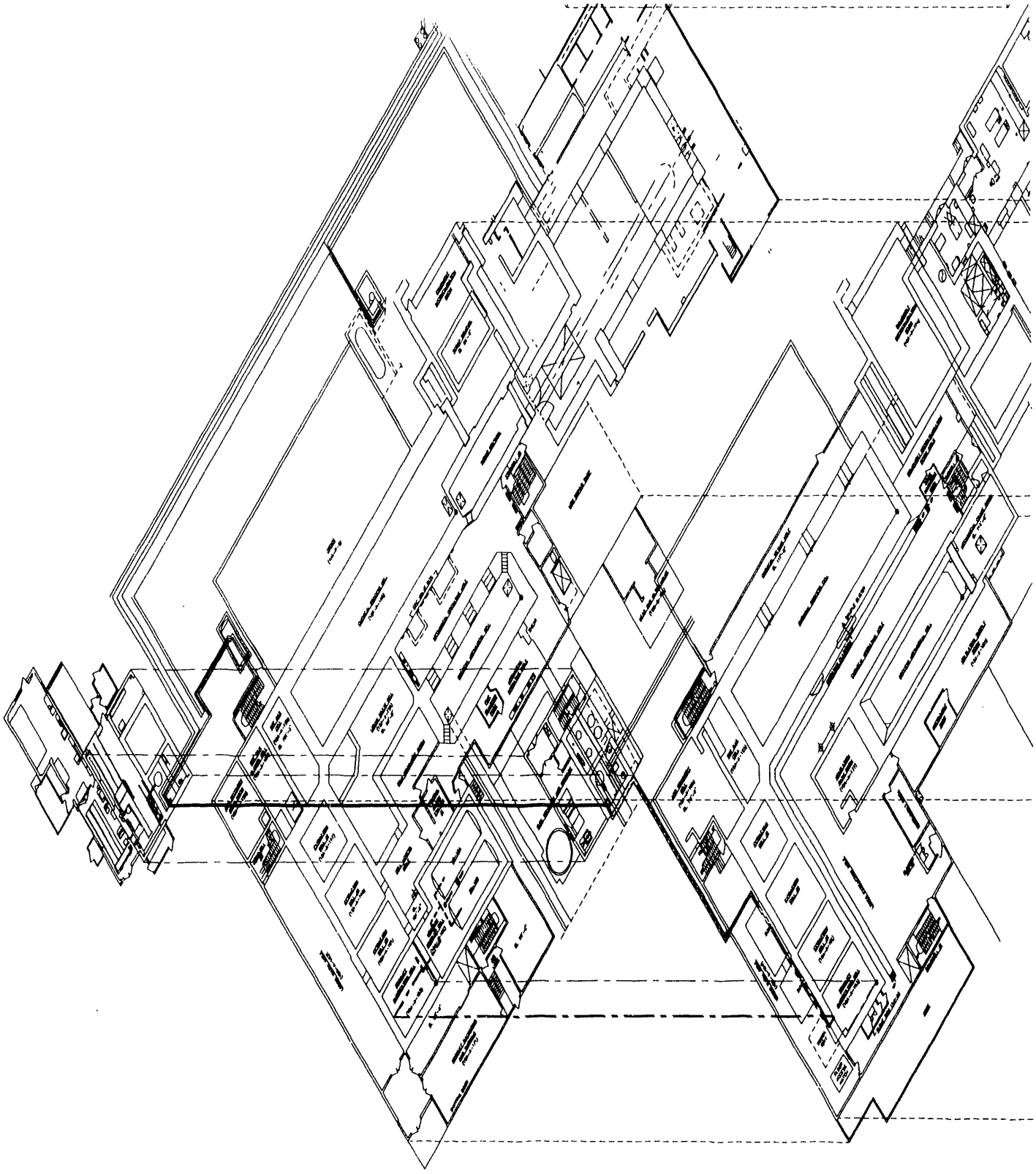


Fig. 1b. Supernatant system support facilities.

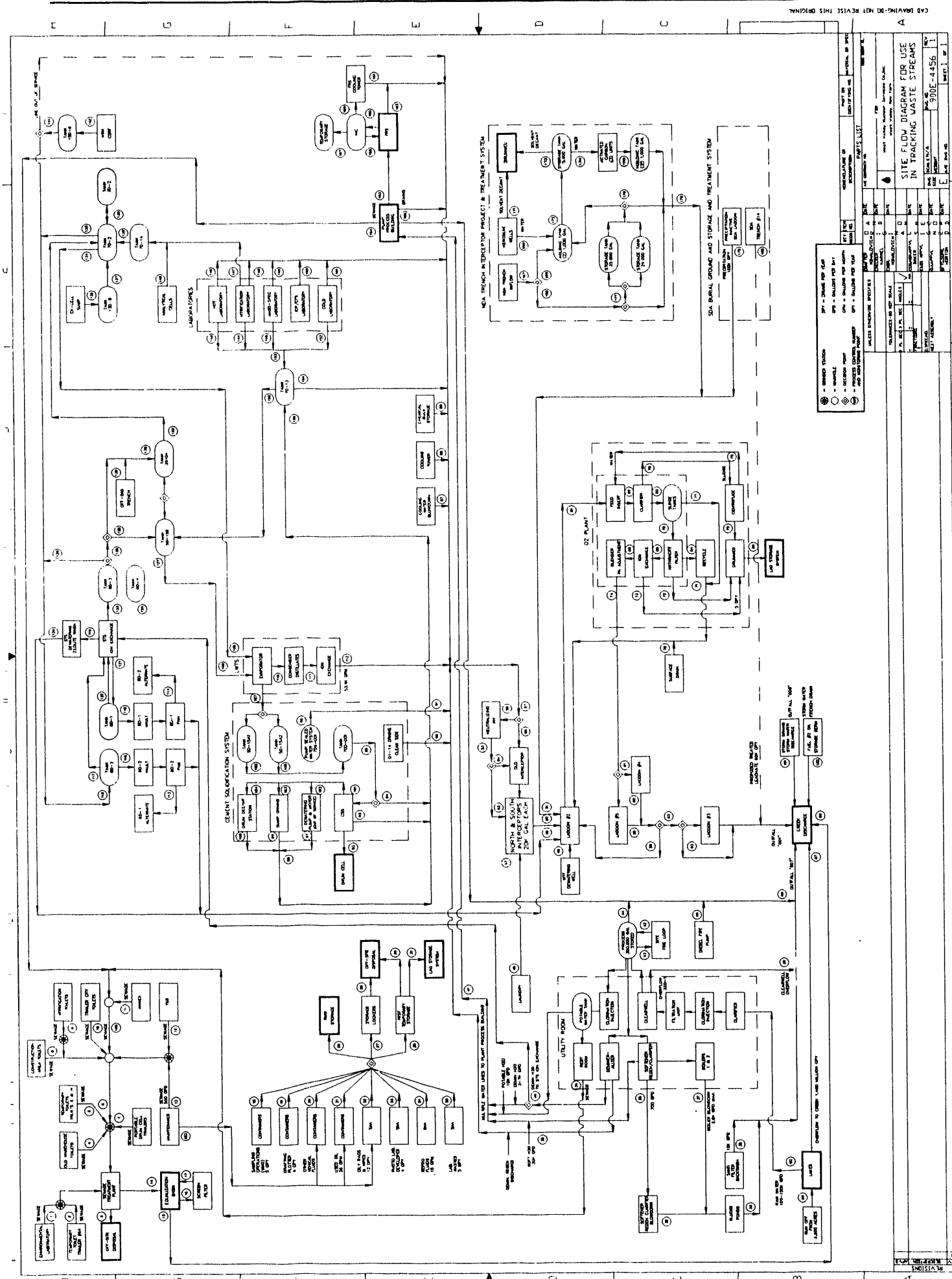


Fig. 2. Site flow diagram for use in tracking waste streams.

1. Distance,
2. Shielding, and
3. Time

These concepts are designed to minimize radiation exposure to personnel. The hazardous waste regulations and protection measures are designed and operated around different requirements The concepts for hazardous materials are designed and operated around the concepts of:

1. Isolation, and
2. Personnel Protective Equipment.

Double Containment and Protection of Personnel

Where the hazardous waste regulations deal with double containment of a material, the radiological regulations and design place distance and shielding as the priority. The materials are then protected from release to the environment with the use of the multiple engineered barriers (Discussed above). This is for the control of the actual constituents with multiple doors, walls and controls, but in addition with the control of airborne constituents with the use of multiple HEPA filters and negative ventilation.

Where piping and pumps could require maintenance the use of double containment is not utilized in the nuclear industry, but the multiple barriers are. This is to allow for the reduction of exposure of personnel (through the reduction of the time spent on the repair). This is not the double containment that is typically seen in the hazardous materials operations.

The resolution of this issue is that the multiple engineered barriers do meet the definition of a vault for the piping and tanks with structures or inside of multiple engineered barriers. The result was that no piping inside of the structures or design areas required changing to double containment, since from a regulatory stand point they already met this. Only minimal piping that was single contained and not meeting the above requirements required secondary containment.

The second issue was that of dealing with administrative or inspection requirements where the exposure to personnel would be excessive. The use of the detection equipment would meet the requirements for these type of areas. Specifically the labeling of tanks or pipes containing high level waste, the daily or weekly inspection of piping or containers.

MARKING AND LABELING

As an Interim Status Treatment, Storage, and Disposal Facility (TSDF), the West Valley Demonstration Project (WVDP) must comply with labeling and marking requirements for tanks containing hazardous waste, per Title 6, New York Codes, Rules, and Regulations (6 NYCRR), Part 373-3.10(e)(4):

> The owner or operator must mark all tanks with the words "hazardous waste" and with other words that identify the contents of the tanks. For underground tanks, the markings must be placed on a sign in the area above the tank.

All hazardous waste in storage tanks at the WVDP is radiological mixed waste (RMW). Tank storage of RMW at the WVDP is limited to the underground High Level Waste (HLW) tanks and the treatment system tanks associated with the processing of HLW. The RCRA labeling requirements for the underground HLW tanks are met by co-locating "hazardous waste" signs with the "radiation area warning signs at the perimeter of the waste tank area. The "hazardous waste" signs list the hazardous constituents and/or characteristics of the waste.

The treatment system tanks are located in cells or rooms which can not be routinely entered by personnel because of high radiation fields. Due to their inaccessibility, these tanks are analogous to underground tanks. The WVDP meets RCRA labeling requirements for these treatment system tanks by posting "hazardous waste" signs in the tank areas (on airlock doors or in access aisles). These labels are in passageways which would have to be used to gain access to the tanks.

EXTENSIONS

There are a number of extensions that were sought. They consisted of:

1. Extensions due to large number of samples to be taken and analysis of waste materials from a historic process knowledge viewpoint for reduction of exposure of personnel,
2. Extensions due to EIS and RCRA conflict due to concurrent and contradictory requirements, and
3. Extension due to factors outside of WVDP control.

Extension Due to Number of Samples and Historical Analysis

The compliance issue is the need to perform both a sampling and review of process knowledge for a determination as to the content of the containers as they relate to hazardous materials. NYCRR 373-2.4(a) (2) states:

"Before a owner or operator treats, stores, or disposes of any hazardous waste, he must obtain a detailed chemical and physical analysis of a representative sample of the waste. At a minimum, this analysis must contain all the information which must be know to treat, store or dispose of the waste in accordance with the requirements of this subpart...."

The issues arose from the time period involved to complete the analysis of the samples, 30 days. At a minimum the analysis of mixed waste samples takes a minimum of 45 days at a certified lab, and is currently running closer to 90 days. This would be after the identification of the waste as requiring analysis following the historical analysis of the information.

The negotiations of the FSFCA, (Federal and State Facilities Compliance Agreement), has allowed for the WVDP to conduct a detailed historical process knowledge inventory of the wastes stored on site. The results are being tabulated in a report that will be transmitted to the regulators either at signing of the agreement or shortly thereafter.

Extensions due to EIS-NEPA and RCRA Concerns:

On December 30, 1988 the DOE published a Notice of Intent (NOI, 53 FR53052) in accordance with NEPA requirements announcing its plan, together with NYSERDA, to prepare an EIS for Phase II of the WVDP and closure of the WNYNSC. As part of the EIS process three times phased goals have been identified and are: the comprehensive closure of the WNYNSC; its return to the stare; and ultimately its long-term stability either in a compatible reuse or a Perpetual reserve status. This program will result in the formation of an Environmental Impact Statement (EIS) which is planned to be completed and reviewed through the NEPA process which will identify the closure methods, levels of decontamination and allow for extensive public comment. Following

completion of this a Record of Decision (ROD) will be issued for the site.

The issue deals with the fact that Closure Plan for the site needs to be completed for each of the Solid Waste Management Units (SWMU) and submitted for the Part B Permit Application. The NEPA process will not be completed for a number of years and it requires that no pre-disposition of the site prior to the ROD be determined. The result is that the Closure Plans would infact pre-disposition a method for site closure.

The result was that an agreement for "generic" closure plans for each of the SWMU be completed with multiple options for closure discussed and no specific method determined. Additionally, concurrent NEPA documents that are equivalent to RCRA documents will be used. A chart showing this relation is shown in Fig. 3.

Extensions Due to Factors Outside of WVDP Control

These are the cases where factors outside of WVDP control are affecting a required regulatory schedule. These are in the case where fire and emergency teams outside of the site personnel require training, updating and rewording of the site Emergency Plan, Spill Control and Counter Measure Pan, and other documents. The regulators were aware of these potential concerns and agreed that as long as WVDP maintained a "positive and active" measure for compliance there would be no issue involved in meeting these regulatory requirements.

CONCLUSION

The WVDP has through a very proactive and positive working relationship with the regulatory community been able to work with the regulators for a understanding and consensus on the difference involved with a nuclear facility versus a non-nuclear facility. These understandings and interpretations have resulted in assuring that the regulatory requirements are met, but are met in a way that both meets the requirements for nuclear facilities and RCRA regulated non-nuclear facilities.

The key to how this was accomplished was based on a clear understanding that the WVDP fully intends to meet the regulatory requirements, but must also maintain reduction in exposure to personnel, uses methods that are not traditional to non-nuclear facilities but are the basis for design, construction and operation of nuclear facilities and infact not only meet the regulatory requirements from a functional standpoint, but normally exceed them.

This understanding of the need to look at the regulations from a different perspective was an educational process not only for regulatory community, but for the WVDP Personnel as well. The end result is a very advantageous Federal and State Facilities Compliance Agreement, an agreement from the regulators for the use of non traditional methods for meeting the regulatory requirements, and a proactive and positive working relationship between all of the groups involved.

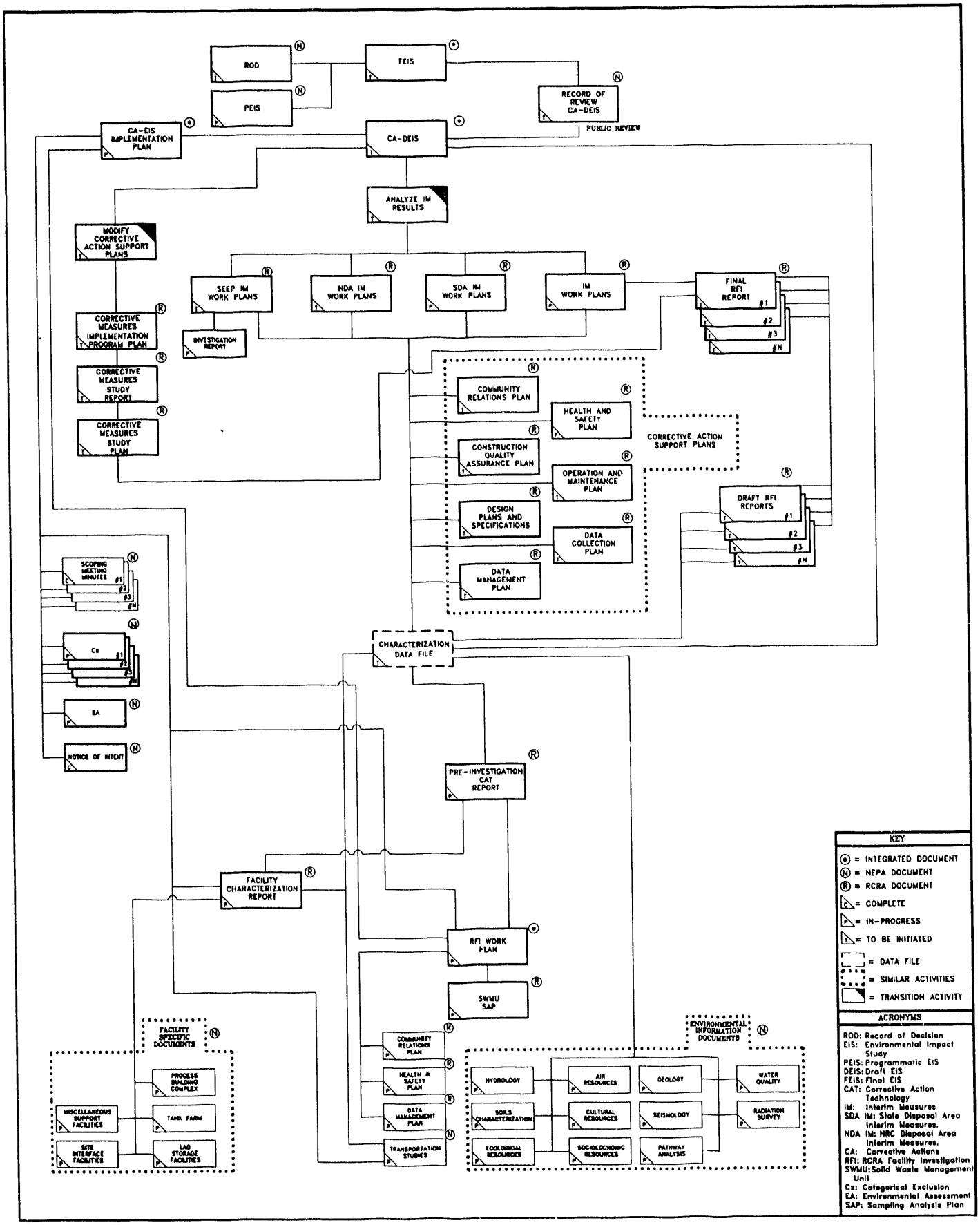


Fig. 3. Diagram showing interrelation of NEPA and RCRA documents.

IMPLEMENTATION OF 29 CFR 1910.120 AT A MULTIPLE-CONTRACTOR OPERATED FACILITY

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ABSTRACT

The application of 29 CFR 1910.120, Hazardous Waste Operations and Emergency Response, at a complex former Department of Energy production facility has been extremely complicated. The requirements established by this Occupational Safety and Health Administration standard are extremely complex and have required a significant expenditure of resources to implement. A discussion of both the specific requirements of the standard are provided along with some of the implementation strategies employed and difficulties encountered. Additionally, a detailed discussion of the scope of the standard is presented.

The Fernald Environmental Management Project (FEMP) formally the Feed Materials Production Center, at Fernald, Ohio is a former DOE production facility which has incurred a dramatic change in mission in becoming an environmental restoration site. Accompanying this mission change was the inclusion of the site on the National Priorities List (NPL). With the initiation of environmental restoration activities, a realization of the extent of application of 29 CFR 1910.120, Hazardous Waste Operations and Emergency Response, has been realized.

The application of this OSHA mandated requirement at a 425 hectare facility employing over 1500 contractor and government personnel, with several hundred separate companies represented, has been extremely complicated. Compliance initially resulted in the stoppage of several projects and the delay of even more at considerable cost to the Department of Energy. 29 CFR 1910.120 has required considerable time and effort to implement and continues to be a difficult tasking at this facility.

This paper discusses how 29 CFR 1910.120 has been implemented at the FEMP, how the problems encountered have been solved and how continuing problems are being evaluated. The following topics are discussed separately:

- Description and Scope of the Standard
- Site Program
- Site-Specific Safety and Health Plan
- Site Control
- Training
- Medical Surveillance
- Handling of Drums and Other Containers
- Other Requirements

This paper will not discuss the specific directives levied against operations conducted at Treatment, Storage and disposal facilities since these requirements are, in general, a subset of the broader requirements of the standard. Additionally, the emergency response requirements of the standard are not specifically addressed since the preexisting operations conducted at this DOE facility were perceived to exceed the requirements of 29 CFR 1910.120.

DESCRIPTION AND SCOPE OF THE STANDARD

29 CFR 1910.120, Hazardous Waste Operations and Emergency Response, was promulgated by the Department of Labor, Occupational Safety and Health Administration (OSHA), as mandated by Congress in the Superfund Amendments and Reauthorization Act of 1986 (SARA). The interim rule was promulgated on December 19, 1986 and modified on May 4, 1987. On March 6, 1989, OSHA promulgated the final rule which became effective on March 6, 1990 (1). (Corrections to this rulemaking were published in the Federal Register on April 13, 1990 (2).)

This rulemaking specifically addresses three types of operations.

1. Operations where employees are engaged in the clean-up of uncontrolled Hazardous Waste Sites. Compliance with all paragraphs of the standard must be achieved with the exception of paragraphs (p) and (q) (1).
2. Operations where employees are engaged in hazardous waste treatment, storage and disposal, as regulated under 40 CFR Parts 264 and 265 pursuant to RCRA, except small quantity generators and those employers with less than 90 days accumulation of hazardous wastes as defined in 40 CFR 262.34. Compliance with only paragraph (p) of the standard is required (1).
3. Emergency response operations for releases or substantial threats of releases of hazardous substances, and post-emergency response operations to such releases at all workplaces. If the site is not an uncontrolled Hazardous Waste Site, only compliance with paragraph (q) is required (1).

One of the major obstacles in determining a strategy for compliance with this standard is determining the scope of the standard. The interpretation of the scope is not consistent between contractors and lead to inconsistencies in the implementation of the mandated program. The standard applies to the following operations:

1. Clean-up operations required by a governmental body, whether Federal, State, Local or other, involving hazardous substances that are conducted at uncontrolled hazardous waste sites (including, but not limited to, the EPA's National Priority Site List (NPL), state priority lists, sites recommended for the EPA NPL, and initial investigations of government identified sites which are conducted before the presence of hazardous substances has been ascertained. An uncontrolled hazardous waste site is defined by OSHA as "an area where an accumulation of hazardous waste creates a threat to the health and safety of individuals or the environment". A clean-up operation is defined as "an operation where hazardous substances are removed, contained, incinerated, neutralized, stabilized, cleared-up, or in any other manner processed or handled with the ultimate goal of making the site safer for people or the environment (1)".
2. Corrective actions involving clean-up operations at sites covered by the Resource Conservation and Recovery Act of 1976 (RCRA) (1).
3. Voluntary clean-up operations at sites recognized by Federal, State, Local or other governmental bodies as uncontrolled waste sites (1).
4. Operations involving hazardous wastes that are conducted at TSD facilities regulated by 40 CFR Parts 264 and 265 pursuant to RCRA; or by agencies under agreement with the U.S. EPA to implement RCRA regulations (1).
5. Emergency response operations for releases of, or substantial threats of releases of, hazardous substances without regard to the location of the hazard (1).

Although the scope of this rulemaking was quite large, some clarification of the guidance is provided in the Supplementary Information published in the Federal Register accompanying the rulemaking on March 6, 1989 (1). Employees at hazardous waste disposal sites who will not be exposed to, or do not have the potential to be exposed to hazardous substances, are not covered by this rule. The provisions of this rule are designed to protect employees who have or may have exposures and would not be needed for those who do not. Operations with no exposure to hazardous substances, i.e., road building for site access, construction of, or the setting up of, temporary facilities in the clean zone, or the closure of a RCRA Site involving the building of a clay cap over hazardous wastes, are considered to be construction activities covered by the construction standards in 29 CFR Part 1926.

Initially at the FEMP, the scope of this standard was interpreted to apply only to the Remedial Investigation/Feasibility Study (RI/FS) work. However, after considerable debate and evaluation, the decision was made that most operations conducted at the FEMP, inside the former production area fence, and any work conducted in support of site remediation activities is covered by this rule. This includes RI/FS activities, drum handling and movement, excavation activities, and material sampling.

Furthermore, since the mission of the site was continuously evolving, all elements of the training requirements were applied to all site employees. The overall objective at the FEMP was to approach the requirements of this standard in an objective but conservative manner in order to ensure that adequate controls, documentation and training was available to protect the site employees to the maximum extent practical.

SAFETY AND HEALTH PROGRAM

29 CFR 1910.120 requires that employers develop and implement a written safety and health program for their employees involved in hazardous waste operations. The program shall be designed to identify, evaluate, and control safety and health hazards and provide for emergency response for hazardous waste operations. The written program must contain an organizational structure, a comprehensive workplan, a site-specific health and safety plan, a safety and health training program, a medical surveillance program, the employer's standard operating procedures for safety and health, and any necessary interface between the general program and site specific activities (1).

Since there are such a large number of contractors at the site, each with an existing health and safety program, the following actions were initiated:

1. Each primary contractor to the Department of Energy at the FEMP was required to review their health and safety program to ensure compliance with the requirements outlined in 29 CFR 1910.120.
2. Each primary contractor was required to develop, if they had not already done so, a Health and Safety Plan.
3. All subcontractors were informed of and required to follow the Health and Safety Plans developed by the primary contractors to ensure some level of consistency.

SITE SPECIFIC SAFETY AND HEALTH PLAN

The site safety and health plan is required to address the safety and health hazards of each phase of the site operation and include requirements and procedures for employee protection. The specific requirements of the safety and health plan is provided in Table I (1).

Ideally one plan could be written which would cover all operations of the site. However, due to the size of the site and the wide variety of tasks being performed on the site, one plan would be too large to be managed or used in the field. In order to implement this requirement efficiently, two levels of documentation have been created. A master health and safety plan has been prepared by each primary contractor which is then supplemented by multiple project/task specific health and safety plans.

The master safety and health plan provides general site information and safety procedures. It establishes site protocols and requirements and identifies how to prepare the task specific plans. The master safety and health plan addresses all of the requirements identified in 29 CFR 1910.120 with the exception of the safety and health risk analysis for each site task.

The project/task specific safety and health plans are written to be field documents which provide specific safety and

TABLE I

Site-Specific Safety and Health Plan
Minimum Requirements

1. Safety and health risk analysis for each site task and operation found in the workplan.

2. Employee training assignments.

3. Personal Protective Equipment.

4. Medical surveillance requirements.

5. Frequency and types of air monitoring, personnel monitoring, and environmental sampling techniques. This includes:

    a. Instrumentation to be used.
    b. Calibration methods.
    c. Maintenance methods.

6. Site control program

    a. Site map.
    b. Site work zones.
    c. Use of "buddy system".
    d. Site communications.
    e. SOPs or safe work practices.
    f. Identification of nearest medical assistance. (Where these requirements are covered elsewhere they need not be repeated.)

7. Decontamination procedures.

8. Emergency response plan.

9. Confined space entry procedures.

10. Spill containment program.

    - Specific requirements for the handling of drums and containers.

health assessments and requirements for the workers. These plans can be written by any of the contractors working at the FEMP. Prior to the initiation of any task/project in the process area or potentially contaminated area, this plan is written and the workers are trained to the requirements identified. The project/task specific safety and health plan must be at the work site during all operations and can be modified as necessary as field conditions change or as new information on the hazards on any project are better defined. Audits are periodically conducted to ensure compliance with the requirements identified in these plans.

These documents are reviewed and audited against U.S. EPA's Office of Solid Waste and Emergency Response (OSWER) Directive number 9285.8-02, U.S. EPA SARA Title I Section 126, Health and Safety Audit Guidelines.

SITE CONTROL

Site control procedures are required to be implemented to control employee exposure to hazardous substances. The site control program must as a minimum include a site map, site work zones, use of a buddy system, site communication and the identification of the nearest medical assistance.

The primary establishment of contaminated areas is derived from DOE Order 5480.11, Radiation Production for Occupational Workers. The only additional delineation of work zones derived from this standard is the creation of exclusion and contamination reduction zones around specific work areas.

Exclusion zones are simply defined as the area where the protective requirements of the task/project health and safety plan are required to be followed. As an example, during the installation of wells to support the field program off site, an exclusion zone must be maintained at, as a minimum, a five foot radius from the bore hole.

Contamination reduction zones are only established in areas where contamination of personnel and equipment is likely. The size of these zones are as required to decontaminate the equipment and can be set up or taken down as required. These areas are directly adjacent to the exclusion zone. In order to fully utilize resources at the FEMP, often equipment is wrapped in plastic and transported to the decontamination building.

TRAINING

All employees, working on site, exposed to hazardous substances, health hazards, or safety hazards, and their supervisors and management responsible for the site must receive the training identified in Fig. 1 (3).

The following issues must be covered in the training: the names of personnel and alternates responsible for site safety and health, safety and health hazards present on the site, use of protective equipment, work practices which can minimize workers risks, safe use of engineering controls, medical surveillance requirements, decontamination procedures, the emergency response plan, confined space entry procedures, and the spill containment procedures (1).

Management and supervisors must be trained on the safety and health program and the associated employee training program, personnel protective equipment program, spill containment program, and health hazard monitoring procedure and techniques (1).

Trainers are to be qualified and each person trained must be certified as having successfully completed the necessary training. Each person trained is required to be provided with a written certificate (1).

The implementation of these training requirements are met by both site training activities and by each contractor obtaining the mandated training for their employees. Each employer is required to ensure that their employees are trained to the requirements identified in Table II (1). Each primary contractor performs periodic checks on the qualification of all workers for the portion of the site activity for which they are responsible.

Special provisions have been established to allow for visitors and incidental workers on site such as delivery men.

MEDICAL SURVEILLANCE

All employers involved in hazardous waste operations must institute a medical surveillance program for employees who meet any of the following criteria:

	40 Hour	24 Hour	24 Hour RCRA TSD	8 Hour Annual	3 Day Field Training	1 Day Field Training	8 Hour Supervisor Training	Rad Safety 5 Hour Training	Safety Film *	Safety OR. *	Nuc. Safety *	Must be accompanied by trained GSW
General Site Worker (GSW)	✓			✓	✓			✓		✓	✓	
Occasional Site Workers		✓		✓		✓		✓		✓	✓	
TSD Workers			✓	✓				✓		✓	✓	
DOE Site Staff	✓			✓	✓		(✓)	✓		✓	✓	
DOE Site Senior Management								✓		✓	✓	✓
Supervisors ***	✓	(✓)		✓	✓	(✓)	✓	✓		✓	✓	
Administrative Workers ****								✓		✓	✓	✓
Process Area Escorted Visitors **									✓			✓
Process Area Non-Escorted Visitors *****								✓	✓	✓	✓	
Process Area Tours - Walking									✓			✓
Process Area Tours - Driving									✓			✓
Non-Process Area Visitors (Gov.)									✓			
Non-Process Area Visitors (Non Gov.)												✓

* Can be combined into 24 or 40 hour course
** Restricted Areas only
*** Supervisor required training is the same as employees plus 8 hour
**** Non-Process Area
***** Effective in 1992 this classification will be deleted
(✓) Optional

Fig. 1. Training matrix.

1. All employees who are or may be exposed to hazardous substances or health hazards at or above the permissible exposure limits or, if there is no permissible exposure limit, above the published exposure levels for these substances, without regard to the use of respirators, for 30 days or more a year (1).
2. All employees who wear a respirator for more than 30 days a year as required by OSHA's Respiratory Protection Standard (1).
3. Members of hazardous material response teams (1).
4. All employees who are injured due to exposure from an emergency incident involving hazardous substances or health hazards (1).

The primary contractors at the FEMP have the responsibility to implement the medical surveillance requirements of 29 CFR 1910.120 for their employees. An example standard physical examination matrix from a contractor at the FEMP is provided as Table III (4). It should be noted that each contractor at the FEMP has the opportunity to develop its own medical surveillance program and that the provided matrix is only one contractor's interpretation of what is appropriate for their employees. (DOE staff receive equivalent levels of medical surveillance.)

HANDLING OF DRUMS AND CONTAINERS

29 CFR 1910.120 levies specific requirements which are not repeated here. However, these requirements forced maintenance and material handling organizations at the FEMP to reevaluate their procedures and make rather significant changes to already established programs.

OTHER REQUIREMENTS

Several other requirements identified in the standard were relatively easy to implement. Emergency response operations including plans and decontamination procedures were already in existence and, in general, met or exceeded the 29 CFR 1910.120 standards. The ongoing health and safety activities including the personnel protective equipment program and the hazard communication program were already

TABLE II

Training Requirements

Initial Training

General site workers engaged in hazardous substance removal or other activities which expose or potentially expose workers to hazardous substances and health hazards.	Minimum of 40 hours of instruction off the site and a minimum of three days actual field experience.
Workers on site only occasionally for a specific limited task who are unlikely to be exposed over permissible exposure limits and published exposure limits.	Minimum of 24 hours of instruction off the site, and a minimum of one day actual field experience.
Workers regularly on site who work in areas which have been monitored and fully characterized indicating that exposures are under permissible exposure limits and published exposure limits where respirators are not necessary, and there are no health hazards or the possibility of an emergency developing.	24 hours of instruction off the site and a minimum of one day actual field experience.
On-site management and supervisors directly responsible for or who supervise employees engaged in hazardous waste operations.	40 hours initial training, and three days of supervised field experience (the training may be reduced to 24 hours and one day if the only area of their responsibility is not general site workers) and at least eight additional hours of specialized training.

Refresher Training

Employees, managers and supervisors.	8 hours of refresher training annually.

TABLE III

Medical Surveillance

	Initial Examination	Annual Examination
Medical History	x	x
Occupational Exposure History	x	x
Vital Signs	x	x
Comprehensive Physical and Summary Letter	x	x
Vision	x	x
Audiometry	x	x
Complete Blood Count with Differential	x	x
Blood Chemistry Profile	x	x
Complete Urinalysis with Microscopic	x	x
Urinalysis for uranium	x	x
Pulmonary Function	x	x
EKG	x	(x)
Chest X-Ray (PA and Lateral)	x	(x)
Thyroid Profile	x	x
Methemoglobin	x	x
Whole body count	x	x
Cardiac Stress Test	x	(x)

in place and were incorporated as part of the overall compliance program.

The application of a complex safety and health standard such as 29 CFR 1910.120, Hazardous Waste Operations and Emergency Response, is extremely difficult at major facilities such as the FEMP. Initially, as the scope of the standard was being determined, a massive training program, supported with the development of numerous health and safety plans, was required. This training/plan development period at the FEMP site caused many of the ongoing programs to be delayed until compliance with the standard could be achieved.

Major disagreements still occur at the FEMP over the interpretation of the scope of the standard, and virtually each organization has its own opinion. As the program continues to develop at the FEMP, more changes will occur with the implementation of this standard, and duplication of efforts will be avoided. However, at the present time, even though a great amount of time and effort has been expended to develop a reasonable and consistent program, confusion and consistency problems abound.

Situations have occurred where multiple contractors have been conducting the same job with different levels of personal protection, different levels of training, and different levels of medical surveillance. As these problems are identified, modifications to the program are made to develop consistency, even though it will be some time before a completely integrated program is in place.

It is extremely difficult to retrofit this standard into preexisting multiple contractor situations at large sites. As more and more Department of Energy Facilities are tasked with

cleaning up their sites, compliance with 29 CFR 1910.120 will become a higher priority. If applied effectively to a facility, this standard can greatly improve the safety of the workers.

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HISTORICAL GENESIS OF HANFORD SITE WASTES

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ABSTRACT

This paper acquaints the audience with historical waste practices and policies as they changed over the years at the Hanford Site, and with the generation of the major waste streams of concern in Hanford Site clean-up today. The paper also describes the founding and basic operating history of the Hanford Site, including World War II construction and operations, three major postwar expansions (1947-55), the peak years of production (1956-63), production phase downs (1964-the present), and some past suggestions and efforts to chemically treat, "fractionate," and/or immobilize Hanford's wastes.

Recent events, including the designation of the Hanford Site as the "flagship" of Department of Energy (DOE) waste remediation efforts and the signing of the landmark Hanford Federal Facility Agreement and Consent Order (Tri-Party Agreement), have generated new interest in Hanford's history. Clean-up milestones dictated in this agreement demand information about how, when, in what quantities and mixtures, and under what conditions, Hanford Site wastes were generated and released.

This paper presents original, primary-source research into the waste history of the Hanford Site. The earliest, 1940s knowledge base, assumptions and calculations about radioactive and chemical discharges, as discussed in the memos, correspondence and reports of the original Hanford Site (then Hanford Engineer Works) builders and operators, are reviewed. The growth of knowledge, research efforts, and subsequent changes in Site waste disposal policies and practices are traced. Finally, the paper places the current Hanford Site waste remediation endeavors in the broad context of American and world history.

IMPORTANCE OF HANFORD SITE HISTORY

On August 6, 1945, an atomic bomb was dropped on Hiroshima, Japan, and President Harry Truman released the story of the special wartime weapons project that had produced it. Although the material in the Hiroshima bomb came from the Clinton Engineer Works (now the Oak Ridge Site) in Tennessee, the President told the world about the entire Manhattan Engineer District (MED), the landlord of the Hanford Engineer Works (HEW - predecessor to the current Hanford Site). Three days later, an atomic bomb consisting of material manufactured at HEW exploded over Nagasaki, Japan, and produced an Allied victory in World War II just five days later. Then as now, the public was hungry for information about HEW. Then as now, it is important that we understand the history and the workings of these vast plants, their genesis, their operating history, and the wastes they produced.

Recent events, including the designation of the Hanford Site as the "flagship" of Department of Energy (DOE) waste remediation efforts and the signing of the historic Hanford Federal Facility Agreement and Consent Order (Tri-Party Agreement), have generated new interest in Hanford's history. Clean-up milestones dictated in this agreement demand information about how, when, in what quantities and mixtures, and under what conditions, Hanford Site wastes were generated and released. The attention of the national media is on the Hanford Site, especially since it has been learned that two-thirds of all the nuclear waste in the DOE complex lies in the lovely Columbia Basin (home to the Hanford Site). The bill for the 30-year clean-up projected in the Tri-Party Agreement is staggering, and must compete with other worthy public projects for funding. For all of these reasons, and also because of the very human desire to know our roots, and to own whatever problems and challenges are attached to them, Hanford Site history has become very important.

As the Environmental Division historian, I study Site history intensively everyday, and I speak and present to audiences who demonstrate the same hunger for knowledge about our past and our activities as was shown in 1945. Our history is rich - with glory as well as with nuclear waste and with difficult challenges - but all of it is ours, and we want to learn it and know it. It binds us together, and arms us to go out and solve the unique riddles in our pioneering waste clean-up program. Today, I would like to share with you some of the understandings that have been gained through the study of Hanford's history.

PRE-SITE HISTORY AND CHARACTERISTICS OF THE COLUMBIA BASIN

Non-Indian settlement of the Yakima Valley and the Columbia Basin began with sparse cattle ranches in the late 1850s. The first towns, Pasco and Kennewick, were founded in 1882, as the Northern Pacific Railroad brought development to the arid region. A small real estate boom between 1905 and 1910 founded the towns of White Bluffs, Hanford and Richland. From that time until 1943, the region stabilized into a network of farms and small supply and grain shipment towns. When MED officer Col. Franklin T. Matthias and two DuPont Corporation engineers came to look at the Columbia Basin in late December 1942, they found a region not highly developed nor populated. About 19,000 people lived in Benton and Franklin counties, nearly a fourth of them in the railroad town of Pasco. Kennewick held 1,800 people, and White Bluffs, Richland and Hanford combined had 1,500. The rest lived on regional farms.

However, the stark and lovely Basin met the criteria defined by General Leslie R. Groves, head of the Manhattan Project, and by leading DuPont and MED scientists. It

provided a large and remote tract of land, served by abundant power and rail lines and by the huge, clean water supply of the Columbia River. Its soil could bear heavy loads and yield a virtually endless supply of aggregate for making concrete. Matthias and the two DuPont scouts quickly realized that here they could establish a "hazardous manufacturing area" of at least 12 by 16 miles, far removed from main highways or populous towns. They reported to General Groves that the place was "far more favorable in virtually all respects than any other."(1) Groves agreed, and land acquisition proceedings began.

WORLD WAR II CONSTRUCTION AND OPERATIONS

Once the land was procured, construction proceeded at a nearly unbelievable pace. Between groundbreaking in March 1943, and the end of the war in August 1945, the MED built 554 permanent structures, among the most prominent of which were B,D and F reactors, T, B, and U processing plants, 64 underground, high-level waste storage tanks and many buildings dedicated to fuel fabrication in the 300 Area. The Hanford Project also constructed the new "government city" of Richland, capable of housing 17,500 people. It accomplished all this at a cost of $230 million.

Secrecy and the unique factor of radioactivity most defined wartime operations at Hanford. In the graphite reactor cores, tolerances for error were held in the range of five ten-thousandths of an inch, in order to compensate for the stresses that irradiation would produce. Newly designed ventilation systems sucked air inward, in an attempt to prevent the spread of airborne activity. 200-foot high stacks were erected to vent the separations plants off-gases (particularly Iodine-131) and to provide for safe dispersal through local air currents. Special fans and blowers added diluting air to the stack gases because, according to DuPont: "From the inception of the work under this program, it was realized...that the extraction of the plutonium from the uranium and fission products...would be accompanied by the removal and liberation of gases either highly toxic in nature or extremely radioactive." MED builders were determined to provide "for the safety of plant employees from the effects of these gases [and]...for the safety of all inhabitants and living creatures within a large radius of the project."(2) However, incomplete knowledge of the exponential generation of the off-gases and of the necessary "cooling" (decay) periods for irradiated metal, resulted in the release of 345,000 curies (Ci) of I-131 during 1945, and of 76,000 Ci during 1946.

MED leaders knew that HEW would need a team of on-Site experts in the new science of health physics. An umbrella organization known as the Health Instruments (HI) Section was established. (This section later expanded to become a division, and consumed 4 percent of Hanford's budget and personnel by 1950.) It defined and measured radiological hazards, established procedures to make jobs in plutonium production safe for workers, and developed and calibrated a number of new and unique environmental-monitoring instruments. Air monitors placed at 29 locations on and off the project, and gas and liquid sampling vessels, Geiger-Mueller counters and other devices for personnel monitoring all were used at Hanford. Film badges and two small, thin ionization chambers ("pencils") were worn by every employee on every shift. Finger rings, alpha monitors ("poppies"), and urine checks also were used to survey employees who worked directly in "danger zones."

In June 1945, in response to unexpectedly high levels of I-131 evolution, routine thyroid checks were begun among workers in the 200 Area. At that time, surveys of vegetation were expanded far afield of the Hanford Site, and routine monitoring of Columbia River water and aquatic life, and project groundwater, were established.

POSTWAR PRODUCTION LULL

After the victory celebrations of WWII, President Harry S. Truman offered a phased-in control of atomic energy and weapons to the United Nations. However, the Soviet Union, racing to develop its own bomb, vetoed the plan. The U.S. then sought to formulate legislation to place its atomic facilities under civilian control. Delays and Congressional wrangling characterized these efforts throughout 1946.

Throughout late 1945 and most of 1946, the MED adopted essentially a caretaker position. In fact, it instituted cost-savings measures that, at HEW, resulted in the closure of B Reactor in December 1945, and in the decrease of power levels at D and F Reactors. The number of contractor personnel at the eastern Washington site fell by half, from 10,000 in September 1945 to 5,000 in December 1946.

During the same period, many government officials and members of the public began to worry about the confused state of U.S. atomic policy and about slowed defense production. Finally, on January 1, 1947, the new civilian Atomic Energy Commission (AEC), formulated in the McMahon Atomic Energy Act of 1946, took control of the U.S. atomic complex, including Hanford Works. (The word Engineer was dropped to symbolize the separation of the plants from wartime control by the Army Corps of Engineers).

FIRST POSTWAR EXPANSION

Meeting early in the year, the AEC's General Advisory Committee assigned its highest priority to weapons research and production. Improvement and expansion of the plutonium-production units at Hanford topped the list. In a series of spring directives, the General Electric Company (prime site contractor since September 1946) was directed to build two new production reactors, and to develop the new REDOX (reduction-oxidation) separations process, as quickly as possible.

In August 1947, the upcoming expansion was announced in Richland. Residents expressed relief and joy and Tri-City businesses, which had been slumping, revived. The expansion of the Hanford plants and the city of Richland that occurred from 1947-49 was the largest peacetime construction project in American history up to that point, and cost more than the original building of HEW ($350 million).

During this expansion, H and DR reactors were constructed, going critical in October of 1949 and 1950, respectively. Z Plant, or the Plutonium Finishing Plant, also was built, making possible the conversion of Pu nitrate paste to hockey-puck-shaped plutonium metal, known as "buttons." Forty-two additional high-level waste storage tanks were also constructed, and Hanford Works became unionized. The Hanford Atomic Metal Trades Council was formed in 1948, and was certified officially by the National Labor Relations Board in February 1949.

Work also went forward on the development of the REDOX process, in order to save scarce uranium that was wasted in the first precipitation cycle of the old bismuth-phosphate processing. In 1949, Hanford Works built C-Plant in 200-E Area as a "hot semi-works" (pilot plant) for the REDOX process. Also during the 1947-49, the AEC built new housing on the west side of Richland, and the city grew to about 23,000. Richland "village," as it was known in the 1947-49 expansion period, was a busy and energetic place. By 1948, it had the highest birth rate in the nation, and it became the first city in the U.S. to adopt a "sister city" in Europe on an ongoing charitable basis. Visitors were enchanted by the optimism and vigor of Richland. In 1949, Time magazine termed it a "model residential city...an atomic utopia."(3)

During this same two-year period North Richland was founded five miles north of the then-current border of Richland. Barracks and small trailers there housed construction workers and their families. By the summer of 1948, just one year after its establishment, North Richland housed about 12,000 construction workers and about 13,000 of their family members.

Nevertheless, there were problems in the booming Richland area. There were frequent power outages as electrical transmission lines underwent constant expansion and there was an acute housing shortage. Billowing construction dust was constantly present. According to AEC records, radioactive particulates, Iodine-131 and nitrous-oxide fumes sometimes burdened the dust, and local officials undertook a vigorous tree-and-grass-planting effort to anchor down the powdery amalgam. Additionally, what the community newspaper described as a "mosquito plague" beset Richland every spring and summer beginning in 1945. For several years, large amounts of DDT were sprayed throughout the town and along the Columbia river to control these pests.

Meanwhile, as Richland and the Hanford plants grew, the Cold War worsened. The Soviet Union precipitated a communist coup in Czechoslovakia, and initiated a blockade of the city of Berlin in 1948. The U.S. responded with the Marshall Plan to aid economically unstable areas of Europe, and with the Berlin airlift (an 11 month ordeal). In 1949, communist and noncommunist nations each formed mutual assistance pacts -- the North Atlantic Treaty Organization (NATO) in the case of the U.S. and its allies, and the Warsaw Pact in the case of the Soviet Union and its satellites.

SECOND POSTWAR EXPANSION

Later that year however, the defense equation was altered by an astonishing new development. In September 1949, the Soviet Union detonated its first atomic bomb, and Hanford Works was plunged into another major growth surge. This expansion, lasting from 1950-52, received added impetus from the victory of Mao Tse-tung's Communist forces over Nationalist forces in China. Quickly, Mao signed a mutual assistance pact with Soviet dictator Josef Stalin. On June 25, 1950, Communist North Korean forces crossed south of the 38th parallel and ignited the Korean conflict. During the same period, some of the most well-known spy cases in American history surfaced, including those of Klaus Fuchs, Julius and Ethel Rosenberg, David Greenglass and Alger Hiss.

These events initiated the greatest era of expansion in U.S. atomic/nuclear history. Between late 1949 and 1952, the Nevada Test Site was established and began trials with atomic weapons, and the Pacific Proving Ground (Bikini and Enewetak - formerly spelled Eniwetok - Atolls) was expanded and refurbished. The same period saw the founding of the Reactor Testing Station (now Idaho National Engineering Laboratory), the Paducah Gaseous Diffusion Plant (KY), the Savannah River Plant (SC), the Rocky Flats Plant (CO), the Pantex Plant (TX), the Fernald Feed Materials Production Plant (OH), and the Sandia Laboratory (as a separate entity from Los Alamos). In January 1950, Truman approved development of the hydrogen (fusion) bomb, known at that time as the "Super."

At Hanford, the REDOX plant was completed and began operations in January 1952. REDOX utilized a methyl isobutyl ketone (known as hexone) solvent extraction chemistry, with prolific use of aluminum nitrate, nitric acid, sodium dichromate, and solutions containing ferrous ions. All of these corrosive chemicals, contaminated with radionuclides, reached the environment through spills, overflows, and ground disposal practices. Additionally, significant particulate releases of ruthenium 103/106 from the REDOX stacks occurred during the first three years of operations.

Other facilities built during the 1950-52 expansion at Hanford Works included C-Reactor, which went critical in November 1952, a large Experimental Animal Farm and Aquatic Biology Laboratory in 100-F Area, and 18 more single-shell storage tanks for high-level waste. The chronic shortage of tank space led to the decision to build two evaporators, 242-B and 242-T. Beginning in 1951, they functioned to boil off low-level wastes for cribbing and to concentrate and reduce the volume of high-level wastes. GE also reorganized the site as the Hanford Atomic Products Operation (HAPO).

In the 300 Area, five large buildings, along with ancillary service structures, opened. The 325 Radiochemistry Building, complete with eight "hot" cells, assumed many of the developmental missions of the WWII Technical (3706) Building. The 325 Building, along with three other new structures, was connected to a Radioactive Liquid Waste Sewer (RLWS) that led to the new 340 Retention and Neutralization Complex for holding radioactive wastes for transport and disposal in the 200 Areas. The 326 Physics and Metallurgy Building conducted approach-to-critical, lattice design experiments that led to safer, more efficient lattice configurations in the KE, KW, and N reactors. The 327 Radiometallurgy Building also opened in 1953, conducting both destructive and non-destructive examination (DE and NDE) of fuel rods and reactor process tubes. The 328 Building, a large machine and fabrication shop that replaced four WWII shops, also was completed. The 329 Biophysics Laboratory opened to develop and utilize state-of-the-art radiation detection instruments for the pioneering Hanford Works environmental monitoring and bioassay program.

Soon after these buildings were completed, continuing defense production expansions brought major additions to many of them. Also, the projected coming of N Reactor led to construction of the 306 Metal Fabrication Development Laboratory in 1956, and the 333N Fuels Manufacturing Building in 1960.

In 1952, U-Plant in 200 W Area, built during WWII but not needed as a processing canyon, was retrofitted as the Metal Recovery Plant. It's mission was to utilize a new tri-butyl phosphate/saturated kerosene (TBP-NPH) extraction technique, pioneered by Hanford chemists, to recover uranium

from the waste stored in Hanford's tank farms. Due to this unique process, the U facility also became known as the "TBP Plant." The scarcity of high-grade uranium supplies made this mission crucial. Much of the U.S. supply of uranium was housed in Hanford's tanks! Unfortunately, this mission also generated unexpectedly large amounts of chemically complex waste. Ferrocyanide salts were added to the waste stream in order to precipitate the cesium-137 component, thereby making the remaining wastes available for evaporation and ground discharge. The problems that have resulted from the ferrocyanide additions now constitute some of the most challenging ones in the Hanford Site clean-up program, and the ground discharges have added radionuclide and chemical burdens to subsurface soils and water.

THIRD POSTWAR EXPANSION

Just as the first Korean War expansion was reaching completion, the election of President Dwight D. Eisenhower initiated yet another huge augmentation at HAPO. The new President, alarmed that the defense budget had tripled in the past three years, believed that a spending slowdown could be achieved by concentrating resources on atomic weapons rather than conventional forces. He called this policy the "New Look" in armaments. His beliefs, in combination with the threat perceived by the explosion of the first Soviet hydrogen bomb in 1953, and with the need for plutonium for the embryonic American intercontinental ballistic missile (ICBM) development program, brought more rapid growth to Hanford.

This second Korean War expansion, sometimes known as the Eisenhower expansion, saw the construction of KE and KW reactors, the PUREX plant, 21 more single-shell waste tanks, and the Recuplex plant. The coming to power of the K reactors, known as the "jumbos," in 1955 brought the total number of reactors operating in the Hanford Reach of the Columbia River to eight. The cumulative effects of their effluent, released into the Columbia after only a few hours in retention basins, attracted the attention of the AEC. Scientists and physicians from the Division of Biology and Medicine conferred repeatedly with Hanford officials regarding potential threats to river life and safety.

The PUREX plant, like the U-Plant, used a basic TBP/NPH chemistry. Despite many advantages such as built-in concentrators and the utilization of nitric acid that could be distilled and reused many times, it produced copious volumes of liquid wastes, and increased groundwater mounds and radionuclide values in groundwater beneath 200-E Area. The Recuplex process, a Pu scrap recycling mission, produced relatively small, but highly concentrated, wastes. Carbon tetrachloride and many acidic wastes, all contaminated with Pu, were disposed to soils around the Recuplex plant from 1955-62.

ADDITIONAL EXPANSION BASED ON THE "PEACEFUL ATOM"

The 1950s also was a time of expansive plans and dreams for the future of the "peaceful atom." President Eisenhower's "Atoms for Peace" program, announced in December 1953, and the passage of the new Atomic Energy Act of 1954, designed to allow for more private, commercial atomic applications, brought innovative, non-defense programs to HAPO. Because U fuel sources were scarce worldwide, it was important to experiment with alternate fuel mixtures and types. In response, HAPO built the 308 Plutonium Fuels Pilot Plant (PFPP) and the 309 Plutonium Recycle Test Reactor (PRTR), both completed in 1960 in the 300 Area. From 1968-72, the 318 High Temperature Lattice Test Reactor (HTLTR) operated to test powdered, pelletized and other experimental fuels at high temperatures. The new 324 Chemical Engineering Laboratory adopted new waste vitrification work, and became heavily involved in fuels examination and in the processing of many Materials Open Test Assemblies (MOTAs) for the Fast Flux Test Facility (FFTF).

PEAK PRODUCTION YEARS AT THE HANFORD SITE

The years 1956-64 witnessed the most intense defense production period at the Hanford Site. Tensions of the Cold War, intensified by the coming to power of Nikita Khrushchev in the Soviet Union, drove the production of special nuclear materials. An confrontational Cold Warrior, Khrushchev told Americans in a 1959 visit: "Your grandchildren will live under communism!" He launched Sputnik I, the world's first, man-made vehicle to orbit the earth, on October 4, 1957. Within seven months, he had launched Sputniks II and III. These achievements combined with a dazzling string of other Soviet "firsts" in space to create a sense of national urgency in the United States. President John F. Kennedy pledged that he would close the "missile gap" with the U.S.S.R., and "get America moving again." Policies that he initiated tripled the U.S. nuclear destructive capability by 1964. In the Cuban "missile crisis" of October 1962, he successfully challenged the Soviet attempt to place ICBMs in the western hemisphere. Hanford's weapons production, as it had done with President Eisenhower before him, gave Kennedy's words the backbone and the teeth to face down the determined U.S.S.R. Without that production, the course of history might have been quite different.

During the peak production years of 1956-64, N-Reactor was built at HAPO, along with the Federal Building and the last four single-shell, high-level waste storage tanks. A larger and more sophisticated plutonium recycling plant, known as PRF (Plutonium Reclamation Facility), opened in 1964. Hanford chemists also pioneered a number of "isotope campaigns," producing megacuries of cerium, strontium, cesium, promethium and other rare earths elements for special military and NASA applications. During that period, Hanford was the world's only source for promethium, a rare earth element not found in nature, but used by Donald W. Douglas in the development of the artificial heart. From 1968-78, B-Plant, the old wartime bismuth-phosphate separations plant, operated to extract strontium (Sr-90) and cesium (Cs-137) from high-level waste.

WASTE MANAGEMENT PROBLEMS GROW IN 1950s AND 1960s

As the years of peak production went forward at HAPO, volumes of wastes produced by the eight single-pass reactors, N-Reactor, and the REDOX, PUREX, Z-Plant and B-Plant separations facilities, increased sharply. A 1956 "feasibility study" (prototype for modern Environmental Impact Statements required by the National Environmental Policy Act) resulted in the voluntary decision by Hanford managers not to construct additional single-pass reactors at the complex. However, power and exposure levels at the existing reactors were raised many times, to the point where each of the eight

older reactors operated at power levels nearly ten times those of World War II. Such levels brought thermal increases and added chemical and radionuclide burdens to the Columbia River. The river was cooled by huge controlled spills of cold water from the bottom levels of Lake Roosevelt, behind Grand Coulee Dam, each summer from 1958-64. By 1960, reactor effluent (wastewater) discharges to the Columbia averaged 14,500 curies per day, after a four-hour decay period in reactor retention basins. Hanford and AEC leaders discussed rising levels of contamination in fish tissues in the river and in shellfish in coastal waters near the river's mouth. Chemists and operators at the Site sought new practices that would reduce radionuclide formation in reactor effluent, or would bind or transmute the isotopes in different disposal practices. Much time, effort and money was applied, but workable, large-scale solutions remained elusive. During the same period, volumes of low-level wastes discharged to the ground also increased. Mounds in the water table beneath 200-E and 200-W grew larger, as did activity values in portions of the groundwater. In the mid-1950s, suspected and sometimes confirmed leaks from single-shell, high-level waste storage tanks began.

In 1958, the first comprehensive Hanford waste management plan was completed, calling for the immobilization of high-level tank wastes. However, the requirements for radioisotopes for the burgeoning U.S. space program and for new medical applications were among the reasons that the plan was not implemented. Many Site and other officials believed that Hanford's wastes could be a source of valuable isotopes.

PRODUCTION PHASE-DOWNS AT THE HANFORD SITE

On January 7, 1964, President Lyndon Johnson surprised the nation with his announcement of a decreased need for special nuclear materials. "Hanford To Cut Back In 1965," proclaimed the local newspaper the following day. Thus, the era of peak production at the eastern Washington desert complex slowed. Between December 1964 and January 1971, all eight single-pass reactors shut down. Production continued at N Reactor for another 17 years, driven by national programs to improve and expand guided missile systems, anti-ballistic missile systems, and other U.S. weapons programs. During these years, 28 double-shell tanks for the storage of high-level nuclear waste were constructed. The Site also engaged in new missions involving chemical extractions of special radioisotopes, and experiments with waste solidification methods. Development and construction of the FFTF brought new growth in many Hanford areas.

MODERN WASTE CLEAN-UP ENDEAVORS AT THE HANFORD SITE

In the late 1980s, the DOE began the large-scale release of thousands of historical reports known as the Hanford Historical Documents. Through these, the public, officials of the U.S. Environmental Protection Agency (EPA) and other agencies learned of the volume and extent of nuclear wastes at the Hanford Site. In consensus with the DOE, the decision was reached to pursue waste remediation at weapons production and testing sites throughout the nation. The pioneering Tri-Party Agreement, signed at the Hanford Site in May 1989 now serves as a national model for clean-up agreements. Historical research plays an important role in Hanford Site clean-up programs. By understanding the technical workings of the old chemical and atomic processes, we can identify and characterize the wastes logically produced by these operations. Further, we can identify and verify waste sites and their contents, always searching for another level of detail in terms of quantities, chemical components, times of discharge, methods of storage and disposal, and many other factors. Historical investigations can locate new waste sites and, in some cases, save the high costs of invasive physical characterization efforts when they are not needed. In the broadest sense, history can help us to piece together pioneering and seminal developments in the emerging discipline of American nuclear history -- to help our nation understand how and why certain events unfolded as they did, when they did, and thus to provide the raw materials for open, democratic discourse about our national history, goals and common identity.

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DISCOVERING WHERE THE PROBLEM IS HIDING: TECHNIQUES FROM THE FORMERLY UTILIZED SITES REMEDIAL ACTION PROGRAM (FUSRAP)

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ABSTRACT

The identification of environmental problems resulting from past operations and practices at federal facilities is not only a good management practice but also a logical precursor to site wide cleanup. Current problems and associated data may date back fifty years, and relevant records and personnel familiar with old operations are difficult to locate. The principal sources for information pertaining to past practices is available in records holding areas at particular facilities and at the Federal Records Centers of the National Archives and Records Administration. The volume of Manhattan Engineer District (MED) and Atomic Energy Commission (AEC) records is on the order of 65 to 70 thousand cubic feet. The FUSRAP program reviewed documents in a systematic, ordered fashion. Reviews were focused on potential radiologic contamination of off-site facilities, and the effectiveness of this tailored procedure, necessitated by the volume of records, is well established. Sources of historical information in the public domain, such as libraries, assessor's offices and elsewhere also should be considered. The decision to use and pursue sources of information should be made by environmental managers rather than facility archivists or librarians. The manager must constantly weigh the potential records value and benefit against the expense of records search and collection. Likewise, environmental managers must realize that the records they collect, maintain and store are a vital legacy to future generations. Colleges and Universities also have an important role. Training in records management should be part of an environmental engineering curriculum, and partnerships/internships in reviewing records and implementing systems for the DOE should be pursued.

INTRODUCTION

Earlier this year an article appeared in the New York Times that reported **the dumping of millions of gallons of radioactive waste on an AEC site during the 1950's** (1). The article noted that the Environmental Protection Agency uncovered "the extent of the unsafe dumping in a continuing review of... documents..." The extent of the dumping - some 127 million gallons - was estimated from information in records, primarily old memos, that were cited in the article.

A 1952 memorandum from an AEC construction contractor discusses methods for disposing of sump liquor from a pilot plant. It reads as follows: "**...the sump material, after being tested to determine that the U [uranium] content is satisfactorily low, will be pumped...into a tank truck...[and] then hauled and dumped into existing manhole No. 175 in the outfall sewer to the... River**"(2).

These are examples of the type of information that can be found in the inventory of records in holding areas at Department of Energy headquarters and Field Offices and in records that have been retired to the custody of the National Archives and Records Administration (NARA) Federal Records Centers located throughout the United States. Considered alone, they may be simply viewed as profound evidence of past sins on the part of DOE predecessor organizations and their support contractors. On the other hand, if they were the product of a deliberate, organized search and are accompanied by other documents that together provide a complete perspective of the past operations, they might be viewed differently -- as evidence of a proactive approach to the identification of potential environmental problems resulting from past operations and practices that require further examination in the light of today's standards.

The latter is descriptive of the long-standing approach initiated in 1974 by the AEC and continued, with some modification, by its successors, the Energy Research and Development Administration (ERDA) and the Department of Energy. This approach was formally defined in the Formerly Utilized Sites Remedial Action Program (FUSRAP) protocols in the early 1980's. The techniques and procedures used to locate information sources and assemble documentation to identify, characterize, and designate properties for cleanup to today's standards under FUSRAP are still in use.

The focus of the search for information under FUSRAP was toward the identification of radioactive contamination in the public domain. However, the lessons learned and the techniques and procedures used to identify sources of information and to obtain and assemble documentation to describe past operations and practices can be applied in support of today's environmental restoration activities on government facilities.

Furthermore, obstacles encountered during the search for records in support of FUSRAP activities made abundantly clear the need for implementation of sound records management practices to ensure that environmental restoration activities are properly recorded for future generations who might question the adequacy of current practices and procedures.

FUSRAP BACKGROUND

The FUSRAP program was initiated in 1974, to review and, if authorized, cleanup facilities formerly used by or for

DOE predecessors in the early phases of nuclear energy development. Although much of the government-sponsored research was centered at national laboratories, commercial facilities were used for storage of uranium and thorium ores and for fabricating and machining metal made from these ores. As a result of these activities, equipment, buildings, and land became contaminated with naturally occurring radioactive substances. These facilities were decontaminated in accordance with contemporary standards; however, subsequent guidelines have become more stringent, and records documenting decontamination are not always adequate for determining the final radiological condition. For example, the 1952 historical memo cited above mentions "satisfactorily low" uranium content in the sump liquor. Qualitative information of this nature is not sufficient to assess prevailing conditions then or the potential for residual radioactive contamination today.

Since 1974, the DOE and its predecessor agencies have identified several hundred Government and contractor owned and operated sites that were used in support of Manhattan Engineer District and Atomic Energy Commission operations from the early 1940's through the early 1960's. Most are known to have been involved in some way with the processing or handling of radioactive material owned by the Government. Through review of operational records from the period and analysis of information from other sources, over 400 sites were identified as potential candidates for consideration under FUSRAP. Many of these sites were covered by other Federal remedial action programs or were clearly under the jurisdiction of other agencies and, therefore, required only minimal review under FUSRAP. Other sites required more detailed investigations and, in some cases, radiological surveys. To date, twenty-eight sites and their vicinity properties have been included in the program for remedial action under authority provided in the Atomic Energy Act of 1954, as amended. Five additional sites were included in FUSRAP under specific legislation enacted by the Congress. Over three-hundred sites have been eliminated from further consideration under this remedial action program, primarily because: 1) records assembled on each site do not indicate a significant potential for residual radioactive contamination at the sites, 2) the Department of Energy does not have authority to conduct the necessary remedial action, or 3) it has been determined that another Government agency or program has authority and is responsible for cleanup of the sites. When sites are eliminated from further consideration under FUSRAP because the Department does not have authority to conduct required remedial action, the Environmental Protection Agency and State in which the sites are located are advised of the Department's decision and are provided information pertaining to the condition and status of the site for their consideration and appropriate action (3).

FUSRAP RECORDS SEARCHES

When the Atomic Energy Commission began survey investigations in 1974 to identify and determine the radiological status of formerly used sites, the emphasis of the investigations was on production and development scale operations. All of the Commission's divisions and field offices were requested to search their files for records needed to identify and define the nature of operations at known sites, to determine the radiological condition of the sites at the time contracts were terminated, to obtain information pertaining to current land use and ownership, and to provide similar information on new sites that might be discovered during the records review process.

By the early 1980's, all major Manhattan Engineer District and Atomic Energy Commission contractors had been identified, and initial radiological investigations were completed. Nonetheless, several hundred smaller prime contractors' and subcontractors' sites that had been identified still required investigation. The investigations had two purposes: to determine the potential for residual radioactive contamination at each site and to determine if the Department had authority under the Atomic Energy Act of 1954, as amended, to conduct remedial actions at the sites, if required. These activities required a detailed review of available historical records.

Record Sources

Records applicable to MED/AEC activities are housed in approximately nineteen facilities scattered throughout the United States. The number increases if one includes holdings of DOE contractors and the National Laboratories. Initial DOE custody is maintained at field and area offices until the records are formally transferred to the National Archives for long-term retention. The primary identifier for records upon transfer to the National Archives is the Record Group, which is nothing more than a unique number assigned to a particular series (or administrative branch) of records. For the MED/AEC, Records Group 326 is assigned to all AEC and predecessor documents. Figure 1 illustrates the top level of the FUSRAP protocol used to search for records.

The records group is a convenient identifier of records of interest; however, document holdings are identified in more detail by the "01 Report" or Accession Number Master List, which identifies the subject, volume, planned destruction date, and other information. As will be discussed in the next section, the "01 Report" is a valuable screening tool for identifying records of interest. Each entry of the computerized 01 report lists a subject entry, such as "operating records" or "radiologic badge data - 1957", and these entries may consist of one to several hundred boxes of documents. Fortunately, inventories of box contents (GSA Form 135 or the Accession Inventory) were available to further refine the search process.

Documents are stored initially in records holding areas of the DOE field offices. In the holding areas documents are prepared for transfer to Federal Records Centers in accordance with DOE Order 1324.2A, Records Disposition. Series of records are transferred to National Archives records centers for long-term retention and, in most cases, eventual destruction. Records management is a continuous, dynamic process: just as important documents addressing site remediation are being generated today, site operations documents from a decade earlier are being transferred to the National Archives, and even earlier documents are being destroyed in accordance with established records management procedures and approved disposition schedules. Because of the dynamic nature of these records, the FUSRAP program concentrated on reviewing as many relevant records as possible.

One of the ironies of the National Archives system is that while records are carefully organized by record group and inventoried by accession series, closely related records may be located in a number of centers, or records may be transferred to a distant center. For example, following closing of

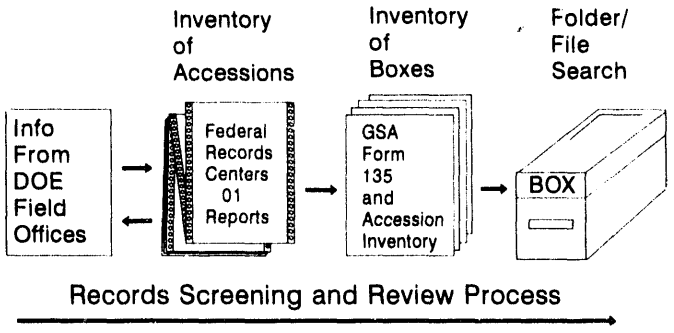


Fig. 1. Records search & screening protocol.

AEC'S New York Operations Office in 1970, records were divided and shipped to as many as six separate locations. Because the records were so widely dispersed, FUSRAP efforts were directed towards the identification of all locations with significant holdings of MED and AEC records.

The results of these surveys are presented in Table I for DOE and non-DOE sources. The information was collected in the mid-1980's, so collection contents and quantities are likely to have changed due to the continued archiving and destruction of documents. Investigations also identified three centers that did not contain any records from Records Group 326: namely, the Federal Archives and Records Centers in Waltham, Massachusetts; Philadelphia, Pennsylvania; and Kansas City, Missouri.

During records search and site investigation activities, a number of obstacles were encountered that increased the complexity and the magnitude of effort required to accomplish these tasks:

- Many of the records were, and still are, protected from public disclosure by their original defense security classification;
- Records inventories were fragmented - transferred to various field/operations offices and to the National Federal Archives and Federal Records Centers throughout the United States;
- Records were destroyed in accordance with records disposition schedules and Government records management practices;
- Records indicating that sites were decontaminated according to site criteria and health guidelines in effect at the time were not, in many instances, supported by radiological data required to evaluate the condition of the sites against today's standards;
- Changes in ownership and land use over the years had a significant impact on efforts to determine the physical location of the properties and to locate the current owners; and
- In some instances, records could not be found that might indicate the location of contaminated equipment, materials, and process wastes known to have been removed from these sites.

Information compiled during record search activities was sufficient to identify a majority of the formerly utilized sites but, in some cases, was not in sufficient detail to determine the potential for residual contamination. Therefore, a protocol was developed and a program of site investigations was initiated to obtain information from other sources, including on-site radiological surveys, if necessary, to evaluate the radiological status of the sites against current criteria and guidelines.

Secondary Information Sources

Secondary sources of information include contractor files, knowledgeable individuals, other Government agencies, and public information. Contractor records on reservations and major production centers may be as useful as those in the DOE or Federal records systems. Likewise, knowledgeable individuals can provide information that might otherwise be lost. Records from other Government agencies, past and present, such as the Nuclear Regulatory Commission, the Department of Defense, the U.S. Geological Survey, the former Metals Reserve Corporation and others, may be useful. References 4 and 5 provide detailed information on National Archives Holdings and Field Branch Holdings. Furthermore, each field branch publishes a detailed guide to its holdings.

Public information sources include public libraries, historical societies, and property assessment offices. Reference sections of larger libraries and historical societies maintain old city directories which contain addresses for companies and individuals, and identify nearby properties. Assessors offices can identify current and past property owners and property renovations. For the FUSRAP program, these sources are used to identify locations of businesses involved with the MED and AEC and trace land usage over time. Applicability to DOE reservations may be more limited.

GENERAL SEARCH PROCEDURES

The volume of records in Department of Energy and Federal Records Center inventories dictates identifying and targeting potential records of interest rather than randomly reviewing documents. For the FUSRAP program, the principal concern was the potential for residual radioactive contamination on off-site, non-DOE properties. Records of interest included contracts, trip reports, legal records, and other documents indicative of off-site operations involving the storage, handling, or processing of radioactive materials. Typically it is simple to exclude categories of records. For example, as-built drawings and personnel records would not have been reviewed during FUSRAP records searches.

As noted previously, the National Archives accession inventory report, or 01 report, provided a brief summary of Federal Records Center document inventories. Accessions of interest were identified from this report and the detailed inventory reports for each box were reviewed to determine if detailed document review was warranted. Most operators of Department of Energy records holding areas maintain inventory listings analogous to the accession inventory report and in some cases, inventories of documents within a defined group of records was available.

The next logical level of the search process addressed records folders or document groupings within each box. When an inventory of the contents of a box was available, the search could be focused on specific folders or groups of documents. Otherwise a quick scan of folder contents was required to identify the groups of documents that required detailed review. The record review process was tedious, and

TABLE I

Records Holdings

Center	Location	Quantity (Cubic Feet)
DOE Headquarters	Germantown, MD	70 to 80
Oak Ridge Field Office	Oak Ridge, TN	1,100
Environmental Measurements	New York, NY	15
Chicago Field Office/Argonne National Laboratory	Chicago, IL	350
Richland Field Office	Richland, WA	5,500
Albuquerque Field Office	Albuquerque, NM	150
Savannah River Field Office	Aiken, SC	2,000
National Archives	Washington, DC	4,200
Washington National Records Center	Suitland, MD	4,200
New York Federal Archives and Records Center	Bayonne, NJ	16,000
Atlanta Federal Archives and Records Center	East Point, GA	6,500
Seattle Federal Archives and Records Center	Seattle, WA	6,000
Chicago Federal Archives and Records Center	Chicago, IL	2,400
Dayton Federal Records Center	Dayton, OH	3,300
Fort Worth Federal Archives and Records Center	Fort Worth, TX	600
Denver Federal Archives and Records Center	Denver, CO	1,000
San Francisco Federal Archives and Records Center	San Bruno, CA	8,300
Los Angeles Federal Archives and Records Center	Laguna Niguel, CA	2,300

it was important to pinpoint areas of interest to concentrate and conserve resources.

Lastly, while FUSRAP targeted primarily Records Group 326, several other records groups assigned for use by DOE and listed in DOE Order 1324.2A are available as follows:

Record Group Number	To Be Used For
RG 201	Records of the Western Area Power Administration.
RG 434	General Records of the Department of Energy, and records generated by the former Federal Energy Administration.
RG 305	Records for the Bonneville Power Administration.
RG 387	Records of the Southwestern Power Administration.
RG 388	Records of the Southeastern Power Administration.
RG 447	Record of the Alaska Power Administration.
RG 430	Records of the former Energy Research and Development Administration.
RG 48	Records transferred from the former Office of Coal Research, dated prior to 1-19-75.
RG 412	Records transferred form the Environmental Protection Agency, dated prior to 1-19-75.
RG 70	Records transferred from the Bureau of Mines, dated prior to 1-19-75.
RG 307	Records transferred from the National Science Foundation, dated prior to 1-19-75.

RECORDS MANAGEMENT

Lessons learned during the FUSRAP experience resulted in a keen awareness of the value of historical records to this environmental restoration program. They provided the documents necessary to reconstruct past operations and practices. They provided information to guide and support site characterization activities, and they were of considerable benefit in a number of litigations in which the DOE was a defendant. The majority of records of interest to FUSRAP were found in DOE Field Office records holding areas and in the inventories of records transferred to the custody of Federal Records Centers for retention pending disposition instructions. The degree of success in identifying the records of potential interest was influenced by the effectiveness of the records management programs in place at the time.

An effective records management program is essential to the successful accomplishment of DOE environmental restoration and waste management goals. Department of Energy Order 1324.5, Records Management Program, defines records management as the planning, budgeting, organizing, directing, training, and control involved in managing the life cycle of records. Record material is broadly defined as papers or other documentary materials, regardless of their physical form, that are made or received in the course of public business and are worth preserving temporarily or permanently. Environmental compliance requirements continue to impact records management programs primarily from the standpoint of the ever increasing volume of records that must be maintained. Department of Energy Order 1324.2A, Records Disposition, was revised in 1988 to provide a set of guidelines to assist Departmental and contract managers responsible for

controlling and managing the records of the Department. Records retention requirements were revised in manner requiring longer retention periods for certain categories of records. Environmental monitoring reports and records pertaining to the disposal of radioactive waste are examples of records that require permanent retention.

All program organizational elements, including Field Offices and contractors, are charged with the responsibility to control, manage, and insure the proper disposition of records in accordance with the Department's Records Management Program.

SUMMARY

The initial objectives of the Formerly Utilized Sites Remedial Action Program are to identify and assess the potential for residual radioactive contamination at sites now in the public domain that were used by the MED and AEC during the early phases of nuclear energy development. Those objectives are being accomplished through an extensive, long-term process of records identification, collection, review, and analysis. The process includes protocols specifically developed to overcome obstacles encountered during efforts to locate and review very large inventories of records scattered across the United States. Techniques were also developed to identify and exploit other sources of information to fill gaps identified during the records review process.

The initial objectives of all environmental restoration remedial action programs, particularly those involving the identification and characterization of radioactive contamination, are similar. The information needs to assist in the accomplishment of those objectives are the same. Therefore, the FUSRAP experience is applicable and can be used to satisfy many of the information needs of other environmental restoration activities, including those remedial action programs on DOE installations.

Lessons learned during the FUSRAP records search and review process include an appreciation of the need for an effective records management system to ensure the preservation of records and provide efficient means for locating records when they are needed. In today's environment of ever increasing requirements to retain records and the tremendous volume of records already on hand, that is a tall order. But -- when the "who, when, where, and why" questions concerning environmental restoration activities of today are asked in ten to twenty years, as they will be, the records needed to provide the answers must be readily available.

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ENVIRONMENTAL RESTORATION TECHNOLOGY PROGRAMS AT MESA STATE COLLEGE: A STRATEGIC LOOK AT MANPOWER NEEDS

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ABSTRACT

The environmental cleanup of Department of Energy (DOE) sites within the next 30 years requires strategic planning to ensure adequate manpower is available when needed. Manpower needs projections within DOE have been based on analyses of current industry trends that indicate a substantial shortage of scientists and engineers. This paper explores the idea that the manpower requirements of DOE's environmental restoration program are not yet fully realized by most sites, which are currently in the predecisional work phase.

Experience at the Grand Junction Projects Office (GJPO), which has had environmental restoration as it primary mission for about 10 years, shows that in the postdecisional phases the manpower need for scientists and engineers decreases while the manpower need for technologists in technical, management, and support roles increases The GJPO, with Mesa State College in Grand Junction, Colorado, has developed an Environmental Restoration Associate degree program based on a strategic look at its manpower needs. This program receives start-up funding from DOE and has received donations in the million dollar range from various industry and state government partners.

INTRODUCTION

The Department of Energy's Environmental Restoration and Waste Management (ER&WM) Five-Year Plan has stated, "To achieve its vision for this program, DOE must compare internal and external human resource needs against the current resource base and take innovative steps to develop, motivate, and allocate needed resources"(1).

The DOE has acknowledged its environmental responsibility and has begun to assess the size and character of the cleanup of its facilities. The commitment has been announced, depending on availability of funding, that the restoration of DOE facilities will be accomplished by about the year 2020.

It is believed by some, including some within DOE's upper management, that the critical path in planning for environmental restoration will be technical manpower. It is a commonly held belief, supported by various studies and projections, that the nation will face a shortage of several hundred thousand scientists and engineers by the end of the century.

Yet if we believe that we need only scientists and engineers, we will limit our manpower objectives. Scientists and engineers will indeed play lead roles in research, development, testing, data analysis, design and technical management. However, applying that scientific and engineering work to the cleanup projects will require technicians, technologists, and many others from the spectrum of disciplines existing in the technical workplace.

If there is a technical workforce shortage, the planning to correct that shortage should be both long-range and strategic. The development of a manpower resource for a long-term program that is not in the traditional range of work for the organization requires not only an analysis on how to reach the objective, but an analysis of what the objective is.

The DOE Grand Junction Projects Office (GJPO) has been involved in the management of several environmental restoration projects long enough to recognize what the general manpower requirements are for the full process and where some of the shortages are in the workforce. A transition in programs at the GJPO has necessitated strategic planning, including manpower development. One of the key elements of the development of manpower at GJPO to meet future programmatic needs is the Environmental Restoration Associate Program at Mesa State College.

WHAT IS STRATEGIC PLANNING TO THE DEPARTMENT OF ENERGY?

"Strategic planning and operational planning should be integrated parts of a total planning process. Operational planning not integrated with strategic planning may easily lead us very effectively to where we don't want to be. The DOE has played essentially the same research, development, and production roles for many years and has not needed to make extensive use of strategic planning. It has always known within reasonable limits, what it was going to be doing. The environmental crisis within the DOE is causing it to rethink its future in terms of its culture and its programs. The *Draft Guideline for Strategic Planning*, Office of Planning and Analysis (PE-60), U.S. Department of Energy, August 1990,(2) includes these observations on strategic planning for DOE:

Strategic planning is not a science. At best it is a process for helping people think about the objectives they should set if they are to fulfill the mission they have been assigned and then how to go about achieving those objectives in general terms. There are about as many strategic planning processes and approaches as there are strategic planners! But there are some common denominators and, although each organization is free to adopt different processes as seem most expedient or appropriate to their organizational component, the following six elements must be developed as a minimum:

Mission
(businesses, task, or purpose)
May be several in a given organization. Why do we do what for whom and how?

Situation Analysis
(Environmental Scanning)
Where are we today in terms of our mission?
What's "our world" like and our likely future?
Who are our customers"
Planning assumptions.

Vision & Strategic Objectives
What do we hope to achieve and how will we know if we get there? What are the critical success indicators?

Strategic Issues
(Gaps between Situation & Vision, Obstacles)
What obstacles or barriers do we see?

Strategies
(Courses of Action to Accomplish Objectives)
What courses of action should we set out on?

Program Planning
(Plans which translate strategies into action)

The *operational* planning most of us are so familiar with deals with *how* to get things done and with the resources (people, money, facilities, time) to carry out tasks. Operating plans like budgets, capital line item projects, R&D (Research & Development) budgets, project proposals, etc. are vital to the mission of the Department. They deal, however, with *how* to carry out programs to achieve some objective or budget assumption. Strategic planning deals with the prior question of *what* it is that should be attempted. It deals with *what* objectives the many programs and activities of the Department should be striving toward. Note that this is a basic and qualitative difference. It is not just a matter of the planning horizon being much longer. Adding 10 to 20 years to an R & D budget, for example, may make it a long-range plan but not a strategic plan. Not also that while strategic plans will tell you where you hope to be in 10-30 years, they will not lay out a detailed road map of how to get there. They will offer strategies - courses of action - but not operational plans.

Another notable difference is that the operational plans we deal with are usually "bottom-up" plans, generated by the field or staff in accordance with assumptions they have been given as to objectives to be reached. In strategic planning, which deals with the generating of the "right" objectives, we need to use a "top-down" approach. The best thinking of the Program Secretarial Officers and their "direct reports" about the future they would like to envision for the Department and the Nation is required. The questions to ask is: What do you envision the "world" you're working in would be like in the longer term future if the programs or activities you are responsible for were to be really successful? Again, what is wanted is the best thinking of our key leaders about the future we should strive toward - not reams of paper, not carefully crafted forecasts of what the future may be, not extrapolations of the status quo, not majority consensuses of what "the public" wants, and not the products of special staff consultants or outside contractors. The output of the strategic planning work should be a thoughtful digest of your thinking and discussions, summarized in as few pages as possible."

STRATEGIC PLANNING AND DOE ER&WM MANPOWER PROJECTIONS

Planning for workforce needs is certainly one area that merits a strategic look. People are the most substantial resource of the DOE and its contractors. They cannot be quickly developed and apparently will not be easily acquired in a technical manpower shortage. They cannot be easily gotten rid of or "excessed" in favor of newer more appropriate models.

Our observation is that strategic planning should play more of a part in the assessment of future manpower needs for DOE ER&WM programs. Most of the DOE sites are only now embarking on manpower needs assessment studies. Most sites are looking at the acquisition of personnel for their ER&WM programs. Some sites are planning for an organizational transformation so that existing production workforces will be educated and retrained to do the cleanup. The intent is to precede what is essentially an operations planning exercise with a strategic planning component.

One DOE site indicates that it will precede its Environmental Restoration Training /Education Needs Assessment with a manpower resource study tied to a "Roadmap." If such manpower needs studies or training/education needs studies are not tied to a separate strategic planning instrument such as a roadmap, reams of unnecessary paper will be produced. There will be carefully crafted forecasts of what the future may be, produced by special staff consultants or outside contractors, consisting of extrapolations of the status quo. If upper management, accountable for the achievement of the organizational objectives, has not played a sufficient strategic planning role, correct objectives for workforce development will not be set. Qualitatively, the understanding of where they want to be in the future in terms of manpower types will probably not be reached. If one has not developed a strategic plan for workforce, how does one plan education and training programs for the development of manpower for environmental cleanup work 10 or 20 years from now?

At least one DOE facility has made a substantial start on assessing its manpower needs for environmental restoration and waste management. In a positive sense, the preliminary version of that study has recognized that manpower needs differ during the different phases of the environmental restoration process. Most other facilities are in the initiation or planning stages of manpower needs assessment studies.

DIFFICULTIES OF DOE ER&WM MANPOWER NEEDS ASSESSMENT

Someone once likened sending a man to the moon to throwing a baseball out of the window of a moving train in Los Angeles and into the window of a moving train in New York City. Planning a workforce for future programs of this nature has at least as many variables, only the variables are not as nicely mathematical. Also there are some issues of thinking and understanding that make this planning an unusually difficult equation:

Not having done this kind of work before, DOE does not accurately understand the nature of the work process, its manpower demands, and how those needs change over the life of the process. The people evidently needed in the beginning

of the process may not be the people needed in the latter stages.

DOE, because of its culture dominated by people with baccalaureate and postgraduate degrees, tends to think of its manpower in terms of scientists and engineers. Organizations tend to think of future manpower needs in terms of the types of personnel that they have traditionally used. Other manpower types may be more appropriate in many cases.

The subterranean nature of the facility contamination to be remediated gives the assessment of the amount and nature of that contamination a high degree of uncertainty. There are those in the DOE system who apparently believe that with enough wells and sophisticated computer modeling tools, the contamination can be delineated to the point that remediation will be merely a well-defined construction project.

It is a common strategic error to mistake the process for the product in the planning process. Before it changes, any business will market to the customer as much as possible of what it is currently capable of doing. If a business is in the R&D business and has a staff of scientists, it will attempt to solve the customers problems through development of technology, even if that development is not required.

In addition, the terminology of strategic planning is often used interchangeably and the meanings blurred. The strategic planning taking place at various levels of an organization adds confusion to the situation. A goal for the corporation may be the mission for a division. The DOE Environmental Restoration and Waste Management Five-Year Plan states that "DOE has set the ambitious goal of having all of its facilities cleaned up and in compliance with all applicable environmental laws and regulations by the year 2019." Another section of the Five-Year Plan states that ER&WM has a *commitment* to "Take innovative steps to develop the human resources needed to implement compliance and cleanup activities." It could probably be said that this *commitment* represents a strategy in the ER&WM strategic plan. The decoding of this terminology is unimportant. What is important is that some strategic thinking has taken place at the ER&WM Office level.

It can be difficult to take strategic thinking to the next level of detail and successfully plan manpower development if one has not done this type of work before, if one has erroneous ideas about the nature and complexity of the work, and if one's existing work process is not generally appropriate to the product.

THE GRAND JUNCTION PROJECTS OFFICE AND ENVIRONMENTAL RESTORATION

There is one tool that can help in the planning. If another organization has done the same work or work analogous enough in process and product, it can be studied as a model. In the case of environmental restoration, very little has been done that would serve as an analog process in the light of current regulatory law. Cleanup of Environmental Protection Agency (EPA) Superfund sites under the Comprehensive Environmental Recovery, Compensation, and Liability Act of 1980 (CERCLA) has been in progress only a few years. DOE site cleanups of significance will follow the cleanup protocol of CERCLAbecause they will either be on the Superfund National Priority List (NPL) or will be assigned CERCLA protocol through an interagency agreement with the EPA and/or the state.

The DOE Grand Junction Projects Office (GJPO) has been managing environmental restoration under the Uranium Mill Tailings Remedial Action (UMTRA) Program for about 10 years. Some of the first Records of Decision on NPL sites within DOE were accomplished at the GJPO in Fiscal Year 1990. One might consider the experience at the GJPO to be a "bench scale test" or planning analog for the DOE Environmental Restoration Program. It could be said that GJPO offers some foresight into DOE's manpower needs for the process of environmental restoration.

GJPO ENVIRONMENTAL RESTORATION MANPOWER AND STRATEGIC PLANNING

The size of the programs and the workforce at GJPO was never so large, at 300 to 650 people, that miscalculations in manpower needs could not be learned from and recovered from. Typically a "single program office," most of the programs stemmed from the early uranium mining and milling operations of the Manhattan Project, each evolving from the other, using the manpower from one program as the base for the next. The evolution of a workforce for changing programs, as well as changes within programs, has been part of GJPO. The UMTRA Program has provided an opportunity to watch the evolution of the workforce for environmental restoration.

It was observed that the manpower types required for the initial site assessment and feasibility study phases were dominated by scientists and engineers. The activity was gathering and analysis of data, examination of alternative courses of action, and preliminary engineering design. After a decision on remedial action was reached and parameters set, the program became managed very much like a construction project, albeit a highly technical construction project. With most of the performance criteria for remediation set, the level of technical expertise required diminished and the manpower mix changed substantially, with more technicians and particularly technologists used.

The evidence of need for a type of technologist not readily available in the Grand Junction workforce was seen during early engineering design for UMTRA. High school graduates were initially hired to do some of the day-to-day engineering tasks like gathering and recording site surface physical data, developing simple remedial action designs, and documenting those designs. It was found that they were able to perform only the most basic tasks without substantial supervision. Reacting to that experience, some graduate engineers were hired to perform those tasks, who were soon dissatisfied with the mundane tasks and desired to move on. The turnover rate was great. It was by circumstance that one of the people hired during this time had an Associate degree in Civil Engineering Technology. His level of mathematics and science competency was appropriate for the tasks and he remained challenged with the work. He had no environmental restoration industry experience, and was limited at first in his ability to move to other areas of the program. We knew that the complexity of our work was increasing. We tried to find other people with his level and kind of education, but were largely unsuccessful.

There were essentially none available locally and the level of salary did not make relocation from other areas a good option. If we were to utilize this type of person, the source needed to be local.

About 5 years ago, as it was known that UMTRA was a program with a finite life ending in 1993, strategic planning was initiated at GJPO as a formal process. We needed to know what we would be doing in the future and what we needed to do to get there. It became apparent that our experience in environmental restoration, although small compared to some of the cleanups to come, made us an important resource for all of DOE. It also became known that local remediation of sites would phase out in favor of management and support roles at other DOE facilities. We would need to become more of a multi-program office with needs for a flexible workforce. We would need to evolve our workforce to meet the needs of new programs. Because of our experience through the environmental restoration process of UMTRA, we found we had some basis for setting manpower objectives.

ENVIRONMENTAL RESTORATION TECHNOLOGY PROGRAMS AT MESA STATE COLLEGE

Our "discovery" of the civil engineering technologist and his success in filling a pivotal technical role led us to Mesa State College. Mesa State was the source of his degree. If Mesa State could educate another technologist oriented to our environmental restoration industry, we could place our workforce in a strategically advantageous situation for future programs.

GJPO has had a long and productive relationship with Mesa State, and they were receptive to our ideas. However, they had no staff or expertise in this area. Around the country there was no comparable program in environmental restoration. While educational programs in waste management were more common, drawing on expertise from the wastewater treatment and process chemistry fields, the most experienced pool of environmental restoration people was at the GJPO. In order to achieve our objective of developing a technologist component in our workforce, we would have to supply the expertise to educate them. We would have to go into a partnership in the education business.

Interestingly, this resulted in a change in Mesa State's planning. For some time, the low enrollment in their Civil Engineering Technology and Drafting Technology programs had been a problem. The possibility of a new type of program which might use some of the existing staff and facility made it possible for them to plan and begin to phase out those programs.

The GJPO partnership with Mesa State in the Environmental Restoration Associate Program began informally in 1988 with a series of ongoing discussions and curriculum development iterations. Eventually, it was decided that there was enough enthusiasm and interest to pilot two of the proposed courses. This was done in the 1989-1990 academic year. The average attendance was encouraging and the evaluation of the success of the courses was high from both students and faculty. GJPO personnel served as adjunct faculty instructors. Many of the students were GJPO personnel wanting to move from their technician positions to roles more applicable to future work.

At this point, steps were taken to make the partnership more formal. A Curriculum Development Committee was formed, consisting of appropriate people from GJPO, Mesa State, ARIX Engineering, and Colorado Department of Health. Before the proposed project went further, it was jointly reviewed by the management of GJPO and Mesa State College. Would such a unique program make sense in the long-range strategy of each organization? What would each organization require from the other in a long-term partnership?

Mesa State required start-up funding for a new program. DOE-EM52 has provided funding in Fiscal Years 1990 and 1991. Mesa State College uses the start-up funding from DOE to acquire staff and infrastructure until the state funding picks up that cost. State funding covers the cost, not covered by tuition, of educating each resident student. The State of Colorado funds college programs on a rolling two-year average; thus, it will be in the third year before a new program receives its first State funding at about 25 percent and in the fifth year before full State funding is received. This staff and infrastructure is quantified in terms of full-time equivalent faculty (FTE).

Once the commitment was made by GJPO and Mesa State, an effort was made to locate other partners to contribute to the development and/or the funding of the program. One of the first to show interest was AT&T, who generously donated a substantial computer laboratory for computer-aided instruction. The Colorado Governor's Job Training Office, USWest, and Public Service Company of Colorado also provided funding grants, mostly toward scholarships for retraining.

By July of 1990, the curriculum was fully approved by the State of Colorado and a formal announcement of the program was made with comments from Dr. Clyde Frank, DOE-EM50; Colorado Governor Roy Romer; Augie Pitrolo of DOE-Idaho; and Mary Ann Littler of AT&T. We have taught the first year of classes and are now beginning with the second year. We will see the first graduates in the spring of 1992.

For GJPO, graduation will be a first step in achieving one of the objectives in our manpower development plan, both in the availability of local manpower resources and in the evolution of our existing workforce. For DOE, it means that there is a model at GJPO which may be followed in lieu of undirected experimentation in environmental restoration manpower development.

A DOE UNIVERSITY-NATIONAL LABORATORY WASTE-MANAGEMENT EDUCATION AND RESEARCH CONSORTIUM (WERC)

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ABSTRACT

This paper presents the results and current status of a consortium of three universities and two national laboratories working closely with industry for an Education and Research program on waste-management and environmental restoration. The program sponsored by the U.S. Department of Energy has been in effect for 18 months and has achieved significant progress towards establishing:

- undergraduate, graduate and associate degree programs involving environmental management,
- interactive TV courses from the consortium members transmitted throughout the United States, Mexico & Canada
- a satellite TV network
- a professional development teleconference series,
- research programs at the leading edge of technology training multi-disciplinary students,
- research laboratories for analyses, testing, and student training
- technology transfer programs, including a TV series on research applications,
- outreach programs, including pre-college and minority education, community monitoring.

INTRODUCTION

In February, 1990, the Secretary of Energy, James Watkins, approved a cooperative agreement for a waste (management) education and research consortium program proposed by New Mexico State University (NMSU) to the U.S. Department of Energy (DOE). This program known by the acronym, "WERC" includes NMSU, the University of New Mexico (UNM), the New Mexico Institute of Miming & Technology (NMIMT), the Los Alamos National Laboratory and the Sandia National Laboratories. This contract is based on the recognition that efficient and safe management of waste is a broad multidisciplinary issue that cannot be addressed by any one entity or organization, but requires a collaborative effort between multiple organizations with diverse expertise and experience.

The program is unique and innovative in many aspects. It provides an integrated approach to this national need, and includes:

1. Education in waste management by the three Consortium universities resulting in graduate, undergraduate, and associate degrees with concentration in environmental management. (The term waste management is used in a broad sense throughout this paper and includes all aspects of environmental management and environmental restoration.)
2. A professional development teleconference series for industry and government.
3. Research programs at the leading edge, providing training to students and information to faculty feeding into the education programs.
4. Education and research at the campuses, as well as from three field sites.
5. Ties with other multidisciplinary university facilities.
6. Ties with two National Laboratories (Los Alamos & Sandia) located in New Mexico and a Federal Laboratory Oak Ridge Associated Universities.
7. Technology transfer and education via an existing fiber optic network, a satellite link, and an existing statewide extension program.
8. An outreach program of special interest to pre-college students, communities and business and government leaders throughout the United States.

A description of this program has been presented earlier (1-4). This paper updates the earlier presentations and describes the current status and achievements of the program.

EDUCATIONAL COURSES

In the first year, WERC successfully set up the following educational programs:

1. An undergraduate option or concentration in Environmental Management with a major in any field that provides the necessary prerequisites.
2. Master of Science degree options with special emphasis on the Management of Radioactive, Hazardous, and Solid Waste.
3. A two-year Engineering Technology Associate degree program in Hazardous & Radioactive materials handling.
4. A series of professional development intensive courses presented through interactive satellite video to laboratories, industry, and federal agencies throughout the country.
5. A capstone design course on environmental problems with competition between universities throughout America.

The Consortiums first major task in education was to set up the curriculum and establish undergraduate degrees accredited by ABET at the Consortium universities in the engineering fields noted below. This resulted in options leading to a minor in Waste Management.

The core programs necessary to satisfy ABET requirements in each of the disciplines are specified in the catalogs of the respective universities. These core requirements are supplemented by 18-30 hours of courses relevant to waste management, covering not just technology, but also other aspects such as legal, public policy, economics and risk evaluation.

The graduate program was also established by Fall 1990. This program requires the students to take core courses in their chosen discipline, but with approximately one half of their credits in the waste management concentration, including a research thesis or research project in waste management.

The Associate Degree program was started in radioactive and hazardous materials technology closely patterned after the accredited engineering technology programs offered on the main campus of NMSU at Las Cruces. An important feature of the new curriculum is the high degree of transferability into existing, accredited four-year engineering technology programs. The engineering technology approach to program design and operation carries implications with respect to faculty credentials as well as course content, level and rigor. The technology program uses the WIPP facility in conjunction with the New Mexico State University Carlsbad Campus as the training facilities. Graduates of this program will be prepared for entry level employment as technicians in industries, laboratories and government agencies concerned with the generation, mining, disposal, transportation, storage or regulation of hazardous wastes and materials.

A major emphasis of the consortium is to interchange courses between the Universities and to transmit the courses throughout the U.S. and even internationally. An interactive satellite video system has been set up with the objective of presenting an overview of economic, legal, policy, management, and technical courses in the problems of radioactive, hazardous, and solid waste management and environmental restoration for U.S. research, industry and educational facilities. The satellite system has been installed and is currently in use for course transmission between the three universities as well as to several other sites. Three courses are being transmitted in Fall 1990 and 6 - 8 courses are planned for subsequent semesters.

As part of the program, student fellowships have been awarded to both undergraduate and graduate students. These fellowships are awarded on basis of academic merit and a desire to pursue a career in the environmental field. In the first year approximately 37 fellowships were awarded to undergraduate students and an equal number of graduate students were awarded research assistantships. In the second year, this was expanded to about 80 students. Industrial interest has resulted in substantial increase of our fellowship funds, thus leveraging the DOE funds.

The degree programs started in Fall 1990 at all three universities. The undergraduate enrollment in the first semester was about 200 students and the graduate about 50. These students range from freshman to graduate students. Our estimate is that we will be awarding 200-300 degrees with the environmental concentration (or minor) in the first 4 years of the program, leveling off at about 100 each year.

As part of the effort to introduce a design component and at the same time encourage enter-university exchange of information, we have developed and implemented a national university design competition. Universities throughout the United States, Canada and Mexico were invited to compete in the design of a plant for an environmental process and follow this up with a small scale demonstration at a central site. This provided a capstone design course to universities and at the same time brought universities students and faculty from diverse parts of America together to exchange information. In 1991 we had seven universities participating and over 50 universities have agreed to participate in 1992. The first year was a fantastic success in achieving the objectives of design education and information exchange based on feedback from the participants and the judges.

EDUCATIONAL RESEARCH TRAINING

The educational research scope of the Center is broad-based and is designed to include all areas of radioactive, hazardous, and solid waste management and environmental restoration. The first round of projects were selected from proposals submitted by faculty and employees of the consortium members with collaboration from the National Laboratories and industry.

The process started with solicitation of proposals. The selection of projects to fund was made by a panel of experts based on the following criteria:

1. Does the proposal have technical merit, a sound approach and the potential to advance the state-or-the-knowledge?
2. Are graduate and undergraduate education already an integral part of the contemplated research? Are students involved in the research? Will the research feed into the education courses?
3. Are the facilities and equipment proposed adequate to accomplish the research contemplated?
4. Does the proposal support the consortium's concept of cooperation among members and/or external federal, state and local research organizations?
5. How well does the research address issues of reduction, storage, transport, disposal, economics, risk assessment, legal and public policy related to waste management and environmental restoration?
6. Do the investigators have the credentials to carry out the research and to train students?
7. Does the proposed research have cooperative support from outside sources (e.g., industry, other programs, etc.)?
8. Does the research have the potential for results applicable to issues in a reasonable time frame?
9. Is the budget reasonable for the proposed scope?

In the first round we received 87 preproposals. After initial discussions with the investigators, these were screened down to 57 full proposals. Twenty-seven of these were selected for funding and the projects were started in February 1990. These covered a range of waste management issues as

shown in the table at the end of the paper. All but one of these projects have principal investigators from at least two universities and a national laboratory. A second round of 62 proposals were received in September 1990. Following an evaluation as above, 33 were chosen for funding in 1991. The second round projects started in January 1991. A listing of the second round projects is shown in Table I.

As a means of facilitating the use of the results of our research for education in a timely manner, this past summer we conducted a satellite television series on the research programs. The faculty members and students involved in each research area presented their results to a wide audience consisting of industry and university people.

It is too early to predict the impact of the research. However several of the projects are already showing promise for meaningful applications. It is our objective that in 2 - 3 years, commercial technologies will result from this program activity. Equally important is the practical experience that about 150 faculty members and students are getting from the involvement in the research projects and the exchange of technology between the three universities and the two national laboratories.

EDUCATIONAL RESEARCH AND TESTING FACILITIES

Three facilities have been set up to assist with the research and education.

1. The Soil-Water-Air Testing and Research Facility (SWAT) on the NMSU campus at Las Cruces is functional and is currently providing analytical services in the areas of toxic and hazardous waste management to researchers from the universities and other organizations. The laboratory is equipped for physical, inorganic, organic and bacterial analysis of soil, water, air and plants.
2. The Radioactive Experimental Facility at Carlsbad (CREF) has the role of exploratory development and research associated with transuranic waste isolation. Furthermore, it provides support for monitoring WIPP activities and for instrumenting experimental activities planned by other facilities.
3. The Oil-Water Experimental Facility at Hobbs (HOWE) provides for educational, research, and development programs related to environmental and waste disposal concerns of the petroleum industry in the United States. A field laboratory is also available for use. The field laboratory consists of a watered out petroleum reservoir. The producing formation is approximately 2,000 feet deep and 15 feet thick.

It is particularly important to note that each of the facilities has an educational component and a technology transfer component.

TECHNOLOGY TRANSFER

The technology transfer function of the Consortium is emphasized throughout the program. Specific activities for technology/knowledge transfer noted below are in various stages of implementation:

- An Executive Board and an Advisory Board composed of representatives from top management of government, industrial and environmental organizations have been formed and functioning for the purpose of directing the program.
- Continual dialogue has been started with industry and government agencies via an Industrial Liaison Program, via briefings and via newsletters.
- The educational program is continually transferring knowledge from theory and research to the hundreds of students and industrial professionals.
- Research results are being transferred via seminars and via formal contacts with participants from industry and government. Results from each funded project are reported each quarter. The fiber optic communication network and the satellite link are used for wide communication of the results; a special ITV series was completed in Summer 1991.
- An eleven part professional development teleconference series is in progress on topics of interest to participants from government and industrial organizations. This series is being transmitted via the satellite system throughout the U.S.
- Over 30 technical papers have been presented and published on the various aspects of this program. This includes progress in the education program, the laboratory operations, and the education research results.
- A number of organizations have joined the Consortium's Industrial Affiliation Program and the program is being expanded to others.
- Planning is under way to use the university's extension program for technology transfer.

Technology transfer is only meaningful if the information is utilized by the outside world. Therefore, the Consortium holds meetings and seminars where industrial and government representatives discuss implementation of research results. These seminars, meetings, and workshops are held at various locations, including the three Consortium university campuses, the National Laboratories and the three field laboratory sites.

OUTREACH

As the program progressed through its first year, opportunities were identified for reaching out to other groups that could benefit by education and research in the waste management and environmental restoration area. Activities thus started include:

1. A model program has been started for environmental data observation by pre-college (K-12) students in close co-operation with the Los Alamos National Laboratory which originated this program (SWOOPE)
2. A summer program on environmental engineering design has been conducted for over 100 high-school teachers and their minority students in the last two summers. This program gives a one week intense training to the high school participants in use of math and science for environmental design.
3. Speakers and tours are provided for pre-college students.

TABLE I

Descriptive Titles of Research Projects Undertaken in 1991

1) Adaptive Control of Manipulators and Telerobots Handling Hazardous Waste: Phase
2) Application of Biotechnology to Industrial Wastes Containing Toxic Metals
3) Design of Operator Interfaces for Hazardous Waste Removal
4) Assessing Risk Costs for Nuclear Waste Transportation
5) Nuclear Waste Storage Vault Closure Determination
6) Remediation of Hazardous Waste Sites by Heap Leaching
7) Minimization and Remediation of Nuclear Waste Using Actinide Chelators
8) Dynamic Modeling for Designing Transportation Packaging Components
9) Enhancement of Solar Photocatalytic Detoxification
10) Understanding Change in Public Perceptions of Nuclear Waste Policies
11) Recovery of Toxic Heavy Metals from Contaminated Groundwater
12) Nuclear Waste Repository Ventilation System Studies
13) Constrained Motion Control for Telautonomous Robot Handling of Waste
14) Study of Geochemical Behavior of Uranium Tailings Leachate in the Substrate
15) Laboratory Validation of Models of Groundwater Pollution Transport
16) Calibration of Near-Field Stability Instrumentation at the Waste Isolation Pilot Project
17) Conditional Simulation and Contaminant Flow Modeling
18) Treatment of Waters with BTX and Heavy Metals Using Tailored Zeolites
19) Efficient Algorithms for Modeling the WIPP Site
20) Biodegradation of Explosives Wastes
21) Evaluation of Unsaturated Zone Contaminant Transport Models for Waste
22) Development of Sensors for Waste Management Applications
23) Stable Isotope Study of Soil and Ground-Water, WIPP Site New Mexico
24) Deformation Mechanisms in WIPP Backfill
25) Reforming and Gasification Technology for the Destructions of Wastes
26) A New Fast Scanning Environmental SEM for use in Waste Studies
27) Charged Aerosol Scrubber for Air Purification
28) Slurry-Phase Bioremediation of Oilfield Production Pit Sludges
29) Vadose Zone Microbiology for Mixed Hazardous Waste
30) Design of Compact Microsensors for Monitoring Organic Contaminants
31) Mobility of Radioactive Colloidal Particles in Groundwater
32) Performance of Rock Reinforcement Systems at Elevated Temperature

4. An environmental design contest has been developed and implemented for competition by university students throughout the U.S. A design demonstration was held on Earth Day 1991 and the next round is planned for April 1992.

5. A laboratory and environmental training program has been started for Native American students at the Navajo Community College at Shiprock, NM. A laboratory has been set up for environmental monitoring around the Shiprock area. Students and faculty will gain hands-on experience. A two year program is under development.

6. A major new effort has been started on environmental monitoring of the Carlsbad, New Mexico area. This community is located near the Waste Isolation Pilot Plant (WIPP) facility which is planned as a repository for transuranic (TRU) wastes. This program was started at the request of the Carlsbad community. An independent group has been formed to do complete monitoring of the area (flora, fauna, etc). This group, which reports to the Director of WERC, will generate the data using state-of-the-art techniques and will also conduct research on monitoring techniques.

ORGANIZATION

The organization is as outlined in Figs. 1 and 2. The overall WERC program is led by a Director who reports to the Dean of Engineering at NMSU. The Dean serves as Chairman of an Executive Board that sets the strategic direction of the Center. The Executive Board is made up of top management representatives from DOE, the National Laboratories, government and industry, and provides oversight of Center plans and progress by reviewing overall program plans and strategies, key resource allocations and key hiring decisions as well as evaluating progress against approved plans and budgets.

The operations are managed by the Director. An Advisory Board, made up of selected representatives form the three Consortium universities, the two national laboratories, selected environmental organizations, and selected industrial organizations, work with the Director to provide advice, information, and ambassadorship to identify key external linkages and promote relationships. This board advises on agency and industry needs, mechanisms to build relationships, and status of key environmental variables including technology state of the art and practice.

Each of the major functions (Research & Education, Facilities, Interactive TV) are supervised by Technical Heads, who report to the Director. The Carlsbad Monitoring Center

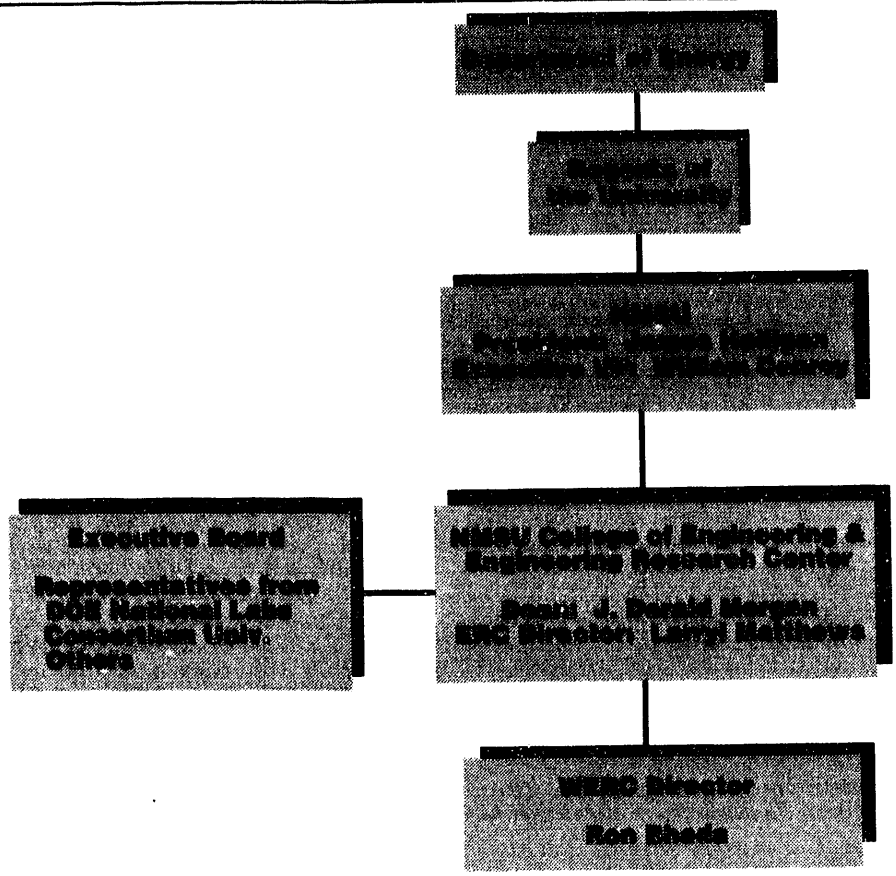


Fig. 1. WERC administrative organization.

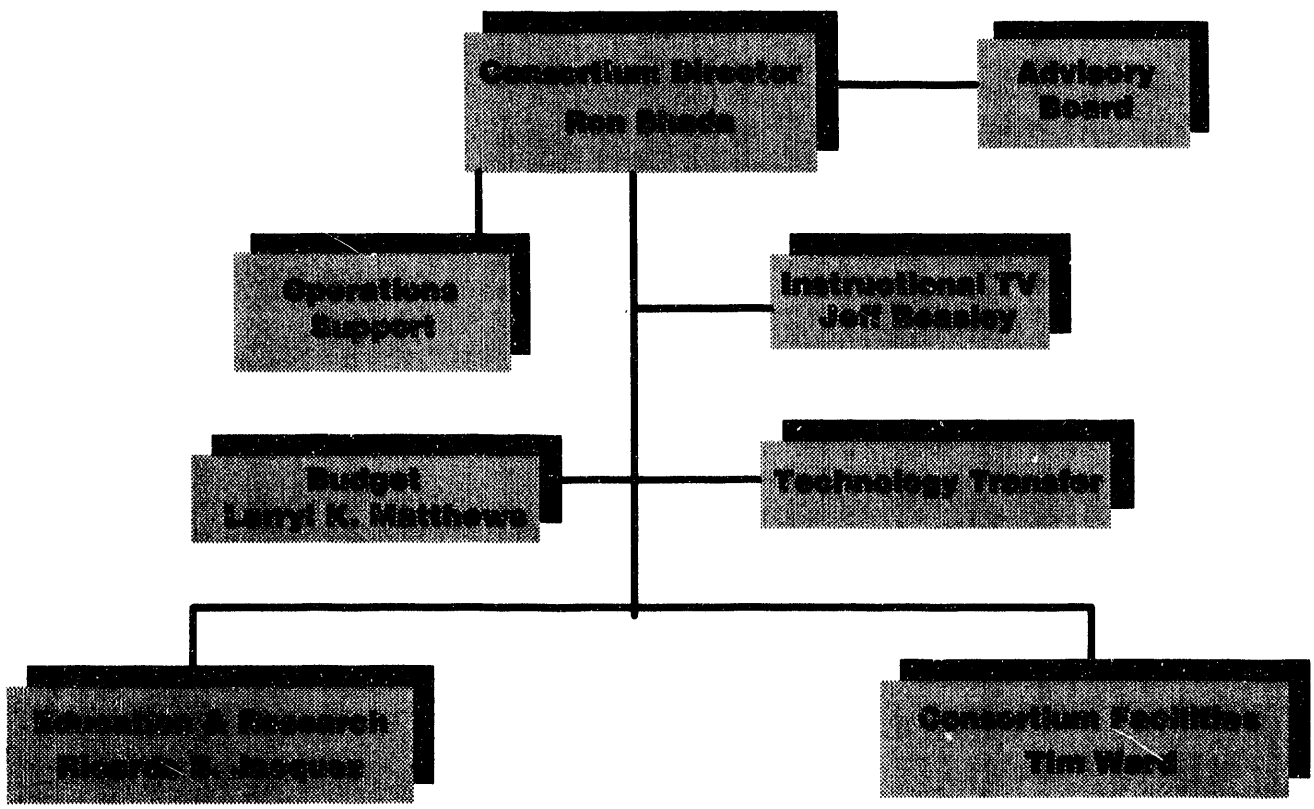


Fig. 2. WERC organization.

is under the operation of an Executive Director reporting to the Consortium Director.

Industrial participation is built into the program as part of the Advisory Board. In addition, industrial participation is included in the Industrial Affiliation Program and the Teleconference Educational Program. Sponsorship is continually sought for specific programs that satisfy the criteria listed previously, i.e., technical excellence and relevance to the Center's purpose.

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LEVERAGING EDUCATIONAL, HUMAN RESOURCES, AND ORGANIZATIONAL INFRASTRUCTURE TO PROVIDE SOLUTIONS TO ENVIRONMENTAL REMEDIATION WORK FORCE PROBLEMS

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ABSTRACT

The field of environmental engineering and environmental science is so new that many colleges and universities have only begun the process of bringing academic programs into their areas. Many professional personnel don't need full degree programs but may need only certain courses to enhance their skills in the environmental area. This article discusses the partnership between the Hanford contractors, DOE-RL, and Washington State University in an innovative way in solving a portion of the remediation work force problems.

SHORTAGE OF ENGINEERS AND SCIENTISTS

Beginning with the landmark 1983 report, A Nation at Risk, over 200 studies and assessments have documented the serious decline in the quality of U.S. education, particularly in science and mathematics. By every current measure, U.S. student achievement in science and mathematics is unacceptably low. Moreover, the number of U.S. students interested in pursuing careers in a scientific or technical field are also declining. This is due not only to demographic changes, but also more seriously, to the minimal numbers of students interested in these career areas -- especially minorities and females (SEN-23-90). This shortage of technical personnel is even more apparent in the areas of environmental science and environmental engineering.

The winds of change are being felt not only at the Hanford Site, as we move away from our 40-year history of a defense-related mission to a new mission of environmental restoration and waste management, but throughout the DOE complex as well. A person does not have to study the demographics too closely to see that the employment pool of experienced environmental professionals is small. The U.S. Department of Health and Human Services estimates that by 1995 there will be a need for 100,000 environmental professionals.

If we are to be successful in our remediation activities we must have skilled and knowledgeable employees at all levels of the remediation mission. We as contractors cannot hope to alleviate this problem by ourselves. We need the tri-partnership of our local colleges and universities, DOE, and contractor programs to train, retain, and attract personnel with the technical skills needed to carry out this mission.

RETRAINING NEEDS

Work force projections for the Hanford Site have concluded that there must be a major reeducation and retraining of the Hanford work force if we are to efficiently conduct the cleanup effort here. One or two programs to meet the transition needs of this diverse working population will not be sufficient. We must be innovative in our approaches to training and education in order to fully utilize the existing pool of talented workers already on the payroll.

The need for environmental professionals is a real one. How do businesses approach this problem? Is it cheaper to grow or to buy? Recruitment and relocation expenses continue to increase and can easily run into the tens of thousands of dollars. This doesn't account for the fact that there is a finite number of professionals to go around and recruitment is not always an easy or successful task. Therefore, it may be more cost effective for a company to spend their money on retraining the long-time loyal employees.

DOE-RL and its contractors have submitted a detailed "Training Transition Plan" outlining programs and partnerships which will be created and/or utilized to help in this retraining effort. Utilizing existing human resources will be a cost effective measure to fulfill worker shortages in critical areas. Some Human Resources specialists fear an "inbreeding" will occur if major recruitment efforts are not undertaken. However, I would suggest that "inbreeding" is not all bad. Successful organizations become successful because this "inbreeding" takes place. The difference is that successful organizations "inbreed" quality, productivity, and innovation. There is no reason that, with the proper management culture, existing employees cannot be retrained not only in a new career but in a new organization culture as well.

There are a number of academic programs throughout the country that deal specifically with environmental issues. The challenge before us -- the environmental industry and DOE in particular -- is to increase our involvement with our colleges and universities to make sure that people with the right skills are available to us in the near future to help offset the current shortage of professionals with environmental skills. The major thrust of environmental activities at Hanford over the next 30 years will be in site remediation.

COLLEGE AND UNIVERSITY PROGRAMS

To develop a more comprehensive picture of the state of environmental education and training at the Hanford Site we looked at a number of college curricula to get an indication of what is being offered at other colleges and universities across the country.

The DOE must utilize already existing partnerships between contractors, the DOE, and educational institutions to identify technical objectives and long-range program plans for remediation activities. This partnership must help establish cooperative efforts and facilitate joint analysis, evaluation, and action planning to address DOE education and training needs.

Organizations must gain a spirit of innovation if we are to resolve these issues in the near term. The old ways of retraining and recareering individuals must be scrutinized. This goes for DOE and contractor organizations as well as colleges and universities. The worker targeted for our efforts is typically between the ages of 35 and 50 years old with at least a four-year degree. Can we really expect these individuals to leave their families four hours a day four days a week to attend the old style night classes? To attend college on a 3/4 or full time basis is akin to holding down another full time job. There has to be a better way.

There have been some innovative approaches to these issues made by other DOE and DOE contractor organizations. We at Hanford wanted to evaluate these programs to see if they would be workable here and if they would be academically acceptable to our local college and university.

Colorado State University offers a distance-learning program called State University Resources in Graduate Education (SURGE). This program utilizes satellite programming and video-taped classes to meet student needs in education. Students can view classes at their convenience. Tests are proctored at local sites. Environmental engineering is not offered at this time but the technology for this type of program structure is relatively inexpensive.

Chem-Nuclear Geotech in Grand Junction, Colorado, has been working with Mesa State College for an associate degree in environmental remediation technology. Students attend school 20 hours a week, work 20 hours per week and are paid for 40 hours. Students are chosen for the program by board members who evaluate applicants for the 10 slots in the program. There has been talk of allowing the use this course work as a minor in the geology baccalaureate program, thus getting as bigger bang for the buck.

Idaho State University and the University of Idaho have teamed with the Idaho National Engineering Laboratory (INEL) for a graduate program in Hazardous Waste Management. Students were given release time to attend classes while being paid their normal salaries. However, the cost of the program has been questioned and modifications are in the works.

HANFORD AND WASHINGTON STATE UNIVERSITY

DOE-RL and the Hanford contractors looked to Washington State University for a mechanism to upgrade the environmental skills of some of their engineering staff. There were some specific needs which needed to be met. The specific educational needs for professionals in environmental remediation may transcend traditional academic disciplines. For example, the skills of environmental engineers, chemical engineers, geologists, soil chemists, and meteorologists are essential for the cleanup of complex environments such as that found at Hanford. To meet job demands, professionals often seek second bachelor degrees or masters degrees in fields other than their original bachelor degrees. In many cases, these cross-over degrees are earned on a part time basis while the professional continues to work full time.

Earning a second bachelors degree may require nearly all the upper division course work as well as qualifying course work at the lower division. Bachelor degrees usually require selected blocks of courses over the entire spectrum in the discipline. The masters degree is more focused but generally requires a research component such as thesis. Furthermore, cross-over masters degrees may require significant qualifying course work at the undergraduate level. Earning a second degree part time can easily take four or more years.

The time for a qualified work force at Hanford is now. A block of nine to eighteen semester credits may be sufficient to qualify a student for a particular work assignment --- especially if the student has gained the industry culture through previous work experience.

Typically, part time students matriculate in one or two courses per academic term (quarter or semester). Earning twelve semester credits can easily consume several years on the traditional semester calendar. By compressing courses into eight week sessions (such as in summer school), the time required to reorient professionals can be significantly reduced.

PROPOSED ACCELERATED AND CERTIFICATED PROGRAM

Working with Kaiser Engineers Hanford (KEH), the environmental engineering faculty at Washington State University-Tri-Cities (WSU-TC) has developed a proposed program which would provide academic courses on an accelerated schedule. The proposed program has two key features:

1. Modules of four semester-length courses will be offered in eight-week blocks. Students could take up to three courses of their choice from a given module or could select courses from several modules. At the completion of nine semester credits, students would be issued a certificate of completion by their company. Students would also earn a transcript from WSU.
2. A sequence of modules, or tracks will be developed so that the student can progress in greater depth toward fulfilling the educational needs of the job assignment. Because all courses will be from the WSU catalog, the student will be progressing toward a degree. If the demand is sufficient, an entire degree program could be accelerated. However, at this time, only two module sequences are proposed to be accelerated. For example, if all the courses taken by a student carried graduate credit, the student could earn over half the credits for a masters degree in sixteen weeks. A two-module sequence would well qualify many students for job assignments in the environmental field.

Because KEH provides architect/engineering services for the Hanford Reservation, an environmental design track and an environmental management track are proposed. Other Hanford companies can use these tracks or can define additional tracks to fulfill specific needs. However, the program is intended for the public at large and is not restricted to the job demands at Hanford.

CURRICULUM

The program could be initiated (Tier 0) with a series of optional refresher classes. Most students expected to participate in the program already have engineering degrees. However, a professional's skills in engineering fundamentals and mathematics can erode with time if not continually used. These skills can be revived through a series of continuing education short courses. For example, a three hour seminar

in differential equations coupled with self study at home can refresh one's skills sufficiently to handle subsequent academic course work. This concept of topical refresher classes at WSU-TC has worked well in preparing graduate engineers for the professional branch licensing examinations. Presumably, students can take refresher classes on their own time and at their own pace. If a student does not feel confident after taking refresher classes, then the student should enroll in regular academic classes on relevant topics.

The first level of academic courses (Tier I) will be upper division engineering courses required for the bachelors degree in Civil Engineering. Because KEH is predominantly an engineering company, most of KEH's professionals hold bachelors degrees in some engineering discipline. The bachelors degree that best qualifies students for the masters degree in Environmental Engineering is Civil Engineering; the bachelors degree in Chemical Engineering also well qualifies students. The Tier I courses are intended to qualify students for graduate level course work. Students need to take only those qualifying courses that fulfill deficiencies. A suggested list of qualifying course work is shown in Table I. The course of study for the Masters degree in Environmental Engineering is shown in Table II.

TABLE I

TIER I: Qualifying Module

CE 315	Fluid Dynamics (3)*
CE 317	Geotechnical Engineering (3)
CE 341	Intro to Environmental Engr. (3)
CE 342	Water and Waste Water Treatment

* Semester Credits

TABLE II

Tier II: Environmental Design Module

NuE	484	Intro to Nuclear Engr. (2)*
CE	446	Hazardous Waste Engr (3)
CE	4XX	Concrete Design Methods (3)
Ce	4YY	Remediation Facilities Design (3)

*Semester Credits

The second level of academic course work (Tier II) will be at the senior/introductory graduate level. At WSU, upper division courses not required for the bachelors degree can be used for either senior electives or as graduate courses. Thus Tier II courses could either be applied to a second bachelors degree or to a masters degree in Environmental Engineering, Environmental Science, or Engineering Management. Tier II courses will be focused into specialty tracks.

Because of KEH's role as an architect/engineering firm, a track in environmental design is of high interest. The treatment, handling, and disposal of radioactive and mixed wastes at Hanford will challenge existing design methodologies. A suggested list of courses for a module in environmental design is shown in Table III. Another track of interest to KEH is one in regulatory compliance. Federal statutes such as RCRA and CERCLA impose requirements not only on design but on other operational functions. A suggested module of courses in this track is shown in Table IV.

TABLE III

TIER III: Environmental Compliance Module

Env S 4ZZ	Intro to Risk Assessment (2)*
Env S 444	Env. Impact Statements (3)
Env S 445	Hazardous Waste Mgmt (3)
Env S 510	Intro to Env. Law (3)

* Semester Credits
Note: Env S 444 and 445 may also be taken at the 500 level

TABLE IV

TIER III: Environmental Monitoring and Characterization Module

CE 415	Environmental Measurements (3)*
CE 475	Groundwater Hydrology (3)
Ch E 465	Envirochemical Engr (3)
Rad S 405	Intro to Rad Physics (3)

* Semester Credits
Note:CE 415 may also be taken at the 500 level

A track in Environmental Characterization and Monitoring should be of high interest to other Hanford contractors and the environmental consultants at large. A suggested module of courses is shown in Table V.

Advanced modules of courses (Tier III) can be offered. These would be strictly graduate level courses and all credits would apply to a masters degree. For the Master of Science in Environmental Engineering, additional modules of core courses or electives as given in Table II can be defined. As a student progresses towards a degree, the student should focus on the core courses and the sequence of prerequisites for elective courses. For the Master of Science degree in Environmental Science, a wide choice of courses in atmospheric science, earth science, and environmental health science can be selected as well as courses in Environmental Compliance. For the Master of Science in Engineering Management, a wide choice of electives can be selected in either environmental engineering or environmental science.

Besides existing course work from the WSU catalog, new courses will be developed in both environmental engineering and science. Technologies such as vitrification (both in-situ and process facilities), soil washing, in-situ contaminant immobilization, slurry walls for hydraulic barriers, and grout vaults for storing radioactive wastes are all outside the scope of traditional engineering course work.

As an example, a new course in Environmental Remediation Facilities and Process Design has been proposed. In this course, students will explore the conceptual designs of processes, equipment, and facilities needed for remediation, immobilization or storage of hazardous materials. Function design requirements would be developed by the students.

TABLE V

Course Matrix

Course	College Program							
	NTU	SMU	NJIT	UT	UI	USAF	WSUE	WSUS
Haz Waste Man./Eng	X		X	X	X		X	X
Env Laws & Regs	X	X			X	X	X	X
Env Pollution Model.	X				X			
Treat of Haz/Chem Waste X	X	X	X		X		X	
Treat Rad Waste	X			X	X			
Remediation Design	X				X		X	
Risk Assessment		X			X	X		X
Env. Chemistry & Biol.		X	X	X			X	X
Sources of Haz Waste		X						
Air Pollution Mgt X		X	X	X				X
Project Mgt X								
Microbio for Env Eng.			X	X			X	X
Bio Treatment			X	X				
Solid Waste Disp Sys			X	X			X	
Water/Waste water Analy.			X				X	
EIS			X				X	
Hydrology				X			X	
Hydraulics				X				
Env Systems Eng.						X	X	
Env Planning						X		
Env Measurements								
Ground water Pollu.							X	
Geotech Eng X						X	X	

Compliance to regulatory requirements such as RCRA and industry codes and standards would be discussed. Process flow diagrams and plant layouts would be developed by student design teams. Such practical design efforts might replace the typical thesis culminating most masters degree programs.

QUALITY CONTROL

Because the proposed program is nontraditional in terms of academic calendar, and because many students are expected to seek cross-over degrees, academic quality must be maintained. Three elements are affected: course work, students, and instructors.

As discussed above, regular courses from the WSU catalog will be selected. Any new course will undergo the same approval process of any regular course. This process involves approval by qualified faculty and review by curriculum committees. Course content will not be reduced for the sake of student convenience. Students will have to take the same prerequisite courses and will have to fulfill the same standards as though these courses were taken as part of a degree program on a regular campus and on the traditional academic calendar.

Presumably, students can apply any course to a degree program either at the bachelor or graduate level. Consequently, degree-seeking students must fulfill certain admission standards. For those seeking a bachelors degree, students must have a two point five (2.5) grade point average (on a four point maximum scale) and must fulfill the necessary qualifying course work for the particular degree. For those seeking graduate degrees, students must have a three point (3.0) average and must fulfill all qualifying course work. For students not seeking a degree, courses can be taken for credit as personal enrichment; such courses may not be applied to a degree.

Only instructors with proven credentials in the fields of environmental engineering or science will participate in the proposed program. Regular faculty from WSU are expected to participate either in person or via the WSU television network. Local adjunct (part time) faculty are expected to participate. Adjunct faculty at WSU-TC in environmental engineering all have doctorate degrees coupled with significant industrial experience.

CLOSURE

The scope and complexity of Environmental Restoration at Hanford requires a highly qualified work force. The most practical means of acquiring a qualified work force is to reorient the work force presently on hand. While the restoration of Hanford is expected to take more than thirty years, the need for an educated work force is now. Reorientation is expected to take form as a combination of continuing education short courses, hands-on training, and academic courses.

The program proposed herein is nontraditional in that it is to be accelerated and course work is less required than for a full degree. This program is intended to reorient a work force quickly but still maintain high academic quality.

Courses and curriculum of programs at other educational institutions have been researched. They are: Washington

State University (WSU) [Environmental Engineering (WSUE) and Environmental Science (WSUS)], which works closely with Hanford and DOE-RL; Idaho Sate University (ISU) and the University of Idaho (UI), sponsored by DOE-ID; National Technological University; New Jersey Institute of Technology; Southern Methodist University; United States Air Force Air University; and the University of Tennessee.

As the matrix points out, no courses are currently being offered in site characterization, management and remediation of underground storage tanks, remedial investigations, role of laboratories, analysis of hydro-geologic conditions, site closures, remedial measures (ROD), remediation project management, and other topics that directly relate to the management of engineering activities at a cleanup site.

Across the country there is a broad scope of course work in the environmental arena. The field is so new there is no consensus on what areas of the field should be taught at the university level. When a person majors in one of the established engineering disciplines, core requirements are very similar. Yet in the environmental field, there are environmental engineering programs, environmental science programs, engineering management programs with emphasis in hazardous waste management, etc. The field has yet to be defined.

THE ROLE OF COLUMBIA BASIN COLLEGE IN TRAINING TECHNICIANS FOR ENVIRONMENTAL REMEDIATION AT THE DOE HANFORD SITE

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ABSTRACT

Community colleges have the ability to play a vital role in the environmental remediation training process for DOE hazardous waste sites. Columbia Basin College in Pasco, Washington is presently involved in such training through numerous workshops offered primarily for employees at the Hanford DOE site, and a two-year associate of applied science degree in Hazardous Materials Management Technology. The workshops are oriented towards specific applied technical training (40 Hour OSHA/80 Hour WISHA, Hazardous/Radioactive Waste Video conference, and others) whereas the degree program provides a broad background in the skills needed for environmental technicians (16 hazmat courses plus support sciences and humanities). The degree program, combined with hazmat work experience, should provide the necessary background for project supervision as well as for skilled field technicians.

INTRODUCTION

The Hazardous Materials Management Technology (HAZMATT) program was started at Columbia Basin College (CBC) because of the change in emphasis at DOE Hanford to environmental remediation. As a result, many of the previous workers at the Hanford site are being retrained to fit the new emphasis at the project, with CBC providing both workshop and degree training. When the CBC HAZMATT program was announced in the spring of 1990, calls of inquiry generated an "interest" list that by the Fall of 1990 grew to about 300. By Spring of 1991 when the first offering in Hazmatt was made, the interest list numbered over 500 with about 20 to 30 new names added per month. Most of those interested in the HAZMATT program either work in some capacity at the Hanford project or desire to work at Hanford. This need to train qualified Hazardous Materials Technicians who are capable of being productive at Hanford and other DOE sites, as well as for private sector environmental companies, helped dictate the nature of the CBC training program. The technician must be able to perform a variety of site assessment tasks including:

- on-site preliminary hazardous waste characterization
- air monitoring
- characterization of soil contamination (soil profile descriptions, soil gas monitoring, sampling, and the like)
- working with drillers of groundwater monitoring wells to characterize the soil cores and auger/drill samples,and develop and sample the monitoring wells
- being functional with basic QA/QC practices including valid sampling methods, chain- of-custody requirements for samples, use of blanks and spikes, and others
- performing valid basic laboratory analyses of the samples collected

In addition to the above field tasks, the technician is trained in Environmental Health and Safety for Hazardous Waste Operations (40 Hour OSHA and 80 Hour WISHA) and will have a basic background in pertinent sciences.

The subsequent sections will describe the CBC training program and detail the interactions between the college and Hanford regarding CBC sponsored workshops and the AAS degree program.

WORKSHOPS

One of the training programs CBC continues to offer, is specific job-training workshops on an as-needed basis for the contractors of Hanford. To insure that the workshops suit the needs of the contractors at Hanford, experts from the DOE site are used as instructors whenever practical. The first offering was made in December 1990 with the War On Waste series, a two-day workshop including, with instructor credentials in parenthesis, TSCA Regulations (Westinghouse compliance expert), AHERA Requirements(Kaiser Engineer Asbestos Projects Coordinator), Environmental Enforcement Issues (EPA enforcement officer) and Radon (Radon contractor and tester for EPA).

In the Spring of 1991, CBC and Kaiser Engineers Hanford-Quality Training and Resource Center (QTRC) cosponsored two workshops. The first was a three-day prep course for the Certified Hazardous Materials Management exam, for predominantly Kaiser employees. The second was an eleven part video conference series on Hazardous/Radioactive Waste Management presented by Waste-management Education and Research Consortium of DOE facilities and Colleges in New Mexico. The attendance at this video conference was dominated by Hanford employees although it was open to the general public.

In the Summer of 1991, CBC offered its first Environmental Health and Safety workshop. To ensure that the training provided not only complied with the OSHA and WISHA regulations, but also that it was compatible with the procedures and equipment used at Hanford, many of the instructors of the workshop were the same people involved in similar training at Hanford. Thus, CBC was able to provide at a minimum the same Environmental Safety and Health training as that presently being offered at the site for Hanford employees.

In the main, CBC has endeavored to present workshops that are directly applicable to the functions at the nearby DOE site by offering the types of workshops requested by the contractors and by using Site personnel as instructors

whenever feasible to ensure that the material presented fits the needs of the Site.

ASSOCIATE OF APPLIED SCIENCE

The main thrust of the CBC HAZMATT program is to provide an associate degree in hazardous materials technology. Because of the broad scope of environmental technology, the technician should have a varied background in the numerous disciplines. CBC's position of providing a broad background was supported by a survey conducted by CBC before initiating the HAZMATT program. Of the nearly 100 private sector environmental/engineering companies (and the contractors at the DOE site) surveyed, 35 responded. One of the questions asked was to indicate the degree to which they felt each potential course listed was VERY IMPORTANT, IMPORTANT or NOT IMPORTANT in a hazmatt program. The results of the survey are presented as Table I.

Environmental Laws and OSHA were considered the two

TABLE I

Survey of HMMT Courses Needed

Course	Very Important	Important	Not Important
ENVI Laws	66	34	0
OSHA	65	20	15
TOXICOLOGY	56	32	12
DOT REGS	50	41	9
SITE ASSESSMENT	49	43	8
HAZMAT CHEM	43	46	11
TSD	31	42	27
WASTE MIN	24	55	21
CLEAN AIR	10	59	31

most important areas of training needed by hazardous materials technicians. Toxicology was considered next in importance, followed by DOT regulations, Site Assessment, and Chemistry of Hazardous Materials. Surprisingly, background knowledge of Treatment/Storage/Disposal of Hazardous waste and Industrial Waste Minimizationwere considered of lesser importance for the technician less than one third of those responding considered those disciplines "very important". As a result of the survey, all disciplines ranked as very important and important were included in the required curriculum for the HAZMATT degree. Table II lists the required HAZMATT courses for the AAS degree.

The writer believes that the varied definition of " hazmat technician" is the reason for the range in emphasis in hazmat training at the various institutions which offer such programs. Some apparently consider the technician as an extension of the labor force (mainly 40 Hour OSHA trained) whereas others appear to consider the technician as an extension of the environmental assessment scientist in gathering environmental data (soil, air, water measurements and monitoring). The CBC HAZMATT degree program is designed to provide the training necessary to cover the total spectrum of the duties of the hazardous materials technician. Furthermore, the training that CBC technicians receive is designed to provide them with the comprehensive background needed, when combined with

TABLE II

CBC HAZMATT Curriculum

INTRODUCTION TO HAZARDOUS MATERIALS MANAGEMENT
ENVIRONMENTAL LAWS AND POLICIES
TREATMENT/STORAGE/DISPOSAL OF HAZARDOUS WASTE
ENVIRONMENTAL HEALTH AND SAFETY (OSHA)
SITE INVESTIGATION
WASTE MINIMIZATION AND RECYCLING
INDUSTRIAL TOXICOLOGY
CHEMISTRY OF HAZARDOUS MATERIALS
RADIATION HEALTH PHYSICS
AIR MONITORING AND INSTRUMENTATION
ASBESTOS INSPECTION
EMERGENCY RESPONSE LEVELS I,II,III

hazmat work experience, to make them capable environmental supervisors.

The courses which are central to the training program are Site Investigation Phase I and Phase II, supported by the Environmental QA/QC course. Site investigation is designed two courses. Phase I is the predominantly off-site study of a property designated for transfer. The investigation will require a search for information about prior use, air photos, topographic maps, soil survey maps, subsurface geological data, groundwater use data, interviews of previous workers, shipping manifests and MSDS sheets, and other data. The location of the property is the area north of the CBC main campus which contains stacks of drums, soil stains, vehicles, soil-fill area, and physical debris (Fig. 1). The preliminary investigation will reveal sufficient cause to recommend a detailed environmental assessment of the property for Phase II.

The objective of Site Investigation is to, as realistically as possible, simulate the actual sampling procedures and reporting done during an actual site investigation and to combine the measurement data with laboratory analyses to determine the nature and extent of hazardous waste contamination. To make the student investigation as realistic as possible, Phase II will require detailed soil sampling, soil gas monitoring, coring and producing a soil columnar section for water table wells, "groundwater" sampling, laboratory analyses of the samples, chain-of-custody protocol, determining a remediation program, and preparing a Phase II manuscript. Contamination data is difficult to obtain in the investigation of a "clean" area, therefore one needs to "salt" the study area with controlled contamination. This is done by burying 55 gallon drums with the tops removed, filled with soil and oriented open end up. Within the drums are placed retrievable containers of known "contaminants" (Buried Drums on Fig. 1). The student will measure contamination of the soil with field instruments (PID, OVA, FID, CGI) and hand auger observed "stain". After the initial data are tabulated, "ground water wells and soil monitoring wells" will be recommended. These wells are indicated on Fig. 1 as "simulated wells" (which consist of 10 feet of 4 inche diameter closed PVC pipe in which is placed water with slightly altered pH to simulate a contaminant). Several groundwater wells are augered (Fig. 1, Pumping wells) which provides experience in permitting, directing the augering, performing soil core analysis, and well



IMPROVING CONDUCT OF OPERATIONS IN NUCLEAR WASTE CLEANUP PROJECTS*

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ABSTRACT

The West Valley Demonstration Project (WVDP) is a cleanup effort which is actively removing liquid high-level waste from an underground storage tank, extracting radioactive cesium from the liquid using an iron-exchange system, and stabilizing the resulting low-level waste in an NRC-endorsed cement waste form. Additional activities involve:

- Volume reduction of low-level waste
- Low-level waste treatment
- Spent-fuel management
- Hazardous waste management
- Facility and equipment decontaminating and decommissioning
- Vitrification facility construction and testing
- Analytical and environmental chemistry
- Engineering, construction, and quality-related activities

This project involves managing nuclear and hazardous wastes, with utmost attention to safety of the workforce, public, and environment. An aggressive program in under way to improve conduct of operations in all areas. Implementation of DOE Order 5480.19, "Conduct of Operations Requirements for DOE Facilities", is proceeding on schedule. The effective use of champions among first-line supervisors, application of ownership, and effective interaction among the facilities and technological expertise at other Westinghouse divisions has resulted in value added to the Department of Energy at this facility.

INTRODUCTION

The West Valley Demonstration Project (WVDP) is a cleanup effort which is actively removing liquid high-level nuclear waste from an underground tank, extracting radioactive cesium from the liquid using an ion-exchange system, and stabilizing the resulting low-level waste in an NRC-endorsed cement waste form. The tank contained about 600,000 gallons of liquid high-level nuclear waste left from the only commercial spent-fuel reprocessing operation in the United States. Additional activities involve:

- Volume reduction of low-level waste
- Spent-fuel management
- Hazardous waste management
- Decontamination and decommissioning work
- Wastewater treatment
- Vitrification facility construction and testing
- Analytical and environmental chemistry
- Engineering, construction, and quality-related activities

Nuclear waste cleanup projects require the utmost attention to detail and discipline of operations. The U. S. Department of Energy (DOE) has issued DOE Order 5480.19, "Conduct of Operations Requirements for DOE Facilities," which requires improvement of operational discipline at all contractor facilities, and national laboratories, involved in remediation of DOE facilities. At the WVDP in Western New York, the move to incorporate the principles first established by the Institute of Nuclear Power Operations (INPO 85-017, April 1988) is well under way and taking root. Our direction and goal is to instill conduct of operations into all activities and disciplines, based on a Westinghouse Conduct of Operations Manual. We have seen an improvement in "operator" discipline and attention to detail through an ownership system. The next step is to use a graded approach to full acceptance by all personnel at the project.

FIRST-STEP - SELF-ANALYSIS

In late 1989, the DOE issued, for implementation at contractor facilities, the 18 chapters of the INPO guidelines for Conduct of Operations. In July 1991, these guidelines were published as DOE Order 5480.19, "Conduct of Operations Requirements for DOE Facilities". At the WVDP, a management task team was formed to provide guidance and an implementation plan was prepared to upgrade operations.

The task team first evaluated existing procedures and work practices to determine how best to incorporate the Conduct of Operations guidelines into our culture. The WVDP, started in 1982, has used written, disciplined, procedures in our work. A formalized operator qualification program was in place which required both written and oral examinations before personnel were able to operate waste treatment systems or plant safety equipment. In our review, it was noted many of the DOE Conduct of Operations

* Work Performed Under Contract DE-AC07-81-BE 41139

guidelines existed in our procedures while the entire order could serve to improve the discipline of operations, control room activities, and logkeeping in our facilities, to cite a few examples. Although the systems in place were good, the DOE Conduct of Operations guidelines would make us much better. Table I summarizes the initiatives taken to implement the order.

TABLE I

Conduct of Operations Implementing the Initiatives at the West Valley Demonstration Project

Implementation Initiatives

- Implementing Procedures
- Space and Process Ownership
- Supervisory "Walk-Your-Spaces"
- Management Space Evaluation
  - Area Supervisor
  - Safety Observer
  - DOE
- Managers Teach
- Conduct of Operations Manual
- Formal Graded Approach
- Site Visits and Observations
  W Savannah River Company
  W Hanford Company
  Commercial Nuclear Plants
  W Commercial Divisions
  W Materials Co. of Ohio

THE NEXT STEP - PROCESS AND SYSTEM OWNERSHIP

The implementation of an improved conduct of operations philosophy has been successful at WVDP because the first-line supervisors have become champions of the concept and process. The formal introduction to the basis of a needed culture change and to case studies of conduct of operations problems occurred in June 1990. We brought George Toto and Fred Carlson (DOE Tiger Team training experts) to the WVDP to provide our supervisors and managers an opportunity to understand why it's important to "Walk-Your-Spaces", what kinds of operational improvements to seek, and how to get things changed. Since that training, supervisors have actively participated in preparing a Space and Process Ownership philosophy (Fig. 1). Each area supervisor adopted the "Walk-Your-Spaces" form of self-evaluation, whereby operators and the supervisor are charged with inspecting their plant areas of responsibility. The task is to find and fix problems, upgrade plant conditions, revise procedures, and/or identify instrumentation or other equipment problems to the proper work group for repair. Plant housekeeping and adherence to procedures are evaluated during these walk-downs. WVDP line, safety, and engineering management performs additional assessments in all plant areas on a once-per-week rotation to assure a broad evaluation of the total condition of the plant areas. Every quarter we review lessons learned and managers discuss areas needing additional attention. Our management



Fig. 1. Financial control department ownership.

facility assessment and space ownership programs have received much attention and praise from outside auditors and have been incorporated into the Conduct of Operations programs at other Westinghouse DOE facilities. Supervisors and managers have pitched in to bring heightened awareness to all operators by participating in, and sponsoring trips to, other Government Owned, Contractor Operated (GOCO) operations. These visits allow participating personnel to evaluate beneficial practices at other plants. Similarly, visits to operating commercial nuclear power plants permit our operators to witness and share the discipline and operations controls at those facilities. The lessons learned, as applicable, are being factored into our conduct of operations improvements and into Standard Operating Procedures (SOPs).

IMPLEMENTING PROCEDURES

Operating procedures were written to implement the 18 chapters of DOE Order 5480.19, "Conduct of Operations Requirements for DOE Facilities", as shown in Table II. Formal training classes have been held for each chapter and procedure. The management spaces evaluation program noted above provides review of both acceptance and compliance of the theory of improving conduct of operations. Acceptance by clerical, support groups, and process and design engineers will take time, but this philosophy will also be used to improve their conduct of operations.

CONSISTENT APPROACH - THE WESTINGHOUSE MANUAL

In January 1991, at a meeting of operations managers of the six DOE contractor Westinghouse divisions, (West Valley Nuclear Services, Waste Isolation Pilot Plant, Westinghouse Savannah River, Westinghouse Idaho Nuclear, Waste Isolation Pilot Plant, and Westinghouse Hanford) the concept of producing one manual for use throughout the Westinghouse GOCOs was conceived. It was considered that technical expertise, waste treatment technology, and a broad spectrum of opportunities existed in these Westinghouse divisions which could be used to good effect by publishing a manual containing both the requirements of the DOE order and good practices used at our various facilities. In July 1991 the manual was issued as a result of a concerted effort by representatives of the divisions. Fig. 2 shows a cross-section of our employees with a copy of the manual.

TABLE II

Procedures Implementing Conduct of Operations at the WVDP

DOE Order 5480.19 Chapter	Title	West Valley Procedure No.
I	Operation, Organization and Administration	SOP-00-24
II	Shift Routines and Operating Practices)	SOP-00-21
IV	Communications)	
XVII	Operator Aid Posting)	
III	Control Room Activities	SOP-00-16
V	Control of On-Shift Training)	SOP-00-26
XIV	Required Reading)	
VI	Investigation of Abnormal Events)	WV-987
VII	Notifications)	
VIII	Control of Equipment and Status Systems	SOP-00-20
IX	Tagouts	SOP-00-4
X	Independent Verification	SOP-00-27
XI	Logkeeping)	SOP-00-19
XV	Shift Orders)	
XII	Shift Turnover	SOP-00-17
XIII	Operational Aspects of Plant Chemistry	SOP-00-22
XVI	Operations Procedures	SOP-00-2
XVIII	Equipment Labeling	SOP-00-30

The underlying theme of this manual is that conduct of operations does not apply solely to "operations" personnel or organizations nor solely to nuclear facilities. Conduct of operations is a philosophy of discipline and formality which applies to everybody. Our challenge is to bring this realization and rigor of task performance to all personnel through a graded approach. Table III shows schematically how this is perceived.

GRADED APPROACH

Another aspect of needed improvement is to recognize and involve all those who work on waste cleanup projects through the use of a graded approach to implementation. A graded approach simply means that not all disciplines need to apply the same set of rules, or control, to the same depth as required by nuclear waste plant or hazardous waste management operators. A boiler room or sanitary wastewater treatment operator requires certification by local or state authorities and must adhere to written procedures. The consequences of a problem in either of these areas does not pose the potential for national publicity or adverse public reaction that one would see should a nuclear waste incident occur. Maintenance personnel must maintain their skill levels and qualifications just as chemistry lab technicians do. These groups are part of the focus of our program, and each evidences a need to improve adherence to procedures



Fig. 2. Westinghouse conduct of operations manual accepted in all departments.

TABLE III

Graded Approach to Conduct of Operations

Disciplines	Implementations	Personnel
Nuclear Reactors HLW/LLW/ Tank Farm Ops Chemistry	All chapters apply	Managers Supervisors Operators Technicians
Engineering Maintenance Quality Assurance Utilities/Boilers Haz Mat Ops Security	Many chapters apply	Engineers Technicians Crafts Operators Managers Supervisors Guards
Financial Purchasing Warehouse	Few chapters apply	Secretaries Managers Supervisors Professionals Clericals
None	Where only one chapter applies	

(maintenance instructions, chemistry methods) and development of an owners approach to their work spaces and equipment.

SUMMARY

In summary, the WVDP has initiated an aggressive effort and has taken the lead in conduct of operations acceptance by our work force. Benefits have already been noted in:

- more formalized control room ethics
- formalized logs
- improved lock and tag out control
- elimination of posted notes
- pride in areas (cleanliness)

Many more actions must be taken to fully implement the order, and to assure that the cleanup is performed in accordance with recognized standards of discipline and control. This paper will address various aspects of the effort at West Valley and will show how the local DOE customer has supported the effort.

TECHNOLOGY DEVELOPMENT FOR A DISPOSAL CELL AT THE WELDON SPRING SITE REMEDIAL ACTION PROJECT

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ABSTRACT

The Weldon Spring Site Remedial Action Project (WSSRAP) is a DOE cleanup of property and facilities near St. Louis, Missouri, that were used during WWII to produce explosives such as TNT, and during the post-war years, to produce uranium metal. The long history of operations at the facilities generated a complex mixture of contaminants, including toxicants such as nitroaromatics, metals, and radionuclides such as uranium and thorium. These contaminants occur in soil, sludges, construction debris, and bulk wastes from a nearby quarry that was used for waste disposal.

Final decisions for site and quarry remediation have yet to be determined. Alternatives being evaluated include on-site and off-site disposal options for contaminated materials. As part of this effort, studies are under way to define technical approaches and performance criteria for an engineered disposal cell that could be located at the WSSRAP chemical plant site. This cell would be designed to contain by-product radioactive wastes and the end products of treated chemical wastes.

A program of support studies has been initiated to facilitate remedial planning. These studies include an evaluation of site suitability and potential long-term cell performance. This information will assist regulators in determining the acceptability of on-site disposal and will address public concerns should on-site disposal be selected as the preferred alternative. The studies will also lay the groundwork for the conceptual design of the disposal cell.

The disposal facility studies encompass a broad range of topics in four basic categories: siting, barriers, waste, and constructibility. Because of the breadth of technical topics and an aggressive schedule, most studies are being performed concurrently by a broad array of experts. A result of this concurrency is that each principal investigator must proceed with a degree of uncertainty about the final configuration of cell components related to his or her topic of investigation. This paper describes how the disposal facility studies have been defined, and how they are managed to assure that all relevant technical information is provided in a format that will support the evaluation of the acceptability of on-site disposal and will provide a meaningful foundation for the conceptual design of a disposal cell.

INTRODUCTION

The Weldon Spring Site Remedial Action Project (WSSRAP) is part of the Department of Energy (DOE) Environmental and Waste Management Program under the Office of Environmental Restoration and Waste Management. The site, which is approximately 50 kilometers (30 miles) west of St. Louis, Missouri, consists of two major areas. First is the Weldon Spring site, which includes a former uranium feed materials plant and raffinate ponds. Second is the Weldon Spring quarry, which is a limestone quarry used since WWII for the disposal of wastes generated during the operation of the facility. Water, sediments, and debris at both the site and the quarry are contaminated with radionuclides of the uranium and thorium decay chains and metals and metalloids associated with the uranium feed process. Nitroaromatic contamination is also present at both locations due to large-scale munitions production at and around the site during WWII. Table I summarizes waste forms and contaminants at the site.

The project is proceeding in accordance with the requirements of the National Environmental Policy Act (NEPA) and Comprehensive Environmental Response Compensation and Liability Act (CERCLA). The requirements of these two environmental laws are being integrated into a remediation strategy for both the chemical plant and quarry. Remedial action alternatives for contaminated materials from the chemical plant are being evaluated as part of a Feasibility Study - Environmental Impact Statement (FS-EIS) being prepared by Argonne National Laboratory under independent contract to the DOE. Alternatives under consideration include both transport of the treated waste off site to a regulated waste disposal facility and disposal in an engineered cell at the chemical plant. Prior to disposal, radioactively and chemically contaminated raffinate sludges and selected soils will be treated using either vitrification or a chemical cementation process. The preferred disposal alternative will be identified in the record of decision (ROD) that will be issued in accordance with the Superfund process for the cleanup of the chemical plant.

Design and construction of a disposal facility that complies with regulatory requirements to isolate contaminated materials from the environment is a challenging task. Many technical issues must be identified and resolved. The possibility that a disposal cell could be constructed at the Chemical Plant served to initiate a program of support studies to acquire data and address technical issues. This comprehensive program is under way and is focused on a disposal cell that would be constructed to accommodate chemically and radioactively contaminated materials. The cell would be designed to contain by-product radioactive waste and the endproducts of the treatment of chemical wastes with hazardous characteristics.

TABLE I

WSSRAP Waste Forms*

Media	Contaminants				
	Radionuclides	Asbestos	PCBs	Metals & Metalloids	Nitroaromatics
Inactive Structures, Tanks, Pipes, etc.	X	X	X		
Demolition	X	X	X		
Debris	X			X	
Wood Products	X		X	X	
Soil and Sediments	X			X	X
Raffinate Sludge	X			X	
Water	X			X	X

*WSSRAP Waste also includes small quantities of containerized chemicals, as well as byproducts of water treatment.

THE SUPPORT STUDIES PROGRAM

The WSSRAP Support Studies Program was formulated in part to address technical issues associated with design and construction of an on-site disposal facility. The following objectives were established for the program:

- Determine the acceptability of on-site disposal by characterizing site suitability and anticipated cell performance.
- Provide documentation in a format that will enable regulators and the public to understand the disposal alternatives.
- Establish design criteria and assemble data for use in preparing a conceptual design for the cell should on-site disposal be adopted as the preferred alternative.
- Identify and resolve issues related to the constructibility of the cell and availability of the required materials.

The Support Studies Program also includes investigations of waste treatment and placement technologies that may apply, regardless of whether the waste is placed in an on-site cell or at an off-site disposal facility. The program began early in 1991 and will continue through the middle of 1992, at which time it will move into the conceptual design of the disposal cell. The studies are being coordinated and, in some cases, conducted by WSSRAP personnel. Most studies are being performed off site by scientists and engineers of Morrison Knudsen Corporation, Jacobs Engineering Group, and specialty subcontractors.

The studies are grouped into four technical categories: siting, waste barriers, and constructibility. In combination, these categories encompass the full range of issues related to the cell and its intended contents. Figure 1 illustrates these technical categories and their general scope. The figure also illustrates how fundamental WSSRAP objectives such as environmental protection, regulatory compliance, public information, and value are considered within each study.

MANAGEMENT CHALLENGES

One important lesson in the integration of the CERCLA and NEPA processes at the WSSRAP has been that more detailed engineering is needed for the disposal alternatives than is required for a project where NEPA alone apples. The result is that many studies are being performed concurrently. For instance, studies related to the cover and liner are being performed simultaneously with studies on waste treatment and leachate production. Thus, issues related to cell design must be addressed in the face of uncertainty regarding the alternative treatment technologies and the resulting waste characteristics. Raffinate sludges and some contaminated soils may be vitrified or chemically stabilized using a cementation process. The end products of these two treatment alternatives differ considerably. For the moment, investigators must address both scenarios and develop decision trees and selection criteria rather than specific recommendations.

There are times when concurrency has been very beneficial, enabling principal investigators to mutually redirect their studies and improve the utility of each based on observations of each other's progress. Communication is the key to minimizing adversity and maximizing benefit from this necessary concurrency. Even though the performance of the support studies has been distributed among locations as widely separated as Atlanta, St. Louis, Albuquerque, San Francisco, and Boise, the investigators have been kept apprised of each other's progress by:

- Targeted distributions of interim deliverables.
- Well organized work sessions involving principal investigators for numerous studies.
- Active involvement by technically qualified managers who track the overall progress of the program on a weekly basis.

TECHNICAL CHALLENGES

Within the four categories being studied, numerous technical issues have been identified that reflect the unique challenge of developing a disposal cell for waste that is both radiologically and chemically contaminated. These issues include:

- Longevity requirements for a disposal cell for byproduct radioactive waste and treated RCRA waste.
- Long-term performance of geosynthetics that could be used in the cell's cover and leachate collection systems.
- Erosion control and aesthetic requirements for the disposal cell cover.

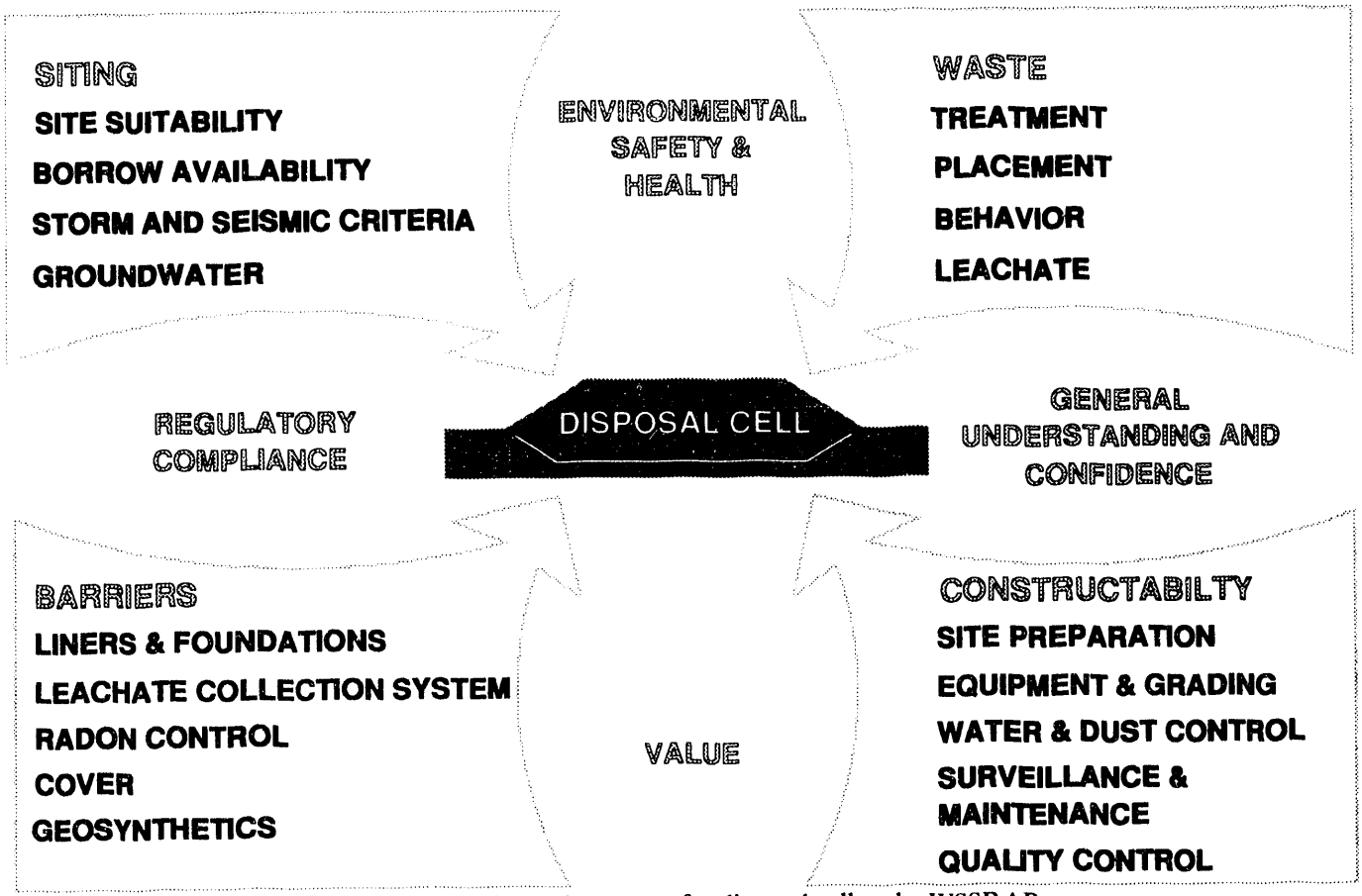


Fig. 1. Categories and concepts for disposal cell at the WSSRAP.

The principal technical challenge when designing a disposal cell for WSSRAP wastes will be to reconcile the seemingly contradictory requirements for a low-level radioactive waste cell with those of a hazardous waste cell under the Resource Conservation and Recovery Act (RCRA). For instance, the design of a cell for the WSSRAP may adopt the longevity standard from the Uranium Mill Tailings Radiation Control Act (UMTRCA) as an applicable or relevant and appropriate requirement (ARAR). This standard, which requires containment for 1,000 years to the extent possible, and 200 years as a minimum, calls for a high degree of reliance on earthen materials such as rock and clay, and using natural supplements such as bentonite (if needed) for enhanced infiltration control. On the other hand, cells built for RCRA wastes have but a 30-year longevity requirement, resulting in greater reliance upon geosynthetics for stabilization and maintenance of water balance.

The WSSRAP cell may not be a RCRA cell per se because any RCRA wastes will be treated to eliminate hazardous characteristics prior to emplacement in the cell. However, RCRA features such as flexible membrane liners and a leachate collection system may be used to minimize moisture flux through the cell and make it possible to detect leaks. Since it is also likely that the cell will be designed to comply with the UMTRCA longevity requirement, the designers will be challenged to create a system that will provide long-term performance even though man-made components may be used that have relatively short (or, at best, unknown) design lives. It is anticipated that a combination of earthen and geosynthetic components will enable this challenge to be met.

In the case of water balance, we might expect a long-term performance scenario such as shown in Fig. 2. A leachate collection and removal system, composed partly of man-made materials, would serve to intercept leachate for some indeterminate period after the cell has been completed. The system will also be fully functional to intercept transient drainage of water introduced to the cell during waste placement and cell construction. However, the performance of the system (or of any liner using man-made materials) will gradually decline as the geomembranes degrade; eventually, flux through the liner will be regulated by the compacted materials therein. Geosynthetics may also be included in the cover, in which case long-term performance of the cover will decline as the man-made materials degrade. However, the reduction in performance will be less severe, and the total potential flux will be lower for the cover than for the liner. This is because the cover uses vegetation to transpire moisture back to the atmosphere, thus achieving lower flux than is possible with compacted layers alone. The reduced flux through the cover relative to that of the liner helps prevent a bath-tub scenario wherein infiltration through the cover occurs at a sufficiently high rate to saturate the material in the cell and allow leachate to accumulate and emerge around the cell's perimeter.

The possible use of a leachate collection system raises other issues besides longevity. Such a system would probably require a long-term commitment to extract and treat accumulated leachate. The passageways in the system might also serve as conduits for the migration and release of radon gas in excess of the relevant standard. Charcoal filters or other high-maintenance solutions may be required to solve this problem. If a leachate collection system is used for WSSRAP wastes, it may

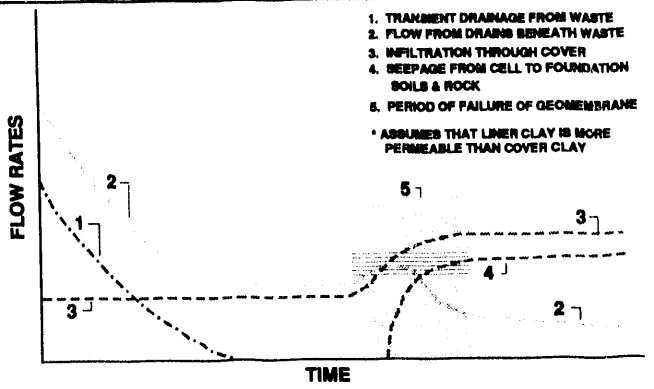


Fig. 2. Potential hydrogeologic performance of cell.

be appropriate to grout or otherwise seal the passageways once steady-state conditions have been reached and the performance of the cell has been demonstrated. This would eliminate the need for continued extraction and treatment of leachate, as well as the potential for radon release, while maintaining an effective liner to work in concert with the cover to control total moisture flux through the cell.

The current thinking at the WSSRAP is that a cell, if constructed at the site, would have a mowed, grass-covered surface as its uppermost layer. Yet, other alternative covers are being studied. For instance, investigators are exploring the use of gravel mulches that will stabilize side slope surfaces (although not necessarily during potential maximum precipitation), and support a vigorous and self-sustaining plant community. Figure 3 illustrates how rock, soil, and vegetation may be combined to provide different degrees of protection against erosion. The configurations also differ in their requirements for maintenance needed to repair rills and ensure adequate vegetation.

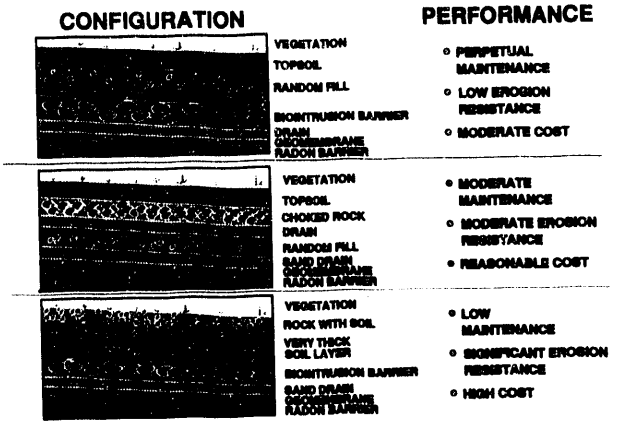


Fig. 3. Cover concepts for WSSRAP disposal cell.

SUMMARY AND CONCLUSION

The WSSRAP support studies are proceeding rapidly, laying the groundwork for the conceptual design of a disposal cell. Because of the high degree of concurrency among the studies, and the treatment alternatives regarding the anticipated disposal waste form, the principal investigators are basing their work on carefully formulated assumptions, are developing decision trees and technology menus that address multiple contingencies, and are tracking each other's progress to stay apprised of the context of their work. The result of this intensive multidisciplinary effort will be a comprehensive set of criteria for the conceptual design of a disposal cell at the WSSRAP.

APPENDIX

SITING

Disposal Facility Siting Criteria: Defines and evaluates siting criteria and provides alternative cell configurations that satisfy these criteria.

Subsurface Soil Geotechnical Characterization: Provides geotechnical characterization with respect to disposal facility construction requirements; utilizes existing site geotechnical information and supplements this with additional investigation in the disposal cell footprint.

Insitu Permeability Testing: Provides for investigation and analysis to assess the influence of macropore features (joints and fractures) on the permeability of principal soil units at the Weldon Spring site.

Groundwater Remediation Interface: Evaluates contaminant fate and transport in geologic media in the event of cell failure. Permeability and sorption data will be used in groundwater modeling using the CFEST model.

Low Permeability Borrow Area Definition: This study includes material source investigations and evaluation of potential borrow sources for low permeability material required for cell construction.

Borrow Area/Material Selection Phase II: Includes identification and evaluation of borrow sources for disposal cell construction materials other than low permeability clays; includes sand, gravel, riprap, etc.

Borrow Area and Soils Selection Criteria: Defines construction material requirements related to cell components and provides physical criteria and testing requirements related to the function of specific components.

Location and Characterization of Underground Structures and Debris: Identifies location and characteristics of buried structures and debris. Existing information will be supplemented by geophysical investigations and borings/ trenching as required.

Soil Permeability Compaction Test Fill: Includes the construction and testing/ monitoring of a test fill in order to establish density, moisture content, and hydraulic conductivity relationships. This effort will demonstrate the effectiveness of using locally available soils (with or without enhancement admixtures) and compaction procedures in meeting performance requirements for a full-scale disposal cell.

CONSTRUCTIBILITY

Subsidence Evaluation: Performs settlement and stability analysis for critical locations in the disposal cell. From this information, assesses the effects of potential instability/settlement and determines factors of safety for slope stability failure.

Geosynthetics for Geotechnical Stabilization of Waste and Cover Materials: Evaluates the use of geosynthetics for geotechnical stabilization of wastes and cover materials. This information will assist in the selection and use of appropriate materials for various stabilization applications of wastes and cover materials.

Grading Plan: Provides a conceptual grading plan for three alternatives (Single CSS cell, 2-cell alternative for vitrification, and off-site disposal). Provides criteria and recommendations for slopes, channels, and cover material.

Soil Permeability Compaction Test Fill: Includes the construction and testing/monitoring of a test fill in order to establish density, moisture content, and hydraulic conductivity relationships. This effort will demonstrate the effectiveness of using locally available soils (with or without enhancement admixtures) and compaction procedures in meeting performance requirements for a full-scale disposal cell.

Excavation and Water Control Plan: Identifies and describes excavation requirements and water control associated with contaminated material excavation (soils, foundations, debris, utilities) in addition to water control requirements during construction and operation of the disposal facility.

Interim Erosion Control and Interim Water Control: These studies will be conducted in parallel and will identify methods and criteria applicable to the entire site for erosion control and surface water control. Specific activities to be reviewed in these studies are: materials excavation, support facility construction, disposal facility construction, and final grading.

Equipment Selection - Criteria/Assessment: Establishes criteria for equipment to be used during the construction of the disposal cell and recommends special procedures for preparing estimates, setting subcontractor prerequisites, and performing prototype tests.

Dust Control - Criteria/Assessment: Establishes radiological, chemical, and nuisance dust concentrations for both site specific and area applications and recommends dust control methods required to meet these limits.

Disposal Facility Operation and Maintenance: Produces a disposal facility operations and maintenance (O&M) plan and a health and safety plan (HASP) relating to construction and operation of the disposal cell. Preliminary surveillance and maintenance requirements applicable to post-closure will also be developed.

WASTE

Seismic Criteria and Assessment: Defines seismic conditions in the study area and provides seismic design criteria applicable to disposal cell components.

Tornado Criteria and Assessment: Existing data will be compiled (frequency, duration, wind velocity, path width) and specific response actions during construction and operation will be described. Design criteria will be defined which will minimize the effects of a tornado.

Design Storm Criteria: Calculates and compiles design storm criteria applicable to all anticipated facilities, considering storm intensities, durations, and/or volumes.

BARRIERS

Performance QA Measurement: Identifies performance measurement requirements for fabrication, construction, and post-closure activities related to the WSSRAP.

Construction Monitoring and Documentation: Outlines the requirements for terrestrial photogrammetry during construction and operation of the disposal cell. Sufficient detail will be developed to determine the feasibility of this technology in monitoring construction/operation of the cell.

WASTE

Waste Form Placement and Compaction: Identifies and evaluates waste forms, placement alternatives, and compaction requirements in order to meet functional requirements related to the waste component of the disposal cell. Physical characteristics of wastes, material compatibility, and operational requirements will be considered in this evaluation.

Processed Waste Characterization and Nitroaromatic Contaminated Waste Stabilization: Tests sludge and soil treatments to develop appropriate mixtures of sludge/soil/admixtures to be used in full scale treatment. Engineering properties and leachability will be determined during this effort.

Leachate Characterization: Data will be compiled from existing information in order to arrive at a "worst case" leachate resulting from the untreated waste fraction to be placed in the disposal cell.

WTP Residue and Leachate Treatment: Determines the hazardous characteristics of residual wastes generated from operation of the site and quarry water treatment plants in order to define disposal options.

Wood Storage, Treatment, and Disposal: Determines best processes for chipping and placing wood to facilitate microbial decomposition. Composting will be used to biodegrade vegetation, wooden demolition debris, and furniture.

Pretreatment Alternatives: Identifies technological methods to process certain waste forms prior to their introduction into the primary treatment technology. Considers bioremediation, soil, washing, and other options.

BARRIERS

Cover Evaluation: Identifies and evaluates cover component alternatives in order to provide a matrix of cover components associated with specific functional requirements of the cover system. These alternatives will be evaluated to arrive at a recommended alternative for WSSRAP disposal cell applications.

Liner and Foundation Assessment: Assesses the disposal facility liner and foundation, including settlement and stability analysis. Develops design criteria for both components and recommends protective cover requirements for the liner during construction. A stability analysis associated with a "clean fill perimeter dike" is also being performed within this study.

Leachate Collection-Criteria/Assessment: Identifies and describes various leachate collection systems and associated applications of each; provides regulatory requirements for specific applications; and determines applicable systems for WSSRAP disposal cell alternatives.

Radon Control Criteria: Determines all applicable regulatory requirements concerning radon emanation which are applicable to cell design, operation (filling), and closure.

Radon Barrier Evaluation: Determines (1) the potential for radon flux from wastes in the disposal cell, and (2) the necessity of a radon barrier to mitigate the potential release of radon. Following actual testing of cover and waste materials, all assumptions and calculations will be re-evaluated.

Radon Movement in Leachate: Determines if a leachate collection system will preferentially channel radon from the waste to the atmosphere, quantify the amount of radon released, and identify design features which will mitigate this problem.

Liner Geochemical/Chemical Compatibility Tests: Both synthetic and low-permeability soil liners will be tested with leachate formulated to simulate anticipated conditions to determine liner performance with varying times and leachate concentrations.

THRESHOLD LIMITED KINETICS OF AROMATIC HYDROCARBONS IN SHALLOW SOIL SYSTEMS

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ABSTRACT

Remediation of petroleum-contaminated soils by biological decomposition is rapidly becoming a preferred methodology at numerous sites, particularly gas stations. Experience has shown that excavating the affected soils and landfarming in 4-inch to 8-inch lifts, above grade is the most effective method as critical design parameters can be accurately controlled. A common misconception with this practice, however, is that the rate of mineralization of hydrocarbons is directly proportional to their concentration over a wide range of concentrations. It is often assumed that microorganisms are able to metabolize and presumably are able to grow on all low concentrations of organic compounds. It was the objective of this study to assess the degradation kinetics of four landfarming plots which exhibited varying initial concentrations but similar soil types.

It is important to understand the kinetic limitations of microbial systems. Cleanup criteria typically being set by state and federal regulators for benzene under the Resource Conservation and Recovery Act (RCRA) and the Comprehensive Environmental Compensation and Liability Act (CERCLA) range from 100 ppm to less than 1 ppm in soils. It was found that benzene concentrations below 100 ppm, cell growth patterns and benzene losses suffered significant threshold kinetic restraints.

INTRODUCTION

Microbial decomposition of numerous types of xenobiotic compounds has been suggested and approved for use at hazardous waste sites in recent years. By a wide margin the most significant subset of applications have been associated with petroleum hydrocarbon contaminated sites. The rate of microbial degradation is generally a function of three variables: (1) the concentration of substrate (chemical) available to the organisms that can degrade them, (2) the quantity of the degraders, and (3) the activity of these organisms. This comparative review of biodegradation by use of the landfarming technique focuses on chemical and physical parameters that control or limit these variables. Kinetic limiting parameters include soil type, oxygen levels, soil moisture, temperature, pH, aeration, and macro-nutrient loading.

Results from four independently performed petroleum landfarm sites were compared in an effort to quantify the significance of several limiting parameters and to determine a threshold concentration below which biological activity ceases. At lower concentrations, it was expected that the microbial mix would change from predominantly eutrophic species to oligotrophic species. The oligotroph is able to grow at low substrate levels, whereas the eutrophic species multiplies at high concentrations. Consider that a single organism must use up a certain amount of organic macro nutrients and substrate to provide enough energy to maintain the cell. Therefore, when the nutrient concentration is quite high, diffusion will provide molecules to the cell surface at a rate that is rapid enough to meet the energy needs for maintenance and growth. As substrate declines, growth ceases and, finally, at a critical substrate concentration, even maintenance cannot be satisfied.

Theory

While the number of microbial species appears nearly infinite, there has been found to be a limited number of pathways for degrading any class of compound(1,2,3). This is particularly true for xenobiotic compounds where certain degradation patterns are common.

Dagley(4) completed a comprehensive review of the degradation of stable organic wastes. His work emphasized the direct insertion of oxygen at the early stage of catabolism. Two types of enzymes are typically involved in the reaction, a monoxygenase:

$$RH + O_2 + [H^-] \rightarrow ROH + H_2O$$

and a coenzyme independent dioxygenase:

$$RH_2 + O_2 \rightarrow R(OH)_2$$

In the case of alkanes, monooxygenase attack results in alcohols. Most microorganisms attack alkanes terminally whereas some perform subterminal oxidations. The alcohol product is oxidized further to an aldehyde and finally, to a fatty acid. The latter is degraded further by beta-oxidation. Extensive methyl branching interferes with the beta-oxidation process(5) and necessitates diterminal attack or other bypass mechanisms. Therefore, n-alkanes are degraded more readily than iso-alkanes. Cycloalkanes are transformed by a not fully understood oxidase system to a corresponding cyclic alcohol which is dehydrogenated to ketone. In the next step, a monooxgenase system distinctly different form the previously mentioned oxidase lactonizes the ring, which is subsequently opened by a lactone hydrolase. It is instructive to note that the above two oxygenase systems almost never occur in the same microorganisms.

Procaryotic microorganisms convert aromatic hydrocarbons by an initial dioxygenase attack, eventually oxidizing the intermediate products to catechol, in the case of benzene. Catechol is the key intermediate in aromatic hydrocarbon degradation. It is opened by ortho-, or meta-cleavage, yielding generally muconic acid and finally to tricarboxylic acid cycle intermediates. Polycyclic aromatics are degraded one ring at a time, by a similar mechanism(6), but biodegradability declines with increasing ring numbers.

As can be readily seen, there exists a large number of integrated steps in the overall decomposition of an organic

pollutant. Inhibition at any step may not only prevent total mineralization of the substrate but also preclude any new degradation chains to form. In the following discussion we investigate the limitations on reaction rates.

Selection of Test Systems

In this review we consider exclusively land treatment systems. Land treatment, or landfarming, is a method by which contaminated soils or sludges are excavated and placed in a lined treatment cell. This technique has several distinct advantages over in-situ treatment. Generally, it allows for better control of the system by controlling the depth of soil and the surface area exposed. In turn, one is able to more accurately control soil temperature, nutrient concentrations, moisture content, and oxygen availability. Placing a liner with leachate collection system beneath the soil column prevents any additional contamination potential and it provides for a means of water and nutrient recovery and recycling.

An added benefit of landfarming is found in the ease of sampling and hence cleanup verification. Zones of slow degradation can be readily identified and targeted for enhancement. This method allows for system optimization in a manner other techniques do not.

Drawbacks to landfarming are primarily those of economics. Excavation and construction of the treatment cell may be costly, but off-site excavation and disposal exceeds that of landfarming by a factor of two or more. Available space to operate is the other significant constraint. Soil depths are maintained between 6 and 10 inches to accommodate complete tilling by a disc or chisel plow. Therefore, the total surface area required may exceed 2 acres for a medium sized tank farm remediation project.

The four landfarms chosen for this review represent varying climatic conditions and initial chemical concentrations. In addition discrete parameter sensitivity analyses were performed at one or more of the treatment sites so that data may be presented both independently and collectively. Each of the four locations (Ohio, California, Michigan, and Texas) contained petroleum hydrocarbon contaminated soils.

DISCUSSION

A synopsis of significant site data are presented in Table I. The maximum initial concentration encountered was approximately 5100 mg/kg and the lowest initial concentration was 3940 mg/kg. The minimum concentration achieved at any site was 74 mg/kg of total petroleum hydrocarbons (TPH). Values less than 100 mg/kg represented less than 10 percent of the total number of observations thereby suggesting that a threshold for effective biodegradation is between 50 and 125 mg/kg accounting for measurement accuracy and precision.

Biodegradation flux or loss rates were calculated for the four sites collectively and partitioned by concentration increments as shown in Table II. Loss rate declines generally fit a first order decay function with acclimated soils containing over 3000 mg/kg TPH degrading substrate at a mean rate of 95 mg/kg/day. Dispersivity of data at concentrations above 500 mg/kg was low, typically less than plus or minus 10 percent of the mean. As substrate declines and competition sites die away, pockets of viable and inviable activity form and dispersivity increased to as much as 80 percent of the mean value at concentrations less than 200 mg/kg. The effects of the several individual parameters contributing to this phenomena are discussed each in turn below.

Specific observations were made with respect to threshold values and inhibition points for four parameters, oxygen, biological population enhancement, soil moisture, and temperature. As noted previously these factors do not constitute all of the potential constraints on biodegradation of petroleum in soils, however, these parameters represent critical elements that can often times be controlled in a applications environment.

Oxygen Limitations

The primary purpose of tilling in a landfarm is to optimize the contact of soil microbes with atmospheric oxygen. In soils, aeration depends on the total amount of air filled pore space. Elimination of air-filled porosity through over watering or compaction, reduces oxygen transfer between the microbial colonies and the substrate. Large amounts of biodegradable organics in the top layer of soil will deplete oxygen reserves in the soil and slow down oxygen diffusion rates to the deeper layers.

Oxygen levels were measured at selected points in each of the four tests at one week intervals. More frequent oxygen monitoring was performed in the first 2 to 3 weeks for purposes of evaluating tilling and moisture requirements. At three sites, Ohio, California, and Michigan, tilling biweekly was optimal. At the Texas site where temperatures were significantly higher, oxygen transfer was more efficient and more frequent, i.e.; weekly tilling produced markedly higher degradation rates. This observation is somewhat contrary to that expected. The maximum oxygen content measured in soil

TABLE I
Landfarming Petroleum-Contaminated Soils Summary Statistics: 4 Sites

No.	Location	Initial Conc. TPH (mg/kg) Max.	Initial Conc. TPH (mg/kg) Avg.	Final Conc. TPH (mg/kg) Max.	Final Conc. TPH (mg/kg) Avg.	Final Conc. TPH (mg/kg) Min.	Duration (wks)	Plot Size (ac)	Depth (in.)
1	Ohio	5100	3800	194	158	107	14-232	2	8
2	California	4650	2611	96	87	74	10-42	1.4	8
3	Michigan	2150	1875	147	112	93	16-38	1.5	7
4	Texas	3940	1817	133	106	89	18	0.5	12

[1]TPH = total petroleum hydrocarbons
[2]Activity ceased at point where cleanup criteria were exceeded

water was 6.5 mg/l which is approximately 80 percent of saturation. The minimum amount of oxygen measured,0.9 mg/l, was at 6 inches below the surface in a soil which had not been tilled for 4 weeks. Microbial growth was found to be inhibited at concentrations below 2.5 mg/l and total cell loss was detected at oxygen concentrations below 1.4 mg/l evidenced in very low soil moisture plots.

TABLE II

Petroleum Loss Rates

Concentration (mg/kg) Co	Loss Rate (mg/kg) Max.	Avg.	Min.
>4000	157	95	74
1000-4000	71	53	40
500-1000	57	38	26
250-500	23	9.5	4.0
100-250	8.0	5.4	1.9
<100	1.3	0.8	0

Lowest observed value 74 mg/kg

Microbial Density Enhancement

One way to enhance biodegradation of organic compounds is to inoculate the soil or ground water (as appropriate) with microorganisms known to metabolize the chemical readily. This concept has been roundly debated for its performance by various researchers and commercial vendors of inoculum(7). Both successes and failures have been noted in the literature. It has been this author's experience that commercial bacteria cannot be relied upon as a sole source as their populations tend to die off quickly, thus requiring numerous reapplications. In the natural environment the hybrid species face competition, predation or parasitism. Any of these interactions could account for the inability of introduced microbes to survive(8).

The potential of hydrocarbon mixtures to be eliminated at a higher rate from soil when hydrocarbon degrading bacteria are added to the soil is also a much disputed matter. A general criticism of the seeding approach is that the use of an allochthonous microbial population may not be necessary or effective in most cases. Also, most isolates implicated in petroleum hydrocarbon biodegradation are gram-negative, nonsporeforming bacteria. These are difficult to store in large quantities in a manner that preserves their viability(9).

Bioaugmentation was utilized at the landfarm in Ohio. The ability of a proprietary inoculum to degrade TPH was compared to horse manure as a bacteria additive and simply adding sufficient macro nutrients (fertilizer). Results of this evaluation are given in Fig. 1. Inoculum was applied on a bi-weekly basis as population density levels were found difficult to maintain. Manure was found to last at least four weeks before a reapplication was needed. While the commercial additive needed substantially less acclimation time in the soil, 4 days as compared to 3 weeks for the manure, its effectiveness diminished rapidly after the first month of testing.

After 15 weeks of activity the horse manure subplot performed the best followed by the commercial additive subplot and then the subplot with only macro-nutrient additions. Although the performance difference between horse manure

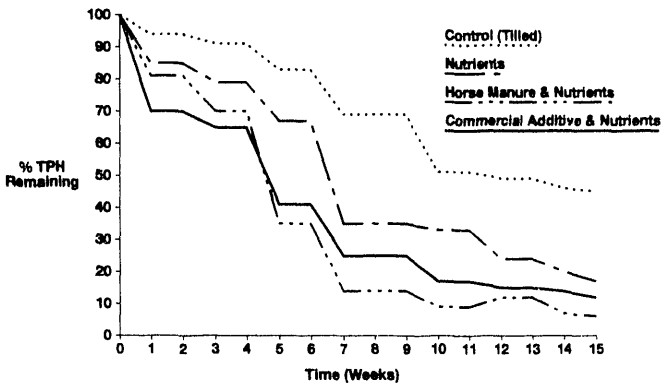


Fig. 1. Biostimulation vs. bioaugmentation plot 1.

and commercial organisms is statistically insignificant, the test indicated that continuous use of commercial bacteria was not beneficial. It was determined, however, that initial injection of commercial bacteria decreased acclimation time and ongoing injection of 5 to 15 percent of such bacteria with fertilization probably is valuable and economically sound.

Moisture Effects

Moisture is essential to the growth of soil microorganisms. Water provides the mechanism for the exchange of reactants and food absorption through the cell walls. Excessive amounts of moisture can be disruptive as discussed previously. Commensurately, when soil moisture drops to near the point of specific retention, usually corresponding to 10 percent or less, metabolic activity ceases. Bossert and Bartha(10) have suggested that moisture contents be maintained in the range of 20 to 80 percent. Biodegradation studies performed at the site in Michigan sought to investigate further for a more accurate or narrow range where moisture content is optimum.

Moisture data from three different subplots are shown on Fig. 2. All other parameters such as temperature, soil type, and nutrient loadings were kept as constant as possible, only moisture content was deliberately varied. Values of 15, 50, and 85 percent of saturation were chosen for the test. These levels were checked once a day for a total test period of 12 weeks. Losses from the 15 percent moisture subplot were minor over the entire duration of the test. TPH loss that was observed is believed to be due almost exclusively to volatilization, not biodegradation. It is thus confirmed that moisture contents below 20 percent are threshold limiting to biodegradation.

Biodegradation was observed in the 85 percent subplot but was only about one third the loss observed in the 50 percent moisture subplot. This evidence suggests that indeed inhibition above 80 percent is present but is not a threshold condition. It is further offered based on the performance of this test that optimum moisture levels are probably in the range of 40 to 60 percent of saturation. Additional study in this area is warranted.

Temperature Effects

Temperature affects the respiration rates of microorganisms and through controlling respiration, temperature affects metabolism. It also affects the solubility of the host hydrocarbons. Temperature is directly related to Fig. 1 the amount of evaporation and volatilization from the soil which

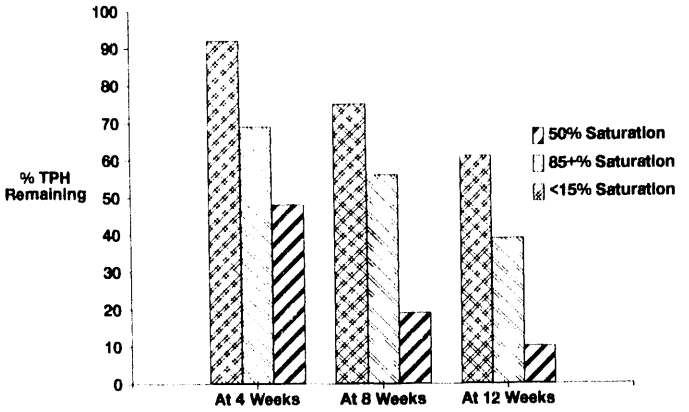


Fig. 2. Moisture effects on petroleum degradation plot 3.

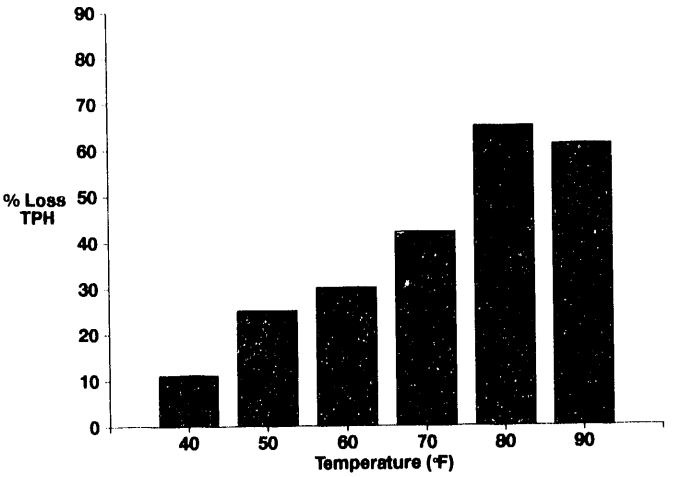


Fig. 3. Temperature effects on microbial activity plots 1-4.

in turn impacts microbial populations. Mesophilic organisms in general perform best at about 95 degrees fahrenheit. Hundleston and Cresswell(11) have reported petroleum degradation as low a 30 degrees fahrenheit. Kuhlmeier and Sunderland(12) found that inhibition became easily detectable at temperatures below 55 degrees fahrenheit.

Temperature was closely monitored at each of the four test locations. Mean TPH loss rates were calculated across a wide range of temperatures. Results of this analysis are presented in Fig. 3. Beginning and ending TPH concentrations for a given period in which the average daily temperature was in a designated temperature bracket, i.e.; 40s, 50s, etc., were summed and the mean loss derived from data in all tests. There was virtually no biodegradation associated with observations at temperatures under 50 degrees. Losses shown on Fig. 3 represent volatilization losses and measurement inconsistencies.

There was a significant difference between degradation rates below 80 degrees from those above this reference value. Biologically attributable losses above 95 degrees interestingly, did not prove to be significantly greater than those at 85 degrees. Although less than 2 percent of the total observations were at temperatures above 100 degrees, there was a noticeable difference from the balance of the data points. When ambient temperatures exceeded 100 degrees the mean percent TPH loss was observed to be 92 percent. The slight drop off from the 80s to 90s bracket is postulated to be attributable to high initial volatilization losses but subsequent cell mortality due to heat stress, rapid moisture loss, or nutrient constraints, or possibly some combination of these factors.

CONCLUSIONS

A review of data collected at four independent petroleum landfarming operations has suggested that biodegradation of contaminated soils may be kinetically limited at concentrations above 50 mg/kg. Loss rates decline dramatically when remaining substrate dips below 150 mg/kg.

Oxygen levels become critical at 2 mg/l as measured in soil moisture. Ideally, soil moisture should be maintained in the 40 to 60 percent of saturation range. Ambient temperature hits a threshold limit for degradation at approximately 50 degrees fahrenheit and reduces microbes to cell maintenance levels only once temperatures drop to 45 degrees.

The addition of commercial microorganisms was not found to be highly beneficial. Natural additives such as sewage sludge or horse manure does enhance microbial activity by introducing large quantities (and diverse types) of microbes. Macro-nutrients although not detailed specifically in the discussion are important for cell activity. A carbon:nitrogen ratio of 160:1 as suggested by the American Petroleum Institute appears to be overly conservative. Carbon:nitrogen ratios of 60:1 to 160:1 were used at the various sites with little evidence that the lower concentration of fertilizer was inhibiting growth.

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SOIL WASHING: A PROMISING TECHNOLOGY FOR THE CLEANUP OF HANFORD

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ABSTRACT

Soil washing is a hazardous waste treatment technology that shows promise for reducing the cost of cleaning up Hanford. The sandy-to-gravelly character of Hanford soil makes the soil a good candidate for the application of the technology. A variety of soil washing vendors offer different approaches to removing contaminants from soil. Factors that must be taken into consideration when selecting soil washing equipment for the Hanford application include properties of the soil and contaminants, cleanup levels required, throughput capacity, secondary waste properties, and cost. Savings of as much as $5000 per ton of contaminated soil may be achievable by using soil washing.

INTRODUCTION

Soil washing is a hazardous waste treatment technology that has been successfully used in the U.S. and Europe to remove certain waste species from contaminated soil. A schematic of a generic soil washing process is shown in Fig. 1. There are many variations of the technology; however, all soil washing approaches employ methods to separate the coarse fractions from the fine fractions. Usually the contaminants are associated with the fine fractions at much higher concentrations than with the coarse fractions. Therefore, the coarse fractions, after removal of the fines, are often clean enough for unrestricted use. If not, the contaminants can often be removed from the coarse particles using chemicals, hot water, intensive scrubbing, and other techniques. The contaminated fine fraction is disposed in accordance with applicable regulations or is further treated to recover or destroy the contaminants. The water used for washing the soil usually requires treatment to remove the buildup of solubilized chemicals. The off gas requires treatment when volatile organic carbon compounds are present in the soil.

Soil washing has been successfully used during the last 10 years in Europe, primarily for the removal of organic contaminants. The U.S. Environmental Protection Agency, (EPA), recognizing the promise of the technology, has been actively testing soil washing since 1982. EPA's Technology Innovation Office is currently promoting the use of soil washing at National Priority List (NPL) sites around the country.

The U.S. Department of Energy (DOE) has also recognized the potential of the technology and has established a plan under the Office of Technology Development (OTD) to test soil washing technologies in organized demonstrations at the Nevada Test Site and at DOE's Fernald Site. At Hanford, Westinghouse Hanford Company (Westinghouse) and Battelle Pacific Northwest Laboratories (Battelle) are working together to conduct a treatability test employing a pilot-scale soil washing system at a radioactively contaminated site. The treatability test will likely be performed through DOE's Environmental Restoration Program. Battelle is currently funded by OTD to initiate characterization of contaminated Hanford soils. Battelle is also assisting the OTD in a planned integrated demonstration on plutonium-contaminated soil by performing characterization and laboratory-scale washing experiments. If the tests are successful, soil washing has the potential to become an important technology in the massive cleanup effort planned for Hanford.

APPLICABILITY TO HANFORD

The Hanford Site is the largest CERCLA site in the nation, encompassing 560 square miles of semiarid desert in South Central Washington. The Site is bordered to the north and east by the Columbia River and is adjacent to the northern boundary of the city of Richland, Washington. Located on the Site are a number of operations that were conducted to produce plutonium for the Department of Defense as well as to support other nuclear research for the DOE. The Site contains over 1000 inactive waste disposal and unplanned release sites ranging in scope from minor spill areas to burial grounds of up to 100 acres in size. Estimates of the extent of soil contamination exceed a billion cubic yards (1) and there are known plumes of contaminated groundwater totaling over 230 square miles. Much of the contaminated soil is radioactive mixed waste which contains RCRA hazardous waste mixed with low-level radioactive waste.

Surface soils at Hanford are characterized by a layer of light brown, fine, slightly silty, wind-deposited sand typically varying from less than one foot to over 15 feet in depth. Surface soils at Hanford have become contaminated as a consequence of unplanned releases to the environment. The unplanned release sites resulted from events such as spills from tanks,

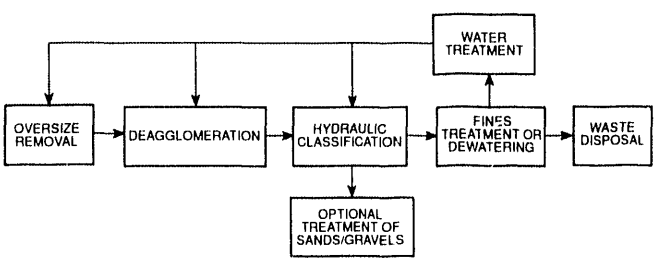


Fig. 1. Generic soil washing process.

ruptures of piping, and windblown dispersion of contaminated animal feces. One site alone contains more than four square miles of contaminated area.

Underlying the surface soil are poorly sorted, unconsolidated glaciofluvial sediments informally referred to as the Pasco gravels of the Hanford formation. These sediments were deposited during catastrophic flooding episodes associated with failures of the Lake Missoula ice dam during the late Pleistocene Epoch. Soil textures vary, but in general the Hanford formation consists of roughly 50% cobbles and gravel, 40% sand, and 10% silt (2). The thickness of the Hanford formation varies from about 20 to several hundred feet. The Hanford formation has become contaminated through the discharge of high volumes of contaminated liquids to underground, engineered structures. These structures resemble large septic tanks and drain fields. The high gravel and sand content of Hanford soils suggests that soil washing may be able to achieve a volume reduction of 80% or higher.

Contaminants identified in Hanford soils include radionuclides such as cesium-137, strontium-90, cobalt-60, plutonium-239, uranium-235/238, and other actinides and fission products. Hazardous chemicals are also present at many sites containing radioactivity. These chemicals include heavy metals, nitrate salts, chlorinated hydrocarbons, and other species. The level of contamination ranges from extremely high (as at the inlet to some liquid waste disposal structures) to light (as in sites with windblown surface contamination).

AVAILABLE SOIL WASHING TECHNOLOGIES

Many companies world-wide market soil washing technologies. For the most part, these companies have integrated common mining and industrial unit operations into processes designed for removing specific types of contaminants from soil. Some of the companies are using patented devices whereas others have modified standard equipment to enhance performance.

A wide variety of equipment and treatment methods are potentially applicable. Treatment methods are listed in Table I.

More than a dozen companies, many of them European, have integrated various of the treatment methods identified in Table I into proprietary soil washing processes. Some of these companies are listed in Table II. The latter six vendors in this table are marketing their processes in the U.S.

Each vendor offers soil washing equipment designed to achieve deagglomeration and hydraulic classification of fines and coarse fractions. The hydraulic classification methods employed to separate sand and pebbles from the fines fraction vary widely and are worthy of discussion.

Several of the vendors utilize hydrocyclones as shown schematically in Fig. 2. The centrifugal action created by injecting slurry tangentially inside the hydrocyclone causes coarser particles to be preferentially driven to the wall of the cyclone. The coarser particles then spin out against the wall, fall by gravity and then are discharged from the bottom of the cyclone. The fine particles remain in suspension and are discharged with the bulk of the water flow through the top of the cyclone. The creative use of hydrocyclones is the heart of the soil washing system employed by Heidemij J.V./Geraghty & Miller.

The AWC-Lockheed TRUclean process uses a device called a Selective Mineral Separator to remove fines that are

TABLE I

Soil Washing Treatment Options

Feed Preparation
- Coarse screening
- Closed-circuit screening/grinding

Deagglomeration and Mixing
- Water jet impaction
- Slurry vibrating attrition
- Trommel screening
- High-shear mixing
- Stirred tank mixing

Hydraulic Classification
- Wet screening
- Screw classification
- Staged hydrocyclone classification
- Dissolved air flotation
- De-emulsification of fats, oils, and greases

Enhanced Separations Methods
- Acid addition
- Alkaline addition
- Reduction/oxidation potential adjustment
- Use of heated water
- Use of surfactants
- Use of chelating agents
- Use of de-emulsifiers
- Use of coagulants/flocculants

Solid-Liquid Separation
- Gravity Sedimentation
- Filtration
- Centrifugation

Wash Water Cleanup
- Ion exchange
- Activated carbon sorption
- Biological oxidation
- Distillation

Treatment of Residues
- Incineration
- Desorption
- Solidification/stabilization
- Biological treatment
- Chemical treatment
- Vitrification

TABLE II

Vendors of Soil Washing Systems

- EWH ALSEN - BRETTENBURG
- KLOCKNER UMWELTECHNIK
- BODEMSANERING NEDERLAND BV (BSN)
- ECOTECHNIEK BV
- HARBAUER
- TBSG INSTREIVEITIETUNGEN
- HWZ BODEMSANERING BV
- HEIJAMAN MILIEUTECHNIEK BV
- MTARRI/WASTE - TECH
- HEIDEMIJ JV/GERAGHTY & MILLER
- BIOTROL
- AWC TRUCLEAN/LOCKHEED
- SEG/WESTINGHOUSE
- BESCORP

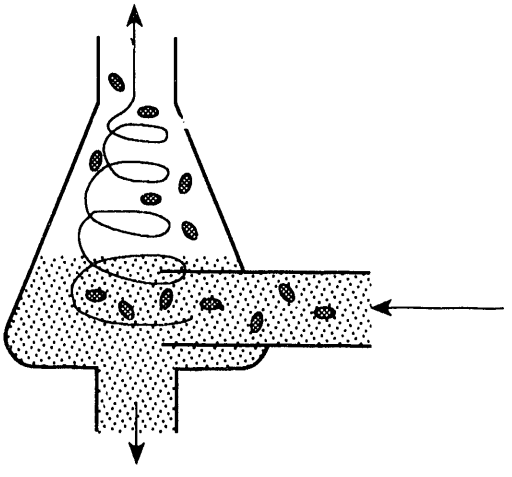


Fig. 2. Hydrocyclone.

at least twice as dense as the soil matrix in which they are contained. The technology has been shown to be very effective in removing heavy metal fines and oxides, such as plutonium oxide, from sand. A schematic of the device is shown in Fig. 3. Separation is achieved by pulsing the bed of contaminated soil. The denser particles settle faster between pulses, resulting in the particles eventually passing through the supporting bed of steel shot and into a collection chamber.

Several companies, including Biotrol, employ froth flotation. A schematic of a froth flotation tank is shown in Fig. 4. Small air bubbles formed at the bottom of the tank combine with fine soil particles. This effectively reduces the density of the particles, causing them to rise and form as a froth at the top of the tank. The froth can be removed by skimming or by overflowing a weir.

The separation system employed by BESCORP is a patented hydraulic separations device (Fig. 5). The device, called a counter-flow separator, has been used for the past two years at a 150 ton/hour placer gold mining operation in Alaska for separating gold-bearing fines. In the BESCORP system, a slurry of fines, sand, and pebbles enters the top of the separating chamber where very fine particles are maintained in

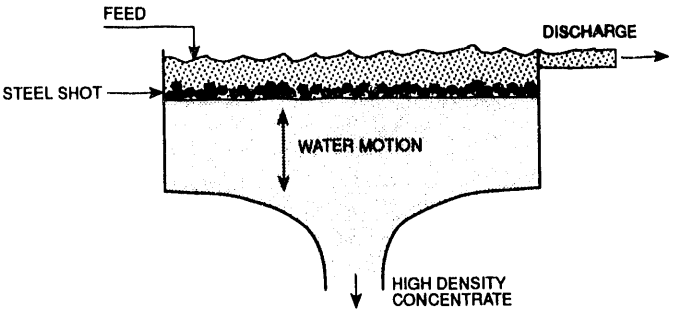


Fig. 3. Selective mineral separator.

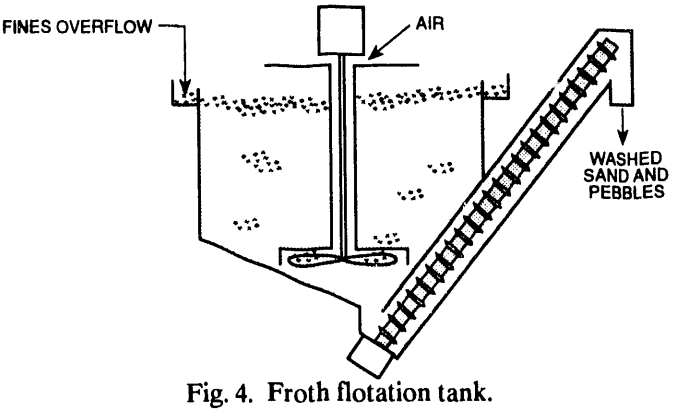


Fig. 4. Froth flotation tank.

suspension by a slight upward flow of water. This suspension is discharged to a clarifier for further concentration of the fines and recovery of the water for recycling. Larger and denser particles settle to the bottom of the chamber where they encounter a higher velocity stream of upflowing, clean water. The largest and densest particles that enter this stream achieve a settling velocity greater than the water velocity and, therefore, settle to the bottom of the counter-flow separator. The settled material is subsequently separated from the water using a spiral classifier.

Particles that are entrained by the higher velocity water stream are discharged to a second separations system where lower velocity flows allow collection of washed particles of a slightly smaller size, or cut. Several of the counter-flow separators can be used in series, allowing many cuts to be collected. Only those still contaminated are disposed.

BESCORP has built a 20 ton/hour pilot plant which is mounted on a small trailer (8 feet x 40 feet) and has demonstrated this unit on clean soil at a site near Hanford. Table III shows the sharpness of the 150 mesh split achieved in that demonstration, which reflects the ability of soil washing technology to produce an excellent separation of coarse and fine soil.

FACTORS AFFECTING THE APPLICABILITY OF SOIL WASHING AT HANFORD

A number of factors must be taken into consideration when determining which soil washing processes are applicable to Hanford and which contaminated soils are amenable to washing. These factors include properties of soil and contaminants, required cleanup levels, throughput capacity, secondary waste properties, and cost. Each of the these factors is discussed below.

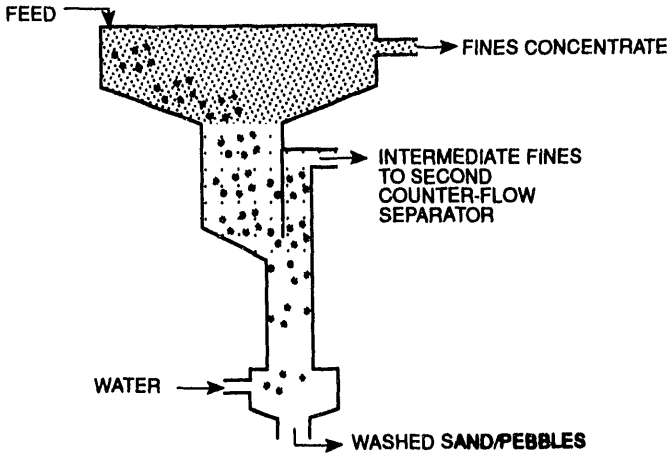


Fig. 5. Counter-flow separator.

TABLE III

Sharpness of Particle Size Cuts produced by Soil Washing Demonstration

Sieve Size	Stream No. 1 (% passing)	Stream No. 2 (% passing)
4	100	100
10	95	100
20	84	100
40	33	100
80	1	100
200	0.3	99
270	0	97
400	0	84
635	0	62

Soil and Contaminant Properties

Soil properties that may affect the soil washing process include moisture content, pH, buffering capacity, reduction-oxidation potential, consistency, physical toughness of agglomerates, and particle type and size distribution. Hanford soils typically exhibit a low moisture content (5 - 10%), a basic pH (8.0 - 8.5), a relatively high buffering capacity, a crumbly consistency, agglomerates that are relatively easy to disperse in water, and a sandy-to-gravelly character with usually less than 20% silt and clay. These properties make Hanford soil an excellent candidate for application of the technology. The basic pH and relatively high buffering capacity raise questions about the feasibility of leaching inadequately cleaned soil with acid, should that measure be needed.

Cleanup Levels

The issue, "How clean is clean?", plays an important role in assessing the feasibility of soil washing. Cleanup limits for contaminated media have been defined at Hanford by Westinghouse and by the Washington State Department of Ecology (Ecology). Westinghouse's requirements are established for radionuclides in accordance with DOE Order 5400.5. Ecology's requirements have been defined for hazardous chemicals pursuant to the Model Toxics Control Act (Chapter 173-340 Washington Administrative Code). These and other requirements and standards will serve as the basis for negotiating limits for the unrestricted release and use of soil cleaned by soil washing. The ability to readily adjust the separation point between the fine fraction and the coarse "clean" fraction may be a key need for meeting the negotiated cleanup limits since contamination levels of Hanford soils are expected to vary widely. Thus, in certain cases, only gravel may be cleaned adequately.

Throughput Capacity

As previously stated, more than one billion cubic yards of contaminated soil exists at Hanford. If it is assumed that 10% of the soil is found to be acceptable for soil washing, then the soil washing systems must be capable of processing at a cumulative rate of approximately 3000 cubic yards per hour if the cleanup of Hanford is to be completed by the year 2018 as stipulated by legal agreement. (This rate is based on the need to recover the bulk of contaminated soil during daylight hours and to avoid double handling associated with stockpiling.) Clearly, the soil washing system must have a high throughput capacity to satisfy Hanford's cleanup goals. Tied to this need is the requirement that the process be simple and reliable. Seemingly simple processes in the hazardous waste arena may not be amenable to radioactive waste operations because of the many special requirements imposed to ensure worker and environmental safety. The high throughput rates and high degree of simplicity of soil washing, however, make this technology very attractive for the Hanford application.

Secondary Waste

Secondary waste is a primary concern in designing a successful soil washing system. Secondary wastes include the contaminated fraction, spent wastewater treatment media (e.g. ion exchange resins and activated carbon), process off-gas, and contaminated equipment. These wastes could contain sufficient levels of hazardous chemicals and/or radionuclides to make their disposal complex and costly. Such could occur if hazardous chemicals were used to augment cleaning or if sufficient concentration of the fines occurred to cause the waste to be designated or classified at a higher level. The use of hazardous chemicals for augmenting washing is not expected to be necessary in most cases at Hanford, however. Also, soils selected for washing will be evaluated before washing to ensure that the secondary wastes produced are economically acceptable.

Cost

Cost is an important factor in determining which Hanford soils are amenable to washing. Many contaminated soils at Hanford are mixed wastes. The current cost for disposal of mixed waste at Hanford is $1900/drum (3). At a soil bulk density of 1.5 g/cc, this cost is equivalent to a cost of $5,500/ton. Various soil washing equipment vendors have reported soil washing costs for chemically contaminated soil ranging to as high as $158/ton, and AWC reported costs of $400 - 600/ton for radioactive contaminated soil (4). As a result, the application of soil washing at Hanford may yield a cost savings of as much as $4900 to $5300 per ton of soil that can be successfully cleaned to the negotiated cleanup limits.

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RESULTS OF VITRIFYING FERNALD K-65 RESIDUE

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To be published by the American Ceramic Society, Inc.

ABSTRACT

Two silos, designated as K-65, at the Feed Materials Production Center in Fernald, Ohio, contain residues from the processing of pitchblende ores. The K-65 residue, which contains radium, uranium, uranium daughter products, and heavy metals (primarily lead), was vitrified in a bench-scale system that allowed the volume and composition of the off gas to be determined. Chemical analyses of both the vitrified and nonvitrified residue were performed, including Toxicity Characteristic Leachate Procedure (TCLP) and Extraction Procedure (EP) toxicity testing. Both the radon emanation rates and the specific gravity of the vitrified and nonvitrified residue were also measured. The nonvitrified K-65 residue tested "hazardous" by the EP toxicity procedure, and the radon emanation rate (52,400 $pCi/m^2/s$) was over 2500 times the EPA limit of 20 $pCi/m^2/s$. After vitrification, the K-65 residue tested "nonhazardous" by the TCLP; the volume was 35% that of the original material (a 65% reduction); and the radon emanation rate was reduced by a factor of over 33,000 from 52,400 $pCi/m^2/s$ to 1.56 $pCi/m^2/s$, an order of magnitude below the EPA limit. Thus to vitrify this residue is an attractive option.

THE K-65 CHALLENGE

Vitrification is being investigated to treat material from the Feed Materials Production Center (FMPC) in Fernald, Ohio. The site, in a rural area in southwest Ohio, is owned by the Department of Energy (DOE) and is operated by Westinghouse Materials Company of Ohio (WMCO). Two large concrete storage silos, designated as K-65, hold residues from the processing of pitchblende ores during the years 1949-1958. This residue contains radium, uranium, uranium daughter products, and some heavy metals (primarily lead). DOE assumed ownership of the material in 1983, and thus also assumed responsibility for remediation of the silos.

K-65 material totals about 8.6 million kg (9500 tons). Radium-226 content is about 4 kg; uranium 11,000 kg (12.5 tons); and thorium-230 about 2 kg. The gamma radiation from the residue is sufficient to result in an average of about 200 mr/h outside the silo dome. The radon concentration of the silo headspace is around 30 million pCi/L.

The problem of the K-65 silos is complex and of a sensitive nature: A number of people live near the silos, with the nearest dwelling only 500 yards away. Until disposal options become available, however, the K-65 residue will have to be stored onsite at the FMPC. The best method is being sought for treating the residue to ensure its safe handling and storage if it is removed from the silos. Moreover, the disposal issue is further complicated by the recently included potential that 40 CFR 191 (regulations for Transuranic [TRU] materials) may become an Applicable or Relevant and Appropriate Requirement (ARAR) for remediating these silos primarily because, like TRU materials, the residue contains long-lived and alpha-emitting radionuclides.

- Remediation of the K-65 silos focuses on addressing four major concerns:
- to control the radon released from the radium
- to prevent leakage into the significant aquifer immediately beneath the site
- to control the spread of radioactive particulate (radium, radon daughter products, thorium, etc.)
- to control the high gamma radiation from the residue.

If the K-65 residue is removed from the silos and put in interim storage, the following requirements must be met: 1) the radon released from the storage facility must not exceed 20 $pCi/m^2/s$, 2) there must be no potential for hazardous constituents to migrate to the aquifer, and 3) the storage arrangement must prevent the spread of radioactive particulate.

VITRIFICATION

The Pacific Northwest Laboratory (PNL)* recently completed vitrification tests on the K-65 residue. These were done in support of the Feasibility Study portion of the Remedial Investigation/Feasibility Study process currently ongoing at the FMPC to determine whether vitrification will meet the remediation requirements. Among the many reasons that vitrification is attractive for treating wastes are that it produces an extremely durable, chemically stable glass product, and it can greatly reduce waste volume and thus be cost-effective. The process as it applies to vitrifying wastes has been under development for years, and was selected as the treatment standard for high-level radioactive mixed waste (1). It was recognized also as a highly effective method for treating wastes that contain arsenic (2,3).

* Pacific Northwest Laboratory is operated by Battelle Memorial Institute for the U.S. Department of Energy under Contract DE-AC06-76RLO 1830.

In addition to the foregoing general reasons, vitrification was selected as a potential treatment for K-65 residues particularly for the following specific reasons. The K-65 residue is a simple oxide waste, much like conventional glass-making materials, and thus does not require extensive glass formulation or glass-former additions to produce a waste form. Vitrification technology can accommodate various forms of feed. Existing technology can be used to retrieve the residue from the silos and to pump it directly as a slurry to the melter, ensuring that the residue is contained throughout the remediation process and that the spread of particulate is controlled.

In a vitrified matrix, the diffusion of gases with atomic radii equal to or greater than krypton (1.03 Å) and xenon (1.24 Å), such as radon (1.34 Å), is virtually nil (4). Thus release of radon from the vitrified residue will be limited to the modest amount of externally exposed surface area. Barretto (5) found that volcanic glass had the highest radon retention ability of the 59 rock samples he studied. Vitrification appears, therefore, to be an environmentally progressive and technically sound option for treating the K-65 residue.

The following tests were performed to provide quantitative data for use in engineering studies that will compare the effectiveness and cost of various approaches to storage and disposal of K-65 residue.

THE VITRIFICATION TESTS

PNL received about 7 kg of the K-65 residue for vitrification tests. The objectives were to determine the quantity and composition of off gas evolved during vitrification, the radon emanation rate from both the original K-65 residue and the vitrified product, and the leachability of the vitrified material. Samples of the residue were vitrified on a bench scale, and the off gas from the process was collected, measured (volume), and analyzed for radon and other constituents. Finally the radon emanation rates from both the vitrified and nonvitrified residue were measured. The work was conducted in four phases as described below:

Phase 1 - The residue was slurried, adding a NaOH solution as the glass-former, and then was melted at 1150°C (minimum) in an Inconel crucible about 4 in. diam by 12 in. tall (~2.5 L) within a bench-scale furnace. The experimental system (Fig. 1) was designed to contain and cool all off gas produced during vitrification of the slurry contained in the crucible. As the crucible was heated, the gas already present in the system expanded and an off gas evolved from decomposition of the K-65 residue. These gases then bubbled through and displaced the water in the collection vessel, and the displaced water was collected in a carboy. Use of both water displacement and adjustments to the carboy height ensured that the system pressure was essentially equal to ambient. After heating, the valve between the crucible and the collection vessel was closed, and the valves to the recirculation loop were opened. This prevented the water in the collection vessel from being drawn back to the crucible through the dip leg by the cooling contracting gas. Instead, the gas traveled through the recirculation loop, and the water in the carboy flowed back into the collection vessel as needed. After the system cooled, the volume of the off gas produced was obtained by measuring the volume of displaced water.

Phase 2 - The second phase involved collecting off-gas samples for chemical analyses and for determining the radon concentration. This was done by first recirculating the off gas

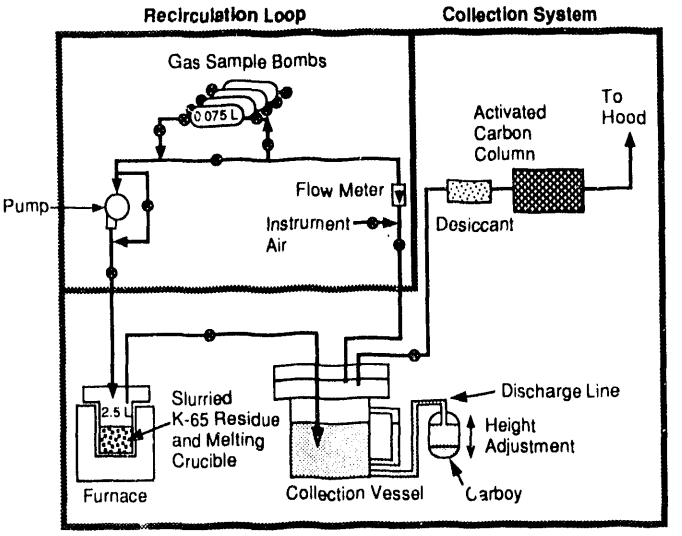


Fig. 1. Off-gass collection system.

through the recirculation loop to ensure homogeneity, then collecting samples in 75-mL sample bombs.

Phase 3 - The remaining off gas was then passed through the activated charcoal column, which collected essentially all the radon. The column was subsequently analyzed for radon exposure data to supplement that obtained with the radon gas monitor.

Phase 4 - For the final phase, the radon emanating from both the vitrified and the nonvitrified K-65 residue was measured.

As received, the residue had a high moisture content (~29 wt%) and contained rock and debris (e.g., metal springs, cloth, and leather gloves). To provide consistency, the residue was dried and sieved through No. 16 (ASTM) mesh (sieve opening of 1.19 mm) to remove the rock and other items. Some of the dried and sieved residue was tamped into a graduated cylinder, and a specific gravity of 1.06 was measured.

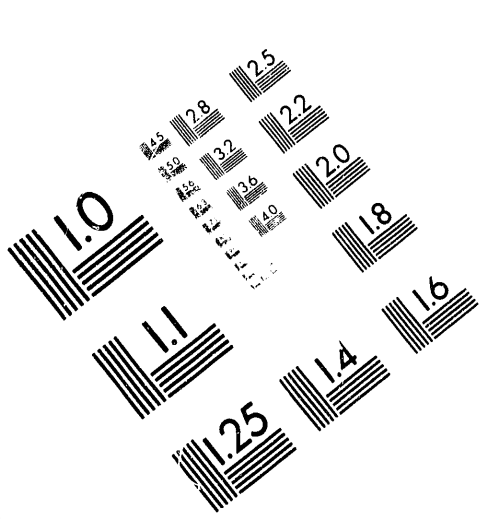
The K-65 residue has been characterized by Controls for Environmental Pollution, Inc. (CEP) and National Lead of Ohio (NLO) as well as by PNL. Table I summarizes the results of those analyses. Extraction procedure (EP) toxicity data (see Table II) were obtained for the K-65 residue.* Except for lead, all the heavy metals from the EP toxicity list (Ag, As, Ba, Cd, Cr, Hg, and Se) in the residue were below the regulatory limit. A gamma scan conducted to determine the isotopic content indicated a ^{226}Ra content of 479.4 nCi/g and a ^{230}Th content of 264.7 nCi/g.

Three separate vitrification tests were performed as discussed below.

Test 1

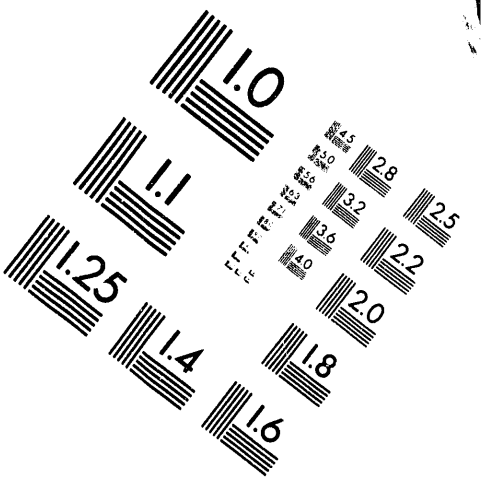
The slurry used in the first test comprised 968 g of K-65 residue, 166 g of reagent grade NaOH, and 885 g of water. Calculations indicated this mixture would produce a slurry that was 44 wt% water and a glass that is 12 wt% Na_2O. The slurry was quite dilute, containing probably more water than would be used in actual processing. During this test, 13.5 L of off gas was produced.

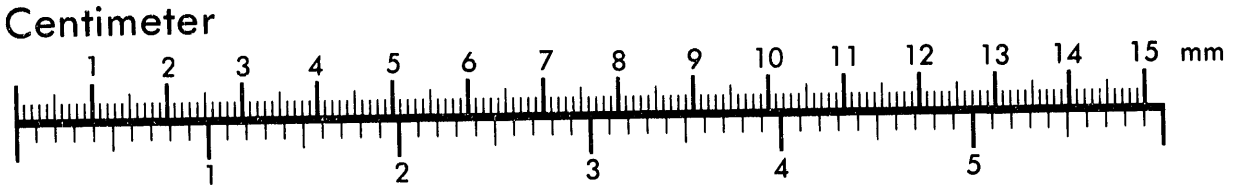
After the system cooled down, off-gas samples were taken for chemical analyses and for measurements of radon concentration. The results of the chemical analyses revealed that the off-gas composition was essentially that of air. In addition, samples of the vitrified residue were analyzed for percent composition and tested using the Toxicity Characteristic

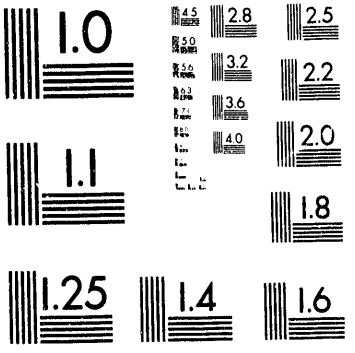


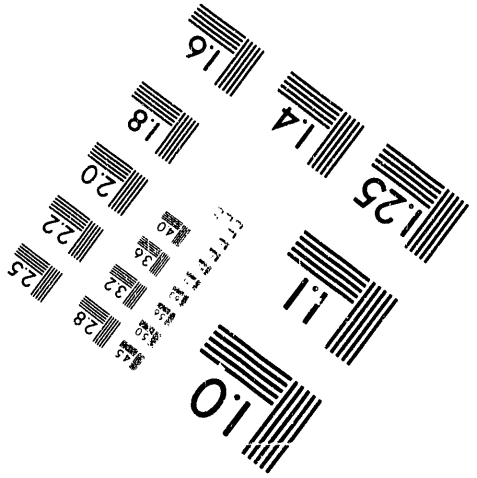


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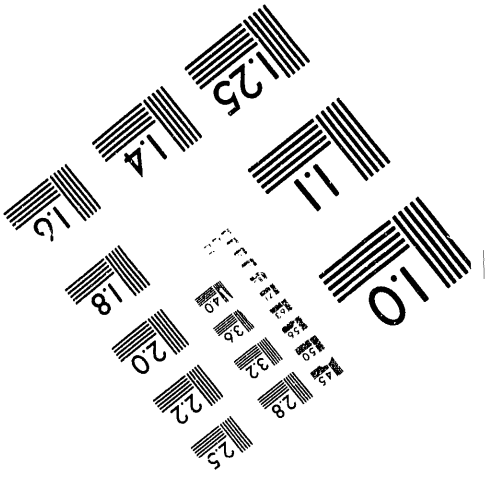








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TABLE I

Summary of Chemical Analyses of K-65 Residue: Normalized (expressed in wt% as oxides)*

Element	1. CEP-90, avg.	2. PNL-90, avg.	3. NLO, avg.	4. PNL-89, avg.
Si	56.62%	61.28%	71.43%	63.46%
Pb	10.27%	9.97%	9.00%	10.45%
Fe	9.67%	5.37%	2.81%	4.43%
Ba	8.12%	2.90%	0.13%	6.36%
Al	6.94%	3.81%	2.71%	3.67%
Ca	1.32%	2.85%	8.91%	3.33%
Mg	2.41%	3.83%	2.30%	1.51%
Na	1.59%	1.19%	1.55%	1.89%
P	0.00%	5.08%	0.00%	0.76%
Other	3.06%	3.72%	1.16%	4.14%
Total	100.00%	100.00%	100.00%	100.00%

TABLE II

EP Toxicity Data for Nonvitrified K-65 Residue

Metals	Value (mg/L)	Limit (mg/L)
Arsenic	<1.0	5.0
Barium	0.76	100
Cadmium	0.1	1.0
Chromium	<0.2	5.0
Lead	630 (above regulatory limit)	5.0
Mercury	<0.03	0.2
Selenium	<0.1	1.0
Silver	<0.1	5.0

*Buelt, J. L.The Adaptability of Vitrification Technology to K-65 Residue Material. Letter, J. L. Buelt to R. A. Vogel, May 25, 1989.

Leachate Procedure (TCLP). The results are presented in Tables III and IV. Based on the data in Table IV, the vitrified K-65 residue is nonhazardous as tested by the TCLP, whereas the nonvitrified K-65 residue is hazardous because it exceeds the EP Toxicity limit for lead (Table II). Thus the vitrified product improved the leach resistance for lead by a factor of over 2000. Moreover, the vitrified product is so durable that it could not be dissolved in a hot mixture of concentrated nitric and hydrofluoric acid by Controls for Environmental Pollution (CEP), Inc., during their analyses of the glass. A specific gravity of 3.1 was measured for the vitrified residue and was compared with that of the nonvitrified residue, 1.06. Thus vitrification reduced the volume of the dried, tamped K-65 residue by 65%.

Test 2

For the second test, a smaller batch of slurry was prepared consisting of 500 g of K-65 residue, 72 g of NaOH, and 114 g of water. Based on calculations, this combination would produce a glass that is 10 wt% Na_2O. Just enough water was added to make a thick slurry, and 7.3 L of off gas was produced

TABLE III

Weight Percent Composition (as oxides) of Vitrified K-65 Residue

Oxide	Wt%
Si	52.75
Na	13.49
Pb	9.57
Fe	9.01
Ba	7.57
Al	6.46
Mg	2.24
Ca	1.23
Ni	0.64
Cr	0.49

TABLE IV

TCLP Leachate Results for Vitrified K-65 Residue (Conc. of Metals in Leachate)

Metal	Value (mg/L)	Limit (mg/L)
Arsenic	<0.01	5.0
Barium	0.98	100.0
Cadmium	<0.05	1.0
Chromium	<0.05	5.0
Lead	0.30	5.0
Mercury	<0.0004	0.2
Selenium	<0.01	1.0
Silver	<0.05	5.0

during this run. The off-gas composition was again essentially that of air. The condensate was also sampled, and both the off-gas and condensate data indicate that, for the chemicals present, 99.5% to 99.95% is retained in the glass. This is typical of results obtained during thousands of hours of melter

testing with simulated high-level radioactive waste slurries (6,7).

Test 3

For the third test, the remaining K-65 residue was divided. Roughly half (946 g) was used for the third melt, and the other half (926 g) was used to obtain radon emanation measurements from the nonvitrified residue. The residue for the third melt was slurried using 149 g of NaOH and 341 g of water, a combination calculated to produce a glass that was 11 wt% Na_2O. The total volume of off gas produced was 12.2 L. The vitrified K-65 residue from Test 3 occupied about 1.5 in. of the 12-in.-tall crucible.

RADON MONITORING

Two different monitors were used for radon concentration measurements: a Pylon AB-5 and an Eberline RGM-3. The Pylon monitor differs from the RGM-3 in the rate at which it pumps. The typical flow rate for the RGM-3 is 8 L/min, while the Pylon pumps at less than 0.5 L/min. The Pylon was used to monitor the vitrified residue from Test 3, and the RGM-3 was used to monitor the nonvitrified residue.

Radon Released During Vitrification

During the measurement of radon concentrations in the off gas, some problems with the test equipment were discovered. Based on the data obtained, the radon released during processing could probably be controlled by absorption onto activated charcoal (8). However, studies are being planned to provide the. . data.

Open-System Tests

To provide a common basis for comparing the radon emanation rates from vitrified and nonvitrified K-65 residue, both were measured in an open system. The concentrations of radon in the sweep air going through canisters of the residue are shown in Fig. 2. The canisters were flushed with air before beginning the radon measurements to ensure that the radon concentration in this test arrangement began at 0 pCi/L.

For the nonvitrified residue, a nearly steady value of 3200 pCi/L was reached and maintained for over 420 h (see Fig. 2). At 8 L/min, this represents an emanation rate of 1.5 million pCi/h or 52,400 pCi/m^2/s. This emanation rate accounts for about 50% of the total amount of radon theoretically generated by decay of the ^{226}Ra present. For the vitrified residue, the radon concentration averaged about 4 pCi/L. At 0.2 L/min, this

Fig. 2. Radon emanation (in pCi/m^2/s) from nonvitrified and vitrified K-65 residue.represents an emanation rate of 48 pCi/h, or 1.56 pCi/m^2/s. This is more than 33,000 times less than the rate for the nonvitrified residue, and is an order of magnitude lower than the EPA limit of 20 pCi/m^2/s.

We predict that during full-scale processing, the radon flux may be further reduced because the test crucible had both unmelted material and a coat of glass on the crucible walls. Therefore the actual surface area exceeded the assumed surface area by more than a factor of 3. Furthermore, the tested glass sample had an exposed surface area-to-volume ratio that is 30 times higher than that of a filled 55-gallon drum, which is a likely casting form for actual processing.

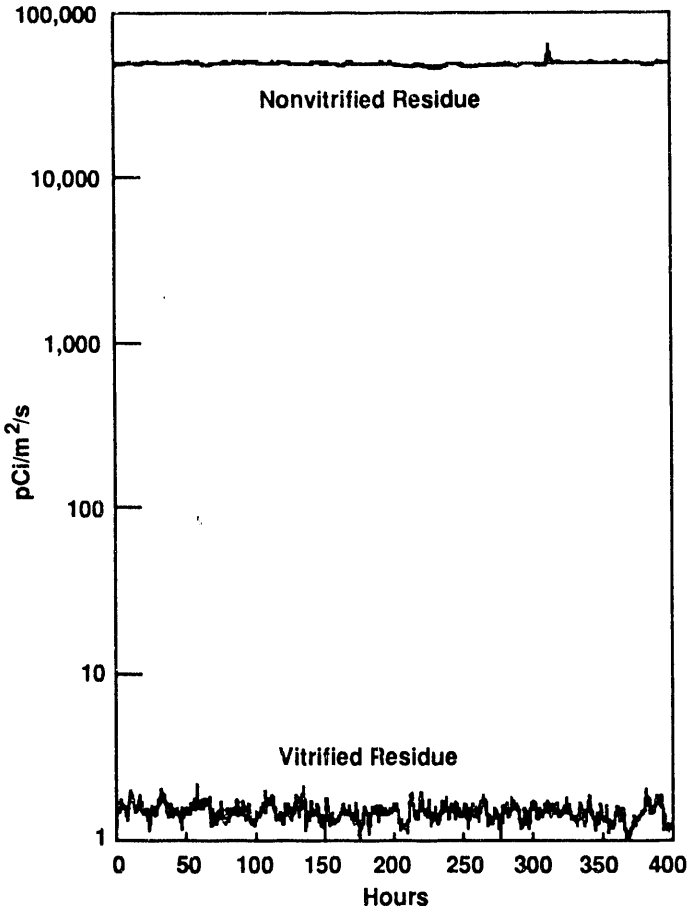


Fig. 2. Radon emanation (in pCi/m^2/s) from nonvitrified and vitrified K-65 residue.

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GROUND WATER EXTRACTION, TREATMENT, AND UPGRADIENT INJECTION SYSTEMS PROVIDE A MECHANISM TO CONTROL TRITIUM PLUMES AT DOE FACILITIES

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CTM

ABSTRACT

Tritium has migrated from waste management units at some Department of Energy facilities and has impacted the environment. The Environmental Protection Agency and the South Carolina Department of Health and Environmental Control have requested that the Savannah River Site remediate a tritiated groundwater plume from the F and H-Area Seepage Basins. Existing tritium treatment techniques were investigated and determined to be infeasible due to the dilute concentrations, and high capital and operating costs. Due to its short half-life, tritium "treatment" of contaminated groundwater through recycling by extraction and upgradient injection offers a cost effective treatment alternative that can be installed relatively quickly.

INTRODUCTION

Some Department of Energy (DOE) facilities generate tritiated wastes as a result of fulfilling their missions. There are cases where tritium has migrated from the waste management units and has impacted the environment. The Savannah River Site utilized a series of three seepage basins for the F-Area Separations Facility and four seepage basins for the H-Area Separations Facility to dispose tritiated wastewater. Fig. 1 shows the location and layout of the seepage basins. These unlined surface impoundments operated from 1955 until 1988 when the Resource Conservation and Recovery Act (RCRA) mandated their closure. Tritium, radionuclide, nitrate and heavy metal waste components seeped from the basins through the vadose zone and mixed with the groundwater. Tritium was detected in a wetlands and a small stream (Fourmile Branch) downgradient from the F and H-Area Seepage Basins approximately 3-5 years after operation of the H-Area basins commenced and 8 years after operation of the F-Area basins commenced. Fig. 2 depicts the seepage basin and Fourmile Branch environment. The South Carolina Department of Health and Environmental Control (SCDHEC) has requested a Corrective Actions Plan for the groundwater in the uppermost aquifer downgradient from the F and H-Area Seepage basins. The presence of tritium within the groundwater has complicated the selection of a remediation strategy.

CHEMICAL AND PHYSICAL CHARACTERISTICS OF TRITIUM

Tritium is the isotope of hydrogen with one proton and two neutrons in the nucleus. Its chemical symbol is H_13. This isotope has three times the mass of ordinary hydrogen atoms. Tritium decays by emitting a negative electron known as beta emission. As the negative charge is lost, one neutron changes into a proton and the atomic number increases from 1 to 2 (General Electric Co., 1989). The original radioactive tritium becomes helium (He_23). This isotope of helium is stable and does not undergo radioactive decay. Tritium is a relatively short lived radionuclide that has a half-life of 12.3 years (General Electric Co., 1989). One gram of tritium contains 9.64×10^3 curies (Radiological Health Handbook, 1970). The curie is the base unit of radioactivity in that one curie represents 3.7×10^{10} nuclear transformations per second. Tritium exists as a gas at normal temperatures and pressures and its chemical and physical properties are almost indistinguishable from those of ordinary hydrogen. Tritium oxide shares most of the chemical and physical properties of water.

TRITIUM TOXICOLOGICAL PROPERTIES

The effects of tritium oxide are comparable to whole body irradiation (Vennart 1969). Tritium distributes uniformly in soft tissue (ICRP30, 1978). The greatest concern regarding tritium oxide, from a human health standpoint, is the risk of cancer and genetic mutations from low-level exposures.

Human and Environmental Health Impacts from Tritium

Tritium is readily absorbed into the bloodstream via the gastrointestinal tract, lungs, and skin (ICRP30, 1978; Caserrett et al, 1980). Tritiated water quickly enters all tissues and irradiates the body in a uniform manner following ingestion. ICRP 30 (1978) reports complete and instantaneous absorption of tritium from the gastrointestinal tract. Tritium uptake in wildlife is similar to that in humans and the effects on the DNA are also similar.

Using ICRP 30 (1979) methodology, a Maximum Contaminant Level Goal for tritium of 90,000 pCi/L was published in the Advanced Notice of Proposed Rule Making (Federal Register, Vol. 51, No. 189).

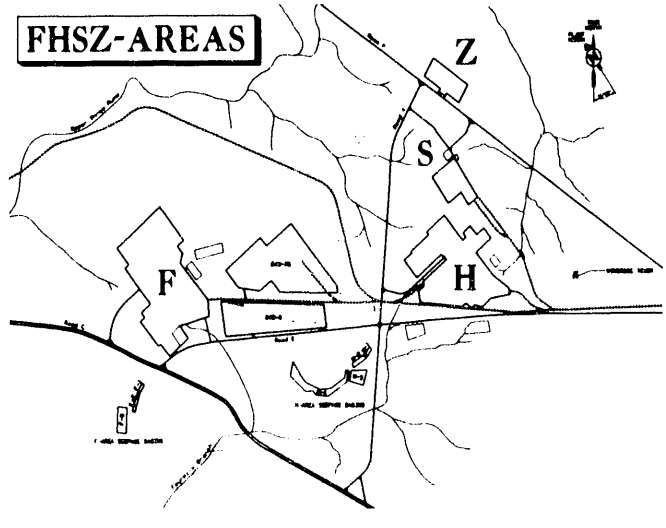


Fig. 1. Central location map.

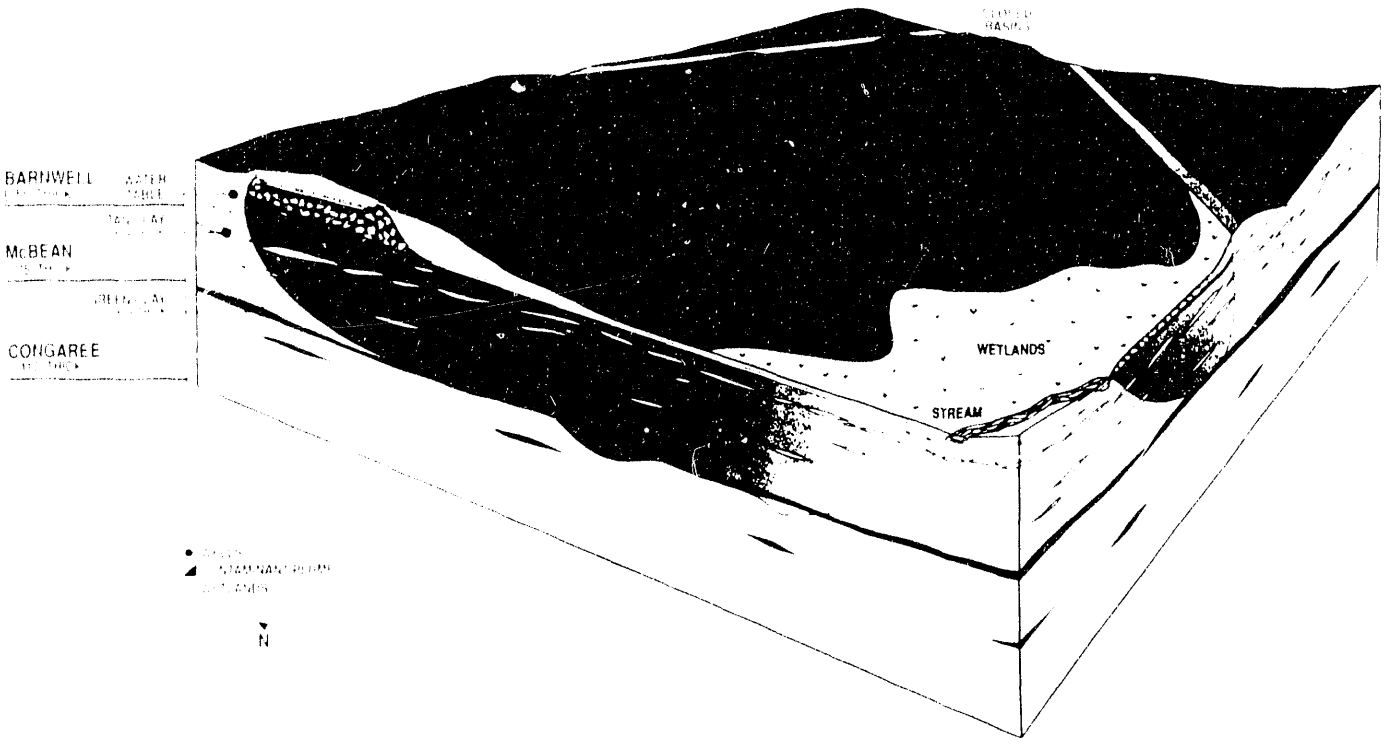


Fig. 2. H-area - seepage basins site hydrogeologic diagram.

However, the Federal Maximum Contaminant Level (MCL) for tritium is 20,000 pCi/L (EPA, 1976). The MCL corresponds to a whole body dose equivalent of 4 mrem/year (40 CFR, 141.16) and is assumed based on the 2 L/day water intake and 168-hr data listed in the NBS Handbook 69 (1963). The South Carolina Primary Drinking Water Regulations are consistent with the Federal Maximum Contaminant Level of 20,000 pCi/L (SCDHEC, 1981).

TRITIUM TREATMENT

Tritium oxide molecules in wastewater behave chemically and physically very much like ordinary water. Thus contaminated water is indistinguishable from uncontaminated water with respect to most conventional waste water treatment technologies. This makes the removal of tritium from wastewater extremely difficult.

Tritium Treatment at Commercial Nuclear Reactors

Tritium treatment techniques have been developed for nuclear power reactors that use large quantities of heavy water for a neutron moderator. Tritium produced as a by-product of these reactors must be removed to protect workers from exposure. The CANDU reactors used by the Canadian nuclear power producer Ontario Hydro are heavy water moderated units that utilize tritium removal technologies.

Four technologies have been implemented to remove high concentrations of tritium from these reactors (Mattus and Taylor, 1989).

- vapor-phase catalytic exchange
- electrolysis catalytic exchange
- direct electrolysis
- liquid phase catalytic exchange

These technologies are commonly utilized in pairs to achieve the required decontamination factor in a cost effective manner. Other technologies are in various stages of research and development.

Vapor-Phase Catalytic Exchange

This technology consists of multiple stages where tritiated water is vaporized, superheated, and contacted with hydrogen gas that contains low concentrations of tritium and high concentrations of deuterium. The mixture is passed over a catalyst bed to promote the reaction of the tritiated water vapor with the deuterium (hydrogen). The resultants of this process are deuterated water (for return to the reactor) and tritiated hydrogen gas that is cryogenically distilled to separate the deuterium from the tritium. The tritium may be discharged through a stack to the atmosphere or contained for storage. Fig. 3 presents a simplified process flow diagram of this procedure.

Electrolysis Catalytic Exchange

This technology consists of multiple stages of an electrolytic cell and absorption column for tritium exchange between

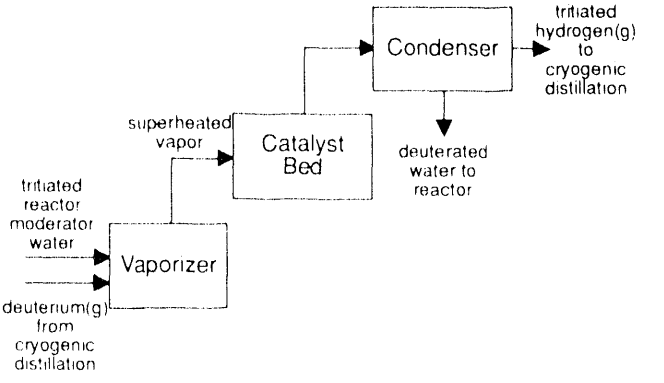


Fig. 3. Vapor phase catalytic exchange.

the gaseous and liquid phases. The electrolytic cell (located at the base of the column) produces hydrogen gas containing deuterium, and deuterium/tritium. This hydrogen gas flows up the column counter-current to the tritiated reactor water. The tritium gas enters the liquid phase as it is preferentially enriched over gaseous deuterium. The tritiated water enters the electrolytic cell where tritium and deuterium gas is produced. A portion of the gas is sent to a distillation column where deuterium is separated and returned to the electrolytic cell or oxidized to water for return to the reactor. The concentrated tritium is contained and stored, or oxidized and vented to the atmosphere. Fig. 4 presents a simplified process flow diagram of this procedure.

Direct Electrolysis

Tritiated water is sent to an electrolytic cell where it is decomposed into oxygen, deuterium/tritium, and deuterium. The deuterium gas is oxidized to heavy water and is sent back to the reactor. The deuterium/tritium may be compressed and stored, oxidized to water, or stored in pressurized containers. Fig. 5 presents a simplified process flow diagram for this technology.

Liquid-Phase Catalytic Exchange

This treatment technology is similar to the Vapor-Phase Catalytic Exchange process except that in this process the exchange between deuterium and tritium occurs between water and deuterium gas instead of between water vapor and deuterium gas. This process is economically superior to the Vapor-Phase Catalytic Exchange system because the water does not need to be super heated to a vapor. A catalyst bed is used to promote the reaction between the tritiated water and the deuterium gas. The deuterated water product is recycled to the reactor moderator and the gaseous tritium is contained and stored or discharged to the atmosphere. Fig. 6 presents a simplified process flow diagram for this method.

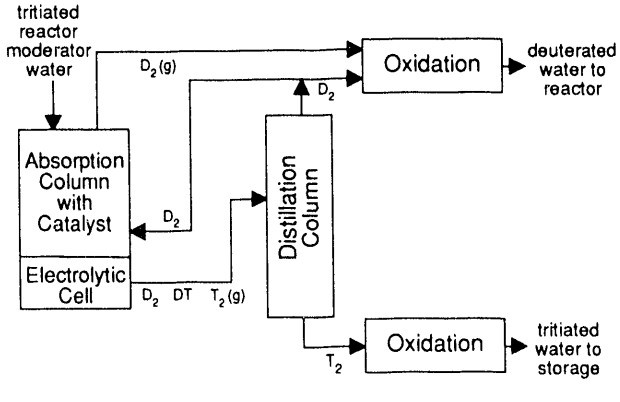


Fig. 4. Electrolysis catalytic exchange.

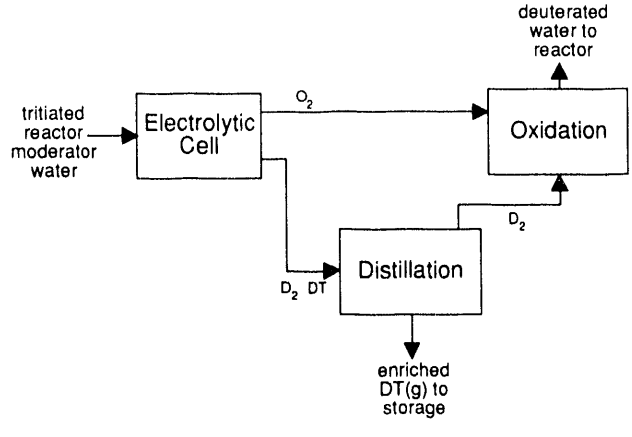


Fig.5. Direct electrolysis.

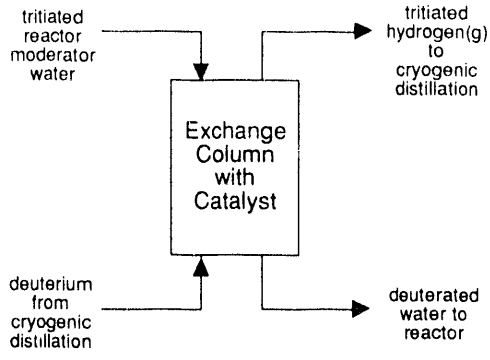


Fig.6. Liquid phase catalytic exchange.

All these technologies are commonly used in conjunction with distillation to maximize the production of heavy water that can be recycled to the reactors. Other technologies such as laser separation, pressure or temperature swing absorption, and freeze technology are in a developmental stage.

Use of Existing Technologies to Treat Tritiated Groundwater

The technologies described above have been developed to separate tritium in relatively large concentrations (1 Ci/L) from deuterated reactor coolant or moderator water. However, these existing technologies are not effective at reducing tritium concentrations to the established 0.02 microcuries per liter (%Ci/L) drinking water standard. Factors that influence the separation of tritiated water from lighter water include the reaction kinetics and mass transfer driving forces (i.e., concentrations). The reaction kinetics are generally fixed depending on the system state and its constituents. Mass transfer is generally unfavorable for separation of a dilute constituent such as tritiated water in groundwater. Therefore, the dilute concentration of tritium found in the SRS F and H-Area groundwater ($1Ci/LH^3$.02%Ci/L) may not be feasibly removed.

An additional system requirement that must be considered is the process feed stream purity. The existing tritium treatment processes require that the influent have a nearly deionized quality with respect to salts, metals, and organic constituents. Relatively "dirty" feeds may poison the catalyst in the hydrogen exchange operations and may cause foaming and carry-over in the distillation columns, or may even cause fouling of the column internals. Therefore, the groundwater would require a complex chemical treatment system to produce a feed that could be accepted by a tritium treatment process.

Characteristics of a tritium treatment system with a small system separation factor, would include very low feed and product rates, very large vapor and liquid hold-up capacities, and long equipment residence times. These are typical for distillation columns operating with a very large reflux ratio. Tritium treatment of the F and H-Area groundwater would require distillation columns with a large reflux ratio.

The use of tritium separation techniques to remediate tritiated groundwater at the SRS is not feasible for the following reasons:

1. Treatment of dilute tritium concentrations has not been demonstrated on a large scale and may not be technically feasible at this time.
2. The process feed is expected to contain impurities which would make the process entirely ineffective and impractical without a sophisticated and expensive chemical pre-treatment process.
3. Capital costs for a tritium separation facility are unknown, but are expected to be very high. An order of magnitude estimate is in the 100 million dollar range, in addition to the cost to pre-treat the water to nearly de-ionized quality (approximately 50 million dollars).
4. Operating costs are estimated to be $2 per liter for 0.1 Ci/Liter feed, and would escalate many times with more dilute feed streams (Mattus and Taylor, 1989). [The tritium concentration in the F and H-Area groundwater ranges from 0 to 0.00002 Ci/Liter.]
5. The tritium plume will have migrated away from the seepage basins and discharged to surface waters by the time a tritium treatment system could be researched, designed, and constructed.

The SRS designed and constructed the Effluent Treatment Facility (ETF) to replace the Seepage Basins in 1988. The ETF is a state-of-the-art chemical treatment facility that had a capital cost which exceeded 50 million dollars. However, due to the reasons stated above, the ETF does not contain processes to treat tritium. The ETF received an NPDES permit to discharge the effluent to Upper Three Runs Creek which is a tributary to the Savannah River.

The Savannah River Site is joined by other DOE sites that release large quantities of low activity tritiated wastewaters to the environment. Currently there is no method used at DOE sites to treat tritiated wastewater or groundwater within the 0.02%Ci/L to 1%Ci/L concentration range (Mattus and Taylor, 1989).

TRITIUM TREATMENT FOR THE SAVANNAH RIVER SITE F AND H-AREA SEEPAGE BASIN GROUNDWATER

Approximately 2 billion gallons of groundwater downgradient from the F and H-Area Seepage Basins became contaminated with tritium at concentrations as high as 0.00002 Ci/L. The areal extent of the tritium contamination covered approximately 440 acres. However, the other radionuclides and metal constituents have migrated over approximately 207 acres and have contaminated approximately 900 million gallons of groundwater (this zone has the highest concentrations of tritium). Fig. 7 and Fig. 8 illustrate the lateral magnitude of the constituent plumes in the F and H-Areas respectively.

The SRS and Chas. T. Main, Inc., worked closely with the South Carolina Department of Health and Environmental Control (SCDHEC) to develop a remediation strategy that would be protective of human health and the environment. The corrective action plan that was submitted in a RCRA Part B Post-Closure Permit consisted of a groundwater extraction system and a neutralization treatment system with solids removal. The treated effluent containing tritium will be injected upgradient of the F and H-Area Seepage Basins and allowed to migrate back towards the groundwater extraction system.

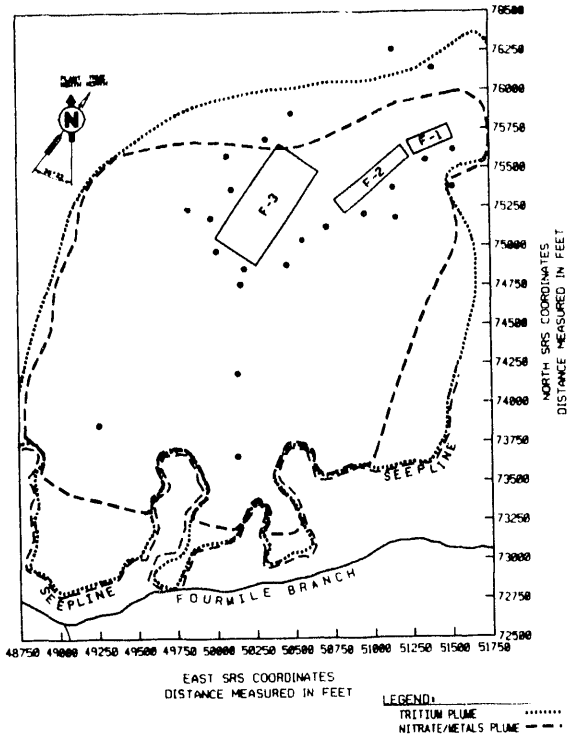


Fig. 7. F-area - water table aquifer tritium plume and nitrate/metals plume.

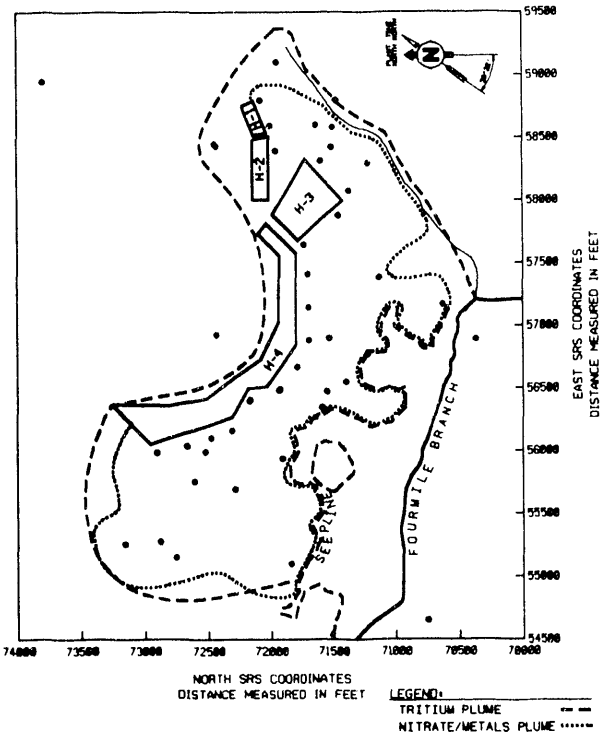


Fig. 8. H-area - water table aquifer tritium plume and nitrate/metals plume.

Therefore, tritium "treatment" will be accomplished by radioactive decay during recycling. The treatment system will extract the constituent plume that contains radionuclides, heavy metal and nitrate contamination. SRS applied for a South Carolina Groundwater Mixing Zone for the tritium contaminated region between the seepline and Fourmile Branch. The South Carolina Mixing Zone consisted largely of a risk

assessment that demonstrated that the tritium and constituents at the fringes of the treated plume would not cause an adverse impact on human health or the environment. Fig. 9 provides the conceptual layout of the remediation system. This system (if approved by the SCDHEC) would represent a new approach to groundwater remediation in South Carolina. Injection wells are currently illegal in the state of South Carolina. In addition, as of December 1990, there has only been one groundwater mixing zone approved by the agency. The SCDHEC indicates that it is reconsidering its position on injection of corrective actions wastestreams in accordance with the proposed RCRA subpart S.

Injection Well Conceptual Design

The treated groundwater will be injected into the aquifers from which it was withdrawn. The rate of injection will be in approximately the same ratio as to the rate of withdrawal from the specific areas in an attempt to recycle the tritiated groundwater without impacting the natural condition of the aquifers.

The conceptual groundwater injection system layout and proposed injection rate was designed with respect to the rate of groundwater recovery, physical hydrogeologic parameters, geologic stratigraphy, and groundwater modeling. In general, the treated effluent will be pumped back into the aquifers which are being remediated at rates which equal the ratios of withdrawal. Numerous injection wells will be used to deliver a low flow of treated groundwater to the receiving aquifers. The wells will fully penetrate and be fully screened in the appropriate aquifer. This should reduce the potential for hydraulic mounding and promote the natural water balance. The injection wells will be equipped with instrumentation that will continuously monitor the water level within the injection well. If the water level reaches a set height, then the instrument will automatically cause the valve to restrict the amount of treated effluent which flows to the well. A series of water level heights will cause further flow restrictions until the valve closes completely when the well is in danger of overtopping. This system in conjunction with regulating extraction, will maximize the volume of water that can be injected while preventing the injection well from overtopping. The wells will be designed to accommodate a flow of up to 10 gallons per minute but are expected to normally inject 3-8 gallons per minute. Each well will have a control valve so that any individual injection well can be placed in or out of service without impacting other injection wells. This system is configured so as to maximize the ease of operation.

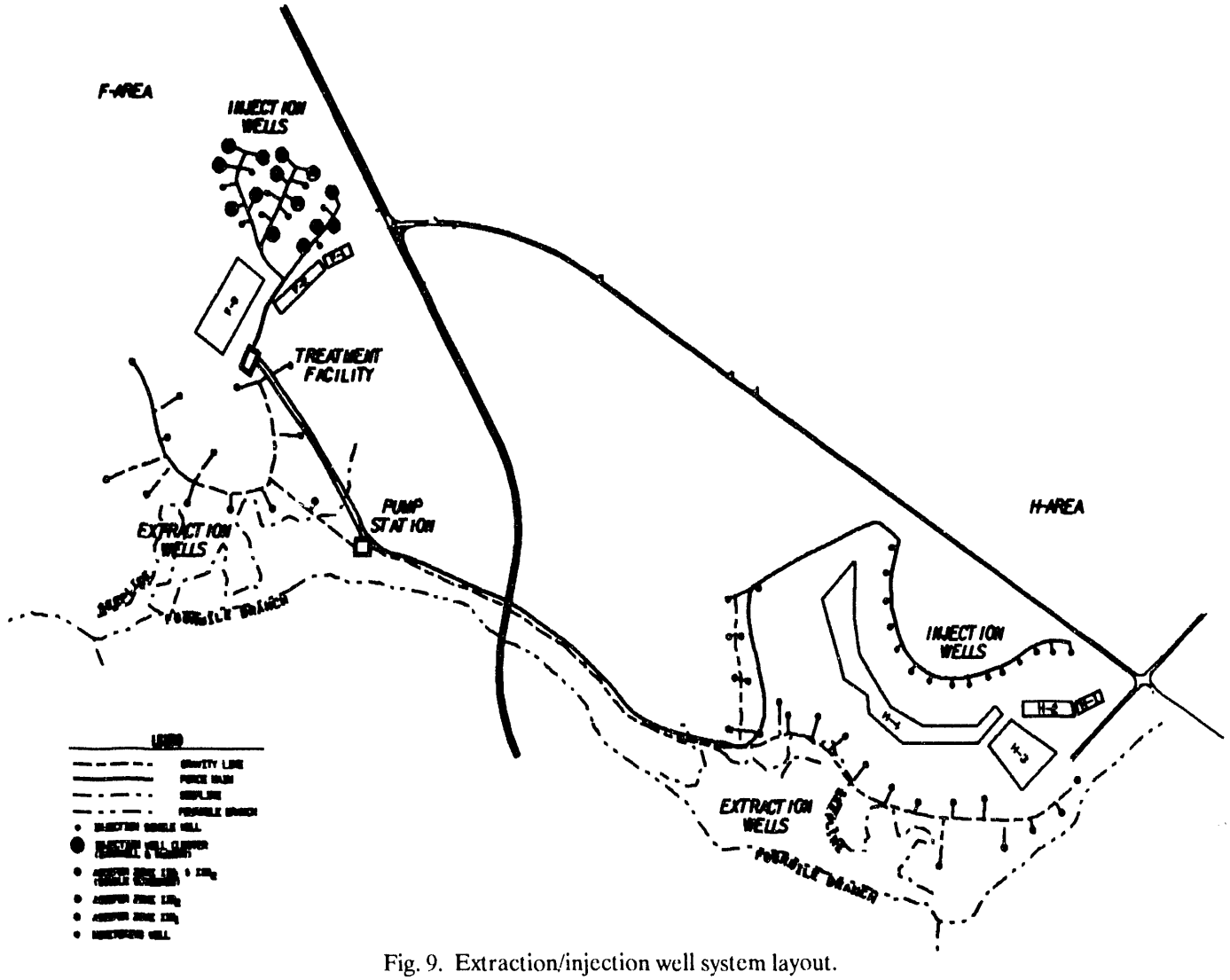


Fig. 9. Extraction/injection well system layout.

Technical Difficulties Associated with Injection Wells

It should be noted that there exist technical difficulties with injection wells that must be overcome. Injection wells are prone to clogging because large quantities of water are forced into a relatively small section of aquifer at the injection well face. Potential causes of clogging are:

- Air entrainment caused by aeration of injected water falling into the injection well.
- Filtration of suspended sediment and organic matter by the receiving aquifer material.
- Formation of precipitates due to geochemical reactions between injected water and native groundwater.
- Swelling of clay colloids in the receiving aquifer.
- Dispersal of clay particles due to ion exchange between injected water and the receiving aquifer materials.
- Precipitation of Iron and Manganese from the native groundwater.
- Initiation of bacterial growths (e.g., iron bacteria) in the receiving aquifer.
- Mechanical compaction of aquifer materials due to pressure imposed by the injected water.

Once clogging occurs, it can be difficult to clear the receiving aquifer. Due to the fact that the velocity of the injected water decreases as water travels away from an injection well, the deposition of fines will occur at some distance from the well screen. This will increase the difficulties associated with cleaning an injection well in an attempt to solve a plugging problem.

SRS is currently studying the design of the injection wells with respect to these difficulties and the site specific hydrogeologic properties.

RESULTS AND CONCLUSIONS

In summary, there is currently no existing mechanism to treat dilute tritium concentrations in wastewater and groundwater at DOE facilities. Research is ongoing and existing technologies could probably be used successfully if a series of treatment trains were utilized. However, this alternative would require a long period to design, construct, and would be cost prohibitive.

Tritium "treatment" of contaminated groundwater via its short half-life through upgradient injection and recycling, offers a cost effective alternative that can be installed relatively quickly. In order for this technology to operate effectively, the regulating agencies must accept the injection of wastewater back into the contaminated aquifers, and the remediation design group must know a great deal about the hydrogeologic characteristics of the site.

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Note: The Savannah River Department of Energy Radiological Division has not endorsed injection and recycling as a tritium treatment method.

RESSAC: REHABILITATION OF SOILS AND SURFACES AFTER AN ACCIDENT; A EUROPEAN RESEARCH PROGRAM FOR REMEDIATION OF RADIOACTIVE CONTAMINATION

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ABSTRACT

Although every precaution has been taken in France and more generally in the Western world, during the design, construction and operation of nuclear reactors, the possible occurrence of serious accidents resulting in a considerable discharge of radioactive products into atmosphere cannot be completely ruled out. It has therefore been considered necessary to draw up emergency plans to protect the population against the effects of such accidents.

As regards the actual accident phase and the period immediately following it, these plans are already operational. They consist of an On-site Emergency Plan, concerning the each nuclear facility, directed by the plant manager, and an Off-site Emergency Plan concerning the immediate surroundings of the plant and directed by a local government representative. The French authorities have also drawn up a Post-accident Action Plan to be applied over a longer period following the accident. Its purpose is to facilitate a return to normal living conditions in the areas affected . These actions should allow to reduce both external exposure due to deposits of radionuclides and internal exposure due to the ingestion of contaminated products.

The program for Rehabilitation of soils and Surfaces after an Accident is aimed at collecting technical data related to the transfer of radionuclides and the methods required to reach the above-defined objectives. It is supported at the national level by the Institute of Nuclear Protection and Safety (IPSN) which provide the main source of finances. At international level it is one of main Radioprotection programs of the Commission of the European Communities. Many countries are actively involved in this research including Belgium, Italy, Spain, Great-Britain and Germany. A collaboration with Soviet organizations is now operational. It will allow to work both on Chernobyl and Kyshtym-Cheliabinsk areas.

The program started in 1985, that is to say before the Chernobyl accident occurred. It has produced a lot of results, of which only a part is related here. This part concerns the techniques that could be used for the remediation of contaminations of diverse origins.

REHABILITATION METHODS

General Presentation

After a radioactive contamination the remediation action may be roughly classified in three categories according to their nature and the importance of their environmental impact:

- **Physical methods** involving the removal of the pollutant along with the contaminated receiving media. For example it means destruction and removal of the vegetal cover (1, 2), scrapping of soils...
- **Chemical methods**; here the pollutant is left where it is, but an addition of a carefully chosen chemical allows to control its migration. A well know example is the addition of potassium to soils in order to reduce the caesium root uptake.
- **Agricultural methods and food-processing**; areas with a relatively low contamination level may not need heavy rehabilitation actions. However it is possible to reduce further public exposure by changing the agricultural practice. For example producing animal feed rather than crops directly used in human alimentation, treating foodstuffs industrially to separate contaminated parts from edible part (milk processing industry...).

Of course these methods may be applied separately or one can use a combination of them. In the RESSAC program, experimental investigations are made of methods belonging to these three categories.

Most of the remediation actions will generate wastes. In the case of vegetation removal the amount of wastes may reach hundreds of tons of fresh matter by square kilometer. It is therefore necessary to implement in the field some sort of pretreatment allowing a reduction of mass and volume along with some extraction of the radioactivity under a liquid form easier to concentrate. Presently we investigate microbial digestion to perform this work. In this paper we will describe the status of our research about decontamination, i.e. physical methods of removal.

Top Soil Removal

The most immediate method for top soil removal is to use public works machinery. However there are undesirable side effects: it is very difficult to remove thin layers that way, it makes contaminated dust, it may reduce the fertility and a tremendous amount of wastes are produced. After a nuclear accident most radionuclides of interest penetrate very slowly into the soils (3). Techniques allowing to cover the soil and then to remove only a thin layer (1 to 3 cm) were developed:

Polyurethane Foams and Strippable Paints

Use of foams has already been mentioned in some papers (4). These foams are commonly used for thermal insulation. They are easily available. They are sold under the form of two liquid components which may be spread separately on the ground with common equipment such as low cost centrifugal pumps and irrigation sprinklers. On the ground they mix and polymerize. An extended temperature range required for

good polymerization may be obtained by adequate dilution. Once the foam has hardened it is possible to remove it with farm machinery. With it comes the first layer of soil and the radioactive deposit.

Strippable paints, commonly used in nuclear industry, may be used in the same way, but they fit better on hard surfaces. The most efficient for this use are resins in aqueous suspension.

Foams and paint protect in some way the deposits from atmospheric agents and therefore they prevent further migration and resuspension.

Such actions were made by the soviets after the Chernobyl accident and they claim an excellent efficiency. We conducted tests on different surfaces such as concrete, asphalt, dirt roads and ploughed land contaminated with ^{140}La.

TABLE I

Efficiency of Different Synthetic Covers for the Containment and Removal of Radioactive Deposits (%)

Product	Asphalt	Concrete	Dirt road	Ploughed land	Grass land
PELABLEAU*	72	90	91	--	70
COLARC*	68	85	92	--	74
ROXPEL*	70	88	87	--	85
PEL-E*	70	85	96	--	86
POLY-URETHANE FOAM	50	60	92	95	98

*Brand name

Decontaminating Vegetal Network (D.V.N)

This method uses turfing plants producing a mat layer over the soil which may be removed together with a soil layer less than two centimeters, by means of a sod harvester. The principle of the D.V.N is to grow grass onto the contaminated area without tillage of the soil, on a cohesive support which will allow a fast and good growth of the plants with a dense root-network able to entrap the contaminated soil particles.

The procedure is derived from existing techniques of hydro-seeding which allows to sow sod seeds together with a growing medium made of a mixture of peat, polysaccharides, fertilizers and water. This technique is used to grow grass for soil fixing in order to prevent erosion (ski tracks, highway sides...). It may facilitate the operational scattering of the D.V.N especially respecting radioprotection criteria. The hydro-seeding mixture may be applied by helicopter at a surface rate of 0,3 km^2/day. Investigations are actually made to adapt the remote-driven system developed by the Direction of Advanced Technologies / Robotic Unit of the CEA to the hydro-seeding process.

In the second step, the D.V.N. is removed together with the 1 or 2 first centimeters of the soil invaded by the root-network, which contains the most part of the contamination (Fig 1). Since the problem of the resuspension is partly solved by the D.V.N, and assuming that the migration rate in the soil profile is a slow process, the D.V.N can remain on the contaminated soil for a quite long period of time (about 1 year) without bad consequences for the success of the rehabilitation. On the contrary, time favors the grass growth and can be used to organize the harvest of the D.V.N. with a sod harvester. These machines already exist at a moderate cost.

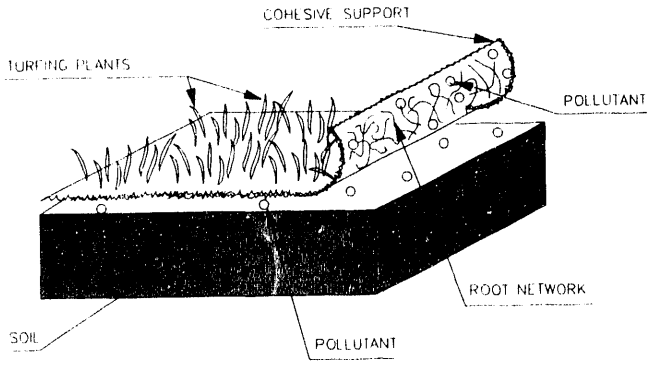


Fig. 1. Decontaminating vetetal network.

The third step will be the storage or the decontamination of the D.V.N. One of the major interest of this technique is that since the soil layer removed is of the minimum thickness that can reasonably be removed, the waste volume will be limited . The main part of the waste is organic and may be treated by bio-degradation.

The technique was tried in the field during 1991 summer. However the results are not yet fully available. The efficiency may be assessed using laboratory results (Table II).

TABLE II

Decontaminating Balance of a D.V.N Made on Plastic Net (% of Introduced Activity)

	White clover		Ray-grass	
	Caesium	Strontium	Caesium	Strontium
Removed soil	83	73	69	70
Plastic net	3	3.3	8	6
Above plant	0.03	1	0.1	1
Total removed	**86**	**77.3**	**77**	**76**
Remaining	13	18	23	24
Balance	99	95.3	100	100

Gels of Organic Polymers

The possible use of different soil stabilizers for land reclamation and cleaning, on the basis of manufacturers and application information has been discussed before (4). These soil stabilizers include polysaccharides which are expected to have electrochemical affinities with Cs and Sr, and polyacrylamides used together with polysaccharides as soil conditioners in modern agriculture (5).

The first step of our work was the selection of different soil conditioners or algal cultures according to their affinity for caesium and strontium in aqueous solutions. In a second step the selected compounds were tested in different application trials : mixed to the soil, sprayed on bare soil surfaces or on plant leaves. These tests were concluded by finding an interesting soil conditioner for both preventing the soil particle resuspension and allowing the removal of the first millimeter of the contaminated soil by mechanical brushing without dust.

According to the results of screening experiments, polymers with lateral chain constituted by anionic chemical groups like carboxyle or sulfate function proved to have the best affinity with Cs and Sr in aqueous solution. Nevertheless, as soil-to-plant transfer experiments and Kd measurements demonstrated, when these radionuclides are bound to soil particles, their chemical affinity for polymers is not high enough to change the equilibrium in order to decrease radionuclide concentration in the soil solution.

Although polymers cannot change the equilibrium status in the soil, they can bind the soil particles and remove them by brushing without dust. The most efficient of tried polymers allows to remove 80% of caesium and 65% of strontium by brushing. The use of this polymer for soil reclamation is being patented.

Another advantage of this technique is a momentary prevention of radionuclides transport by runoff. That may be of interest to prevent a rapid contamination of water bodies.

ORGANIC WASTES TREATMENT

Introduction

Since vegetation may intercept up to 80 % of deposition, clearing is a common decontamination method for agricultural fields, vacant land, wooded areas (1) after a nuclear accident. Considering for example for wheat a dry biomass production of 2 kg/m^2, the waste management for thousands of hectares becomes a complex problem for which feasible solutions should be foreseen.

Caesium and strontium would be the main radionuclides of interest. The technical means for the treatment of this contaminated biomass should be as simple as possible, excluding options like chemical treatment, incineration, not adapted to huge quantities. Natural biodegradation of the piled biomass will occur in any case without human intervention. It could lead to partial decontamination if efficient processes can be managed. Some experiments have been carried out in order to get an idea of the results to expect and of the optimum operating conditions.

Experimental Work

The experimental work was conducted in three steps: For the two first steps (6), in the lab, contaminated fresh biomass was produced by growing cress and haricot on spiked (^{134}Cs and ^{85}Sr) hydroponic system. In the first step a few hundred of grams of this matter was subjected to aerobic and anaerobic decomposition. No inoculation of the biomasss with special microorganisms was applied. Different quantities of water were used from simple immersion to three times this amount. The influence of the amount of water is shown in Fig. 2. In the second step the same kind of experiment was made but with biomasses ranging from 3 to 10 kg and anaerobic conditions only. Fig. 3 shows the kinetics of radionuclides release. Table III shows the reduction in mass and volume achieved in percent of the original. We can see that the reduction in mass and volume of the solid initial biomass is very important.

In the third step a field scale experiment is being conducted. The microbial digestion is still going on and the results are not available. Work is also going on to study a method to treat the contaminated liquids, by further biological decomposition (with the help of enzymes (7) floculation, concentration on ion exchange resins (8).

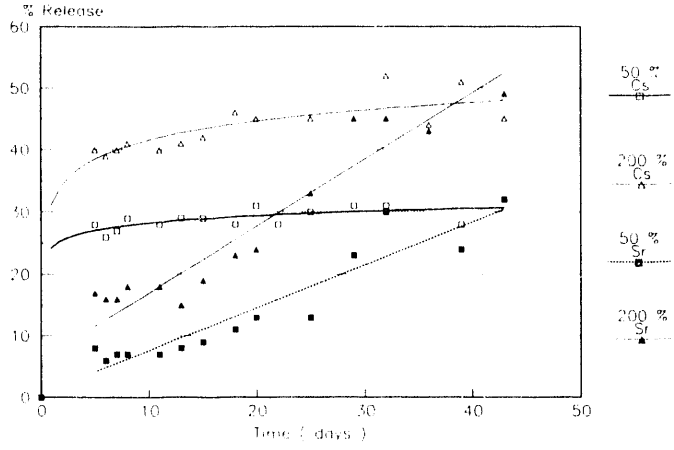


Fig. 2. Effect of water volume on decontamination efficieny in anaerobic digestion of contaminated dry cress.

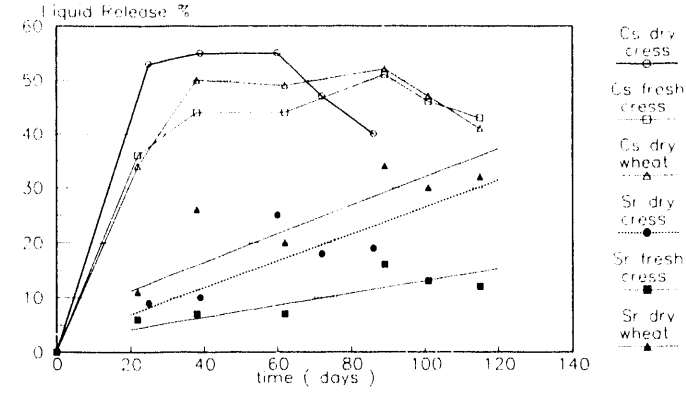


Fig. 3. Kinetics of radionuclide release from different plant biomass : Kg scale experiment.

TABLE III

Remaining Mass and Volume After Three Months of Digestion (% of the initial)

	Solid		Liquid
	Mass	Volume	Volume
fresh cress	12	2	75
dry cress	20	4	71
dry wheat	37	15	78

Conclusion on Organic Wastes Wanagement

Although the problem of contaminated crops seems to be solved only partly because of the transfer of radioactivity to a liquid form, this option presents greater advantages for a further safe treatment of the waste. Liquids are easier to handle and concentrate in view of a final storage.

In anaerobic conditions, the decomposition of fresh moisturized biomass allowed the release under liquid form of about 50 % of caesium and 25 % of strontium present in the plant. Running water washing of the remaining biomass could increase the recovery of strontium and caesium up to 70 % and 80 % respectively. The remaining biomass and volume were respectively 40 % and 15 % of the initial for wheat and yet more efficient for cress.

Anaerobic digestion is fortunately easier to achieve and to manage in the field than aerobic one. The biomass pile should be made in a trench or some kind of excavation covered with a plastic film in order to gather the leachates. The pile should be covered with another plastic film to maintain both anaerobic conditions and the moisture necessary for decomposition.

EXPERIMENTAL POSSIBILITIES OF THE RESSAC PROGRAM

Facilities in Cadarache

In Cadarache, a special building is being constructed for experimental purposes. It is designed to handle safely radioactive contaminations, but other pollutant could also be used. The building will have 4 greenhouses and each of them will allow to simulate a different climate. Each greenhouse will contain three lysimeters. These lysimeters are made of unmodified soil blocks (size: 1.8 x 1.8 x 1.5 m^3). In order to be representative of field conditions the hydric potential in the lysimeter is regulated to reproduce the movement of water in the original soil.

The contamination of the soils blocks will be made using a simulator of a nuclear accident. The physico-chemical form of the radionuclide emitted in a core-melt accident is in many aspects different from that of sources available on the market. In order to simulate the accidental source term, it was necessary to design and implement a device reproducing the conditions encountered during a severe accident on a nuclear reactor. It is an induction furnace capable of reaching a temperature of 3000°C. The aerosols released are collected in a chamber which is heated to 60°C and filled with water vapor to simulate the reactions likely to occur in the reactor building. A mixture of elements representing the corium is introduced in a graphite crucible. 16 elements are used representing the fuel, control rods materials, stainless steel components and of course the fission products of interest.

The operation of this facility (building, lysimeters, and furnace) will be shared between France and four others European countries: Germany, Great Britain, Spain and Belgium, in the frame of contracts granted by the Commission of European Communities (CEC).

Collaboration With the USSR

There are in the USSR two main areas contaminated by nuclear deposition, around Chernobyl and in the Urals. We have established collaboration protocols to exchange information and set up experimental programs in these two areas. There is no doubt that a lot is to be learned from the actual contaminations there.

The work programs, some of them being driven by the CEC, include the study of radioactivity transfers, and of course, all the countermeasures and rehabilitation procedures in natural, rural and urban areas.

CONCLUSION

Unfortunately, there is no miracle cure for contaminated environment. But with a combination of cleaning methods, a lot can be done. Some of them have been proposed in this paper. Other can be foreseen according to each special problem. More research an development will be done on the subject. However, in the implementation of any rehabilitation procedure, one should always think about negative side-effects. The removal of vegetation for example may be a very appropriate action in the case of cultivated field. Is it the case for a natural forest ? At what point of contamination is it better to have no forest than a polluted one?

In every case one should prefer using natural processes to clean polluted areas. From this point of view Vegetal carpets seem better than synthetic foams to remove top soils layers, biological degradation of organic wastes seem better than drastic chemical treatments, and so on. In the RESSAC program it is constant effort to look at environmental remediation with an ecological state of mind.

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A PROJECT MANAGER'S PRIMER ON DATA VALIDATION

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ABSTRACT

While carrying out their central responsibility of conducting an environmental investigation in a high-quality, timely, and cost-effective manner, project managers also face a significant challenge due to the many inherent uncertainties associated with characterizing and remediating sites. From all aspects and considerations (health and financial risks; and technical, professional, and legal defensibility/credibility), the project manager must minimize the uncertainty associated with making decisions based on environmental data. **A key objective for every project manager is to produce sufficient data of known and acceptable quality.**

In simple terms, the level of confidence in the gathered data directly relates to: 1) the upfront determination of the types and uses of the data needed (which drives the required quality of the data); 2) the ongoing verification that the prescribed methods by which the data are to be obtained and analyzed are being followed; and 3) the validation of the verified data to determine whether the pre-established data quality objectives have been met, therefore making the data adequate for their intended use(s). This paper focuses on the **third** element of the equation for data quality, therefore implying that the first two elements (planning and verification) have been accomplished. The "Who," " What," "Why," "When" and "How" of data validation are discussed in general terms.

INTRODUCTION

First and foremost, the ongoing process of data validation should be viewed not as an EPA programmatic requirement, but as a valuable tool by which the project manager (and other data users) can have confidence in the reliability of the data being used for identifying and selecting remedial options. Although the quality assurance professional can assist in identifying/interpreting the applicable requirements, and in developing and monitoring the process, data validation is a project management responsibility, to be planned, budgeted, and scheduled for upfront. The objectives of data quality, as well as the ultimate uses of the data, are to be incorporated into the project's work plan and all other supporting documents.

To determine the success of this paper in providing a general understanding (and the concurrent dispelling of common myths), the following questions should be answered now and then again at the end of this paper. The author assumes that the reader's answers will not be the same.

True or False:

- Validation = Verification = Evaluation
- Validation is Responsibility of QA Organization
- Internal Lab QC/Verification = Validation Process
- Flags Assigned by Labs = Validation Flags
- Data with Qualifiers (Flags) = Invalid Data

UNDERSTANDING OF KEY TERMS

It is essential that an understanding of key terms such as "**validation**," "**verification**," "**evaluation**," and "**data quality objectives**," be established first. Frequently the terms "verification," "validation," and "evaluation," are used interchangeably. This is understandable, because according to Webster's Dictionary, the terms "validate" and "verify" are identical: to declare or make legally valid....to assure the certainty of or confirm as being based on good judgment..." The term "evaluate" means to: determine the worth of...to appraise. However, a Superfund project's definitions for the first two terms derive from EPA guidance, wherein verification is but one aspect of the validation process; e.g., "data validation is a systematic process for reviewing a body of data against a set of criteria to provide assurance that the data are adequate for their intended use. Data validation consists of data editing, screening, checking, auditing, verifying, certifying, and review."(1)

"Verification" is an **ongoing, routine** activity conducted by technical, laboratory, and clerical personnel on **small sets** of the data to determine if data have been accurately quantified, recorded, and transcribed; have been collected and analyzed in accordance with prescribed, approved procedures; if the data appear suitably complete; and if the data appear to be reasonable and consistent, based on prior knowledge of the site being investigated.

The validation process, then, is an ongoing process, with verification being a **subset**, or one discrete activity (albeit a vital one). In most cases, when one is referring to the "validation of data," they are referring to the **last** activity in the validation process, which can be defined as being an **independent, timely** review of a **body** of **verified** data against a **predetermined** set of **qualitative** and **quantitative criteria** to evaluate their adequacy for their intended use (in other words, did the data actually meet the predetermined criteria). Data quality objectives (DQOs) are "qualitative or quantitative statements which specify the quality of data required to support Agency decisions during remedial response activities."(2) These DQOs are established upfront during project scoping in the general work plan, sampling and analysis plans, and quality assurance project plans.

A key word in the above definition for validation is **independent**, as it is commonly believed that the routine verification/validation activities performed by the laboratory upon completion of analysis constitute an acceptable validation of the data. The symbols assigned to the data (called "qualifiers" or "flags" indicate whether or not laboratory statement of work parameters for quality(3,4) have been met. These qualifiers or flags differ from those assigned by the independent validators who utilize EPA Data Validation Functional Guidelines (Organic and Inorganic).(5,6) In very general terms, flags

assigned by the validation team indicate whether or not the data are acceptable as is, the values should be accepted as estimates only, or the data should be rejected.

Only after the data have been verified and validated should they be submitted to the project team for the purpose of "evaluation," which "includes efforts related to the analysis of the data once it has been verified that the data are of acceptable accuracy and precision. The task begins on the date that the first set of validated data are received...and ends during the preparation of the report...includes reduction, tabulation, manipulation, interpretation, and environmental fate and transport modeling/evaluation."(7)

EQUATION FOR PROJECT SUCCESS

The end result of this "cradle to grave" process is the assurance that a defensible "road map" exists which can trace and justify all activities undertaken and decisions made from the onset of the initial investigative planning to the completion of the closure report.

The Equation for Project Success:
Upfront Planning + Ongoing Verification + Validation = Quality Data for Decision Making,

where the commitment and extent of effort by the project manager in these three key inputs have a direct bearing on the confidence level that technical decisions are being based on sound, defensible information. These key concepts are illustrated in Figs. 1a and 1b, "Environmental Data Life Cycle," where the main activities and the sequence of those activities are provided in 1a, and the inputs to those activities are above the boxes and the outputs below the boxes in 1b.

WHY DO WE NEED DATA VALIDATION?

There are at least three good reasons why we need to perform validation on environmental data prior to its utilization in the technical evaluation/decision-making process:

- It is an EPA requirement: "Interim Guidelines and Specifications for Preparing Quality Assurance Project Plans," (QAMS-005/80), stipulates that every monitoring and measurement project must have a written, approved quality assurance project plan (QAPP) which contains sixteen elements; the tenth element, Data Reduction, Validation, and Reporting, requires that for each major measurement parameter data validation must be performed.
- Note: more specific guidance for analytical data (both CLP and non-CLP) is provided in references 5, 6, and 8 provided at the end of this paper. In addition to federal guidelines, the presence of any regional, state, local, or project-specific requirements should be thoroughly researched.
- It is a prudent project management tool which provides a level of confidence in the reliability of the data, thus lowering decision-making risk.
- Public and regulatory scrutiny requires that a defensible "roadmap" exists which can trace and justify all activities undertaken and decisions made, from the onset of the project until the issuance of official reports.

HOW DO WE DO DATA VALIDATION?

Planning the Validation Effort:

Contrary to common belief and practice, validation should not be a "last minute" activity that is initiated only upon the realization that the technical report is almost due. One cannot hope to accomplish the true objectives of the validation process without formal planning. Data validation is a necessary component of a project's management control system; thus, it **should be initiated and included in the work scoping process**. The question should be asked: "which data require validation?" As there are significant cost and schedule considerations, this issue must be judiciously resolved and the criteria for determining which data require validation incorporated into the validation methodology (contained in a stand alone plan, or as an attachment/appendix to the project's quality assurance project plan). The key to determining which data require validation is two-fold: 1) what is the intended use for the data; and 2) what level of quality (confidence) must be present to assure its usefulness.

Remedial investigation/feasibility study (RI/FS) data uses, for an example, can be described in general purpose categories representing generic uses, but can also vary on a site-by-site basis. Section 4.1.1. of Ref. 2 provides categories representing the most common RI/FS data uses; however, the categories do not represent different data qualities, only different uses which may require data of a different quality. In other words, data collected for a site at a given level of quality may be used for different purposes. The data use categories described in the above-referenced document are: Site Characterization, Health and Safety, Risk Assessment, Evaluation of Alternatives, Engineering Design of Alternatives, Monitoring During Remedial Action, and Potential Responsibility Party (PRP) Determination. Once the data use categories are determined, the intended uses must be prioritized, as the priority of the intended use will help identify the most demanding use of each data type, i.e., the use requiring the highest level of confidence, and therefore the highest level of quality. The data quality required will be a function of the accepted limits of uncertainty established by the decision maker.

The level of quality required quite logically determines the extent of validation desired. Five **analytical** (not validation) levels are defined in Ref. 2:

- Level I - field screening or analysis using portable instruments. Results are often not compound-specific nor quantitative, but results are available in real-time. It is the least costly of the analytical options.
- Level II - field analyses using more sophisticated portable analytical instruments; in some cases, the instruments may be set up in a mobile laboratory on-site. There is a wide range in the quality of data that can be generated. It depends on the use of suitable calibration standards, reference materials, sample preparation equipment, and the training of the operator. Results are available in real-time or several hours.
- Level III - all analyses performed in an off-site analytical laboratory. Level III analyses may or may not use EPA Contract Laboratory Program (CLP)

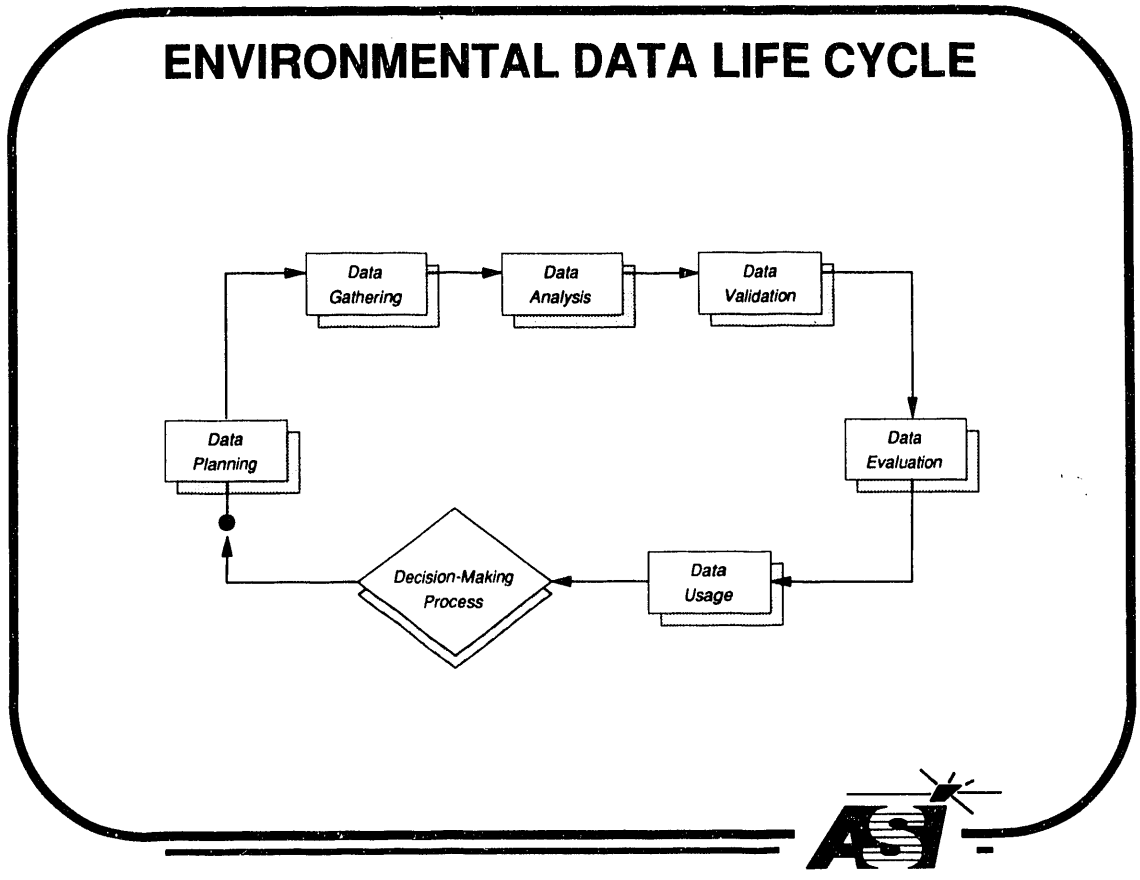


Fig. 1. General environmental data life cycle.

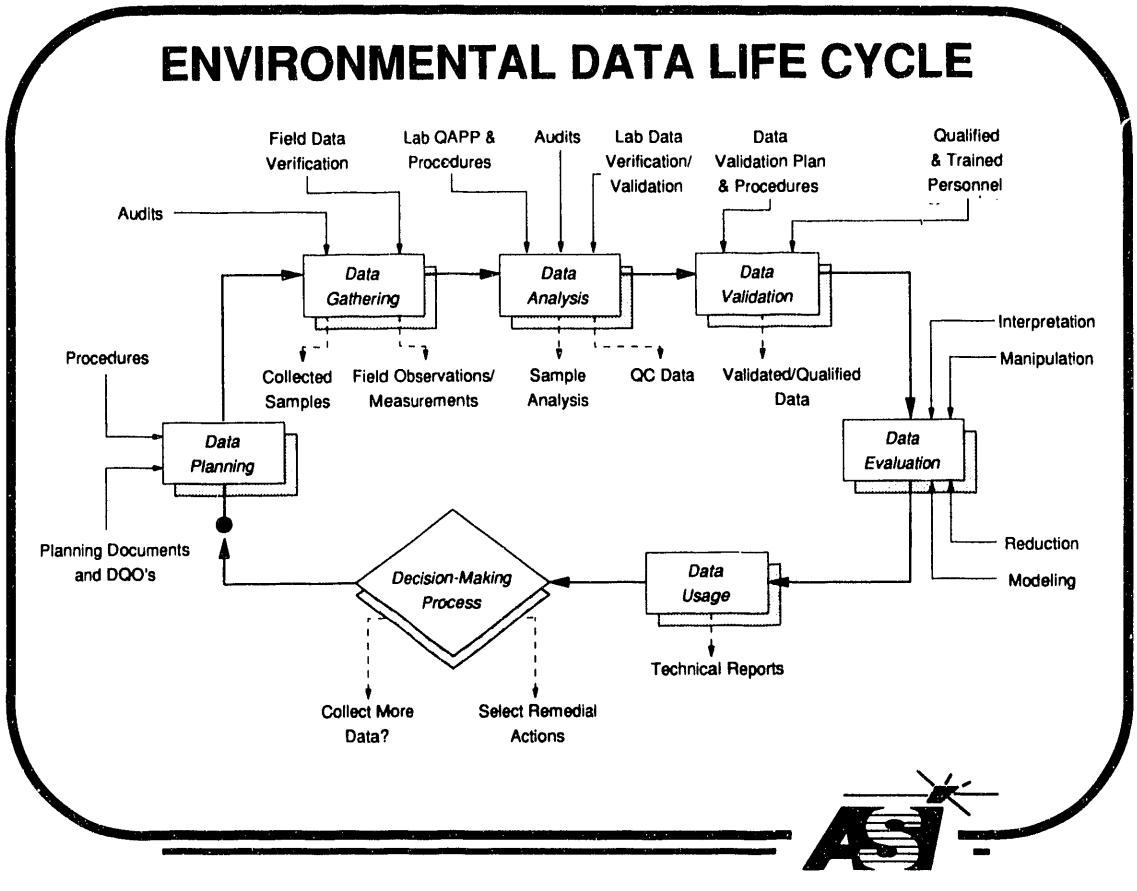


Fig. 2. Detailed environmental data life cycle.

procedures, but do not usually utilize the validation or documentation procedures required of CLP Level IV Analysis. The laboratory may or may not be a CLP laboratory.

- Level IV - CLP routine analytical services (RAS). All analyses are performed in an off-site CLP analytical laboratory following CLP protocols. Level IV is characterized by rigorous QA/QC protocols and associated documentation.
- Level V - analysis by non-standard methods. All analyses are performed in an off-site analytical laboratory which may or may not be a CLP laboratory. Method development or method modification may be required by specific constituents or detection limits. CLP special analytical services (SAS) are Level V.

Some examples of probable data categories are as follows:

- Level I - walk-on radiological screening data
- Level II - field data collected for Ph and alkalinity
- Level III - data collected from SW-846 methods
- Level IV - routine RI/FS target compound list for soil and water
- Level V - radiological samples

The appropriate analytical level must be matched up with the intended use of the data; in some instances several analytical levels may be suitable for a given data use. **The combination of analytical level/intended data use is the key to determining the need for and the extent of validation;** it is also the key to determining the DQOs. These established DQOs should be incorporated into the planning documents, e.g., work plan, QAPP, and sampling and analysis plans. Where validation is warranted, the parameters to be examined and the documentation to be generated **can be graded.**

Development of Validation Methodology

In conjunction with incorporating the establishment of DQOs and the performance of data validation into upfront planning documents, the project manager must also schedule and budget for the validation effort. As part of this scheduling and budgeting process, he must allow for the development of the validation methodology. Like all quality-affecting activities, data validation is to be planned and conducted in accordance with an approved plan/procedure. Specifically, Element 5.10 of reference 1 requires that for each major measurement parameter the following are to be clearly described:

- The principal criteria that will be used to validate data integrity during collection and reporting of data (the DQOs).
- The data flow or reporting scheme from collection of raw data through storage of validated concentrations.
- The key individuals who will handle the data on this reporting scheme.
- The methods used to identify and treat outliers (data flagging).

This validation plan/procedure/checklists should ideally be a component of the project management plan or work plan, but generally appears as an implementing procedure for the QAPP.

Selection of Validation Personnel

Once the plan/procedure is approved and issued, the project manager is responsible for identifying technical personnel who are qualified by both education and experience to serve on the validation team. In general, the reviewer should have the education and experience level commensurate with those scientists/engineers who established the DQOs and data specifications. They should be skilled in the interpretation of project geotechnical or chemical analyses data, and must be able to exercise professional judgement in providing recommendations for data usability based on data quality. The qualifications of these personnel should be verified and documented for the project files. Once the review team is assembled and their expertise verified, orientation/training in the validation procedure should be provided and documented such that these personnel are certified as validators.

Initiation of Validation Process

In very general terms, the validation team member takes the raw data and QA/QC results (both field and lab data), receives input from the data user as to the objectives of the measurement effort and the expected results (preferably stated in formal DQOs), and then attempts to determine if the data truly meets the user's needs. During this process the reviewer will: assess and summarize the quality and reliability of the data; and document the factors affecting quality (discrepancies or gaps in the data, noncompliance to field or lab procedures, equipment problems, site factors--terrain, weather, etc). All validation activities must be clearly documented, either on the appropriate review checklist or in a summary report, or memo.

Once the validation process has commenced, the project manager should request that an independent organization, typically the QA organization, schedule and perform routine surveillances/audits to monitor compliance to the validation plan/procedure by the validation team, and to evaluate the adequacy and effectiveness of the process.

Identification and Resolution of Data Discrepancies

Discovery of an absent or non-compliant attribute necessary to support the integrity of the data may result from the completion of the detailed review checklists. Data of questionable acceptability may result from the absence/insufficiency of one or more of the following general cornerstones required for quality data:

> Specified, adequate procedures and compliance to those procedures by trained personnel, in the areas of sample collection and tracking, and field and analytical instrument calibration and QC.

For those answers to checklist questions which cause the reviewer to question the data's integrity, a formal, documented process of evaluation/proposed resolution, and review/acceptance of that proposed resolution must be conducted. All activities (and documentation of those activities) which are conducted to evaluate and resolve potential data discrepancies must become project file records.

It is recommended that an independent, technical advisory group is appointed by the project manager to evaluate

the data which have been identified by the validation team as being potentially unacceptable. Upon completion of this evaluation the proposed resolution (and a complete justification of how that resolution was determined) should be documented in a memo to the project manager (or designee). This resolution will assign qualifiers, or flags, to the data, which will define the degree of the data's acceptability. If the project manager disagrees with the proposed resolution, discussion is conducted until the issues or questions can be resolved. It is only after concurrence is achieved on the data's acceptability (and associated qualifiers), that the validation documentation is transmitted to the data management staff for input into the project's database.

Note: The validation team will normally perform their review on the original hard copy documentation obtained from the project files. Some of these data contained in these documents may have already been input by data entry personnel into the project's computerized database. It is presumed that data generated as a result of field measurements/observations or lab analysis have been reviewed for completeness (all required fields filled out) prior to being input by the data entry personnel, and then later verified that the information input exactly matches the original hard copy. As it is critical that the database provides for the storage, retrieval and manipulation of validated data only, those data which have been assigned qualifiers must be clearly flagged in the system. Data which have been rejected as a result of the validation process must be removed from the database, or clearly flagged as invalid. Once all the data have been verified and validated, and the database updated, it should then be "secured" so that changes cannot be made without authorization by the database manager.

By now it should be apparent that the validation process is an intensive, ongoing process requiring participation by several project members of different disciplines and organizations.

KEY ISSUES

The author views the following as key issues surrounding the validation of environmental data:

- General lack of understanding/appreciation of what validation is and does
- EPA regional offices are inconsistent with validation policies and guidelines
- No EPA lab data validation guidelines exist for radiological data
- Resolution of data discrepancies is extremely difficult when resampling or re-analysis is unfeasible, or when reports have already been issued using **preliminary** (and unvalidated) data
- Federal/state agreement schedules often do not allow sufficient time to validate data prior to the writing/issuing reports.

A REVISIT TO COMMON BELIEFS

This paper started with some questions to test your general understanding of the process for validating environmental data. Let us revisit those same questions; presuming that you learned something new from this paper, a few of your answers should change.

Validation = Verification = Evaluation	(False)
Validation is Responsibility of QA Organization	(False)
Internal Lab QC/Verification = Validation	(False)
Flags Assigned by Labs = Validation Flags	(False)
Data with Qualifiers (Flags) = Invalid Data	(False)

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ENVIRONMENTAL RESTORATION PROJECT CONFIGURATION CONTROL

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ABSTRACT

This paper provides an overview of the approach that Westinghouse Idaho Nuclear Company, Inc. (WINCO) is using for the implementation of the configuration control requirements for a major system acquisition under the guidance of U.S. Department of Energy (DOE) Order 4700.1, "Project Management System," for environmental restoration.

The two major features of the WINCO environmental restoration approach relate to 1) the product and 2) the maintenance of the baseline for many sites in different phases at the same time.

Historically, a project has typically produced a product. Environmental restoration in some ways produces no typical project product. Essentially, what is produced and what configuration control management is exercised on is one of the following: 1) the development of clean dirt, 2) the documentation to support clean dirt, or 3) the track record of each of the sites. It is the latter approach that this paper deals with.

This approach is unique in that there are four baselines [cost, schedule, scope, and technical (the track record product)] rather than the typical three. This is essential in configuration management due to the lack of a uniquely identifiable product for each site. Essentially, the philosophy behind the four-part configuration controls allows the technical baseline to fulfill the function typically met by the identifiable product.

INTRODUCTION

The object of this paper is to provide an overview of the approach that Westinghouse Idaho Nuclear Company, Inc. (WINCO) is using for the implementation of the configuration control requirements for a major system acquisition under the guidance of U.S. Department of Energy (DOE) Order 4700.1, "Project Management System," (1) for environmental restoration.

The two major features of the WINCO environmental restoration approach relate to 1) the product and 2) the maintenance of the baseline for many sites in different phases at the same time.

Historically, a project has typically produced a product. Environmental restoration in some ways produces no typical project product. Essentially, what is produced and what configuration control management is exercised on is one of the following: 1) the development of clean dirt, 2) the documentation to support clean dirt, or 3) the track record of each of the sites. It is the latter approach that this paper deals with.

This approach, controlling the track record of each of the sites, focuses on the fact that each site remediation is a unique project. This is true although many of the sites will have no physical activity occur at that site. The fact that no construction occurs or that significant remediation occurs at a site has no bearing on the configuration control requirements. What is important is that each site be baselined uniquely and that any changes from that baseline be identified with regard to cost, schedule, scope, and technical (the track record product) baseline.

This approach is unique in that there are four baselines rather than the typical three. This is essential in configuration management due to the lack of a uniquely identifiable product for each site. Essentially, the philosophy behind the four-part configuration controls allows the technical baseline to fulfill the function typically met by the identifiable product.

The tools used to provide configuration controls are traditional for cost, schedule, and scope and the new feature, technical baseline. The technical baseline describes what is known about a site and grows with the site until what is described in the technical baseline matches the scope baseline.

This paper concludes by drawing the correlations between the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) process, the configuration control process, and the baselining process.

CONFIGURATION CONTROL PROBLEM

The configuration control problem faced by most environmental restoration projects (ERPs) operating under the guidance of DOE Order 4700.1 centers on the premise in DOE Order 4700.1 that some "product" was going to be constructed. This "product" premise drives the design of the product, construction of the product, testing of the product, control of the product, and process for the product. Not having a product and not knowing our sites (the closest thing we have to a product) in detail makes controlling our products and the processes for our products difficult.

An additional difficulty is presented when the physical location of two or more sites may be the same, or the actual soil of one site may be the same soil of another site.

POSSIBLE SOLUTIONS

Four possible solutions to the configuration control problem faced by most ERPs will be addressed in this paper. The first solution is to do nothing at all. The problems associated with this solution include lack of traceability, difficulty in determining completion, and difficulty in supporting funding requests. The advantages include possible low cost, quick adjustment to change, and low overhead.

The second possible solution is the "product base." Problems associated with this solution include defining the product years in advance and estimating product costs, and the quality varies based on time and leadership and no meaningful measurement of performance between products. Advantages of this approach include defined goals to work toward, instant rewards on delivery of product, and the "I did this, and I am wonderful outlook."

The third possible solution is the "standard baseline process." Problems associated with this solution are related to the

difficulty in defining the product. Advantages include measurable performance, knowing the scope, being able to see completion, ease in supporting funding requests, and meeting customer requirements.

The WINCO solution is the "standard baseline process plus the technical data base." Problems associated with the WINCO solution are the high up-front costs, the difficulty in planning a project to completion, and the thinking and researching necessary to select probable solutions. Advantages include those for the standard baseline and the advantages of knowing what you know, where you are going, and how you plan to get there.

WINCO SOLUTION

The WINCO approach, controlling the track record of each of the contaminated sites, focuses on the fact that each site remediation is a unique project.

Implementation

The first step in implementation is to create a technical baseline by defining the sites and gathering in one location all the known or strongly suspected information on each site (see Fig. 1). The second step is to create a scope baseline by deciding what will be the most likely final action for each site based on the current technical baseline. The third step is to create a cost estimate for each site (the cost baseline) based on the technical baseline and the scope baseline. Fourth, a schedule is created based on the cost baseline (see Fig. 2). Fifth, the staffing plan, funding forecast, and milestone schedule are created, based on the four baselines.

Next, the items developed in the first five steps are integrated. WINCO is using the software program Primavera to then enter the cost, schedule, and scope baselines into one system. In this system, a one-on-one relationship is developed and maintained for the cost, schedule, and scope baselines. WINCO is using dBase IV to enter the technical information for all the sites into one system. In this data base, all the known or strongly suspected information about each site is maintained. The assumption used in each of the baselines is documented in each of the baselines.

The final step is to establish control of the four baselines. This may be done once the one-on-one relationship and the credibility is established. A check estimate or estimate validation is prepared to develop the stature of the cost baseline. A check of the documentation supporting the technical data base and of the data entry into the data base is performed to assure that the best currently available information has been used. A logic check is performed on the schedule baseline.

CONCLUSION

The institutional systems for configuration control of product, process, and documentation can and do work for environmental restoration projects. The CERCLA process provides a structured system engineering approach to the gathering of information and decision making, and in using that information to maintain the technical baseline. The engineering change control process provides a system to control the changes to the baselines. The baseline process provides a system to develop and maintain the one-on-one relationship for the scope, schedule, cost, and technical bases.

By using and integrating these systems, WINCO is and will continue to provide the customer (DOE-ID) and project management credible current status, performance against baseline, and forecasts, and will meet the intent of DOE Order 4700.1.

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Unit Number: CPP04 **Date:** 08/14/91

Unit Type: SWMU **Score:** 0.0 **Responsibility:** A. Owen

Title: Contaminated soil around CPP-603 settling tank

Current Operable Unit Number:
Current Track:
Initial Operable Unit Number: 9
Initial Track: 2

Location: East of CPP-603, around the settling tank
Location Confidence Level:

Unit Size: 33 feet x 67 feet
Size Confidence Level:
Surface Area: 2,211
Coordinate: N 693, 191
E 296, 651

Subsurface Area:
Area Confidence Level:
Subsurface Coordinates:
Applicable Autocad Drawings: 055345
Volume:

Continuous:

Date for One Time Occurrence: 05/53
Dates for More Than One Time:

Event Description: In May 1953, soil around the settling tank was found to be radiologically contaminated. The contaminated soil was removed.

Release Site Category: Tank leak

Waste Type: Radiologically contaminated basin water.

Type Confidence Level:

Waste Quantity:
Quantity Confidence Level:

Radionuclide Type:
Type Confidence Level:

Radionuclide Quantity:
Quantity Confidence Level:

Physical State of Waste Stream: Liquid

Media Contaminated: Soil
Media Confidence Level:

Observer's Name:
Phone Number:

Fig. 1. WINCO Environmental restoration technical database.

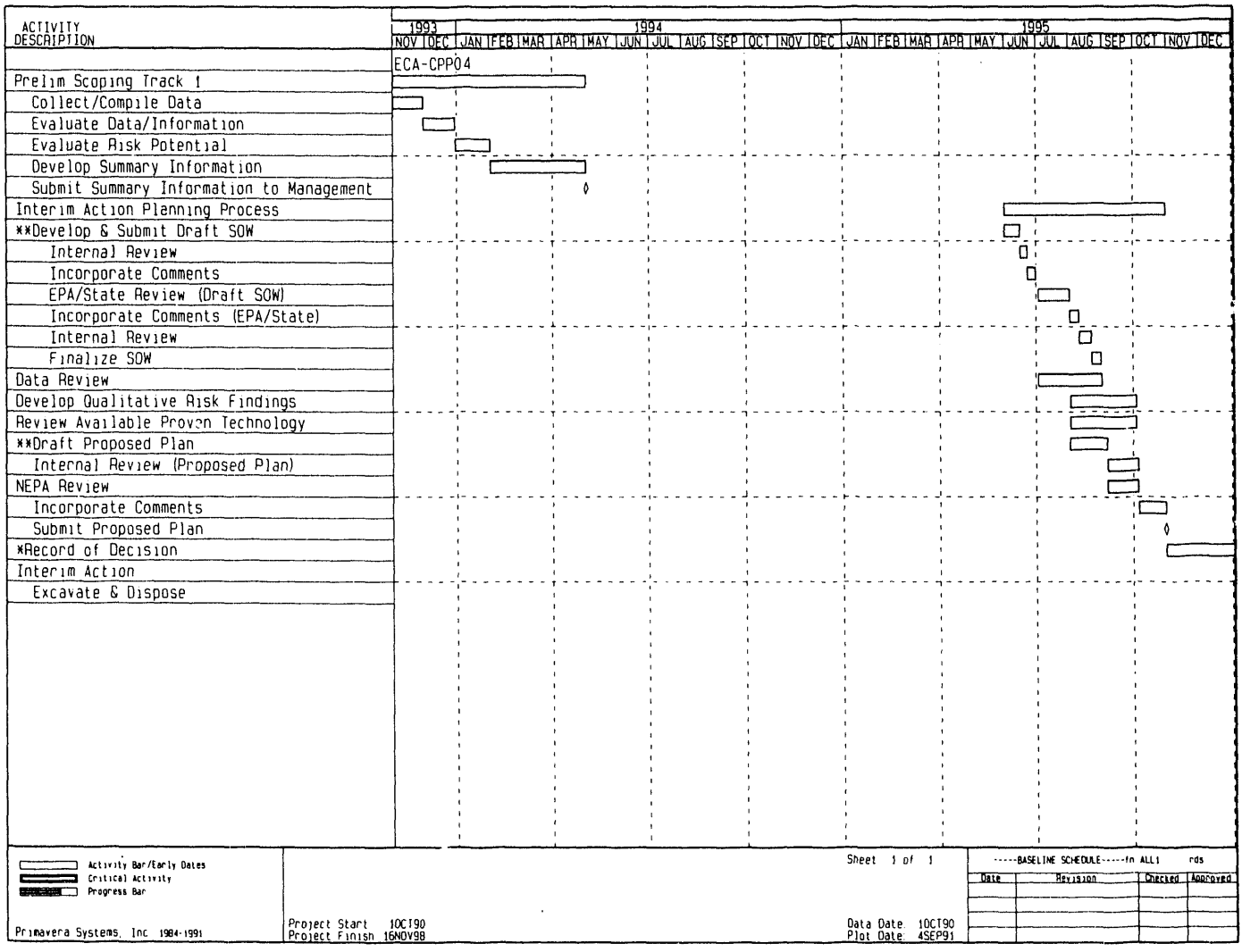


Fig. 2. WINCO environmental restoration project WAG 3 baseline.

ENVIRONMENTAL RESTORATION REMEDIAL ACTION QUALITY ASSURANCE REQUIREMENTS DOCUMENT

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ABSTRACT

The environmental Restoration Remedial Action Quality Assurance Requirements Document (DOE/RL 90-28) defines the quality assurance program requirements for the U.S. Department of Energy-Richland Field Office Environmental Restoration Remedial Action Program at the Hanford Site, Richland, Washington. This paper describes the objectives outlined in DOE/RL 90-28*. The Environmental Restoration Remedial Action Program implements significant commitments made by the U.S. Department of Energy in the Hanford Federal Facility Agreement and Consent Order** entered into with the Washington State Department of Ecology and the U.S. Environmental Protection Agency.

PURPOSE FOR THE QUALITY ASSURANCE REQUIREMENTS DOCUMENT

The Hanford Site's new mission [Environmental Restoration (ER)], requires the U.S. Department of Energy-Richland Field Office and its contractors to implement and comply with multiple quality assurance program requirements promulgated by the Hanford Federal Facility Agreement and Consent Order (Ecology et al. 1990 commonly called the Tri-Party Agreement) and the U.S. Department of Energy (DOE) to ensure that environmental data operations are planned and performed in a systematic and controlled manner. The DOE policy is to ensure the protection of the public and the environment. The effectiveness of Environmental Restoration Remedial Action (ERRA) Program results through a comprehensive quality assurance (QA) program.

OBJECTIVES

The *Environmental Restoration Remedial Action Quality Assurance Requirements Document* (DOE/RL-90-28) (QARD) defines the baseline QA program requirements governing activities that affect quality of ERRA program activities at the Hanford Site.

The QARD combines and consolidates multiple or overlapping requirements (where they exist) for similar activities to avoid confusion and misinterpretation of requirements by ERRA program participants.

QUALITY ASSURANCE REQUIREMENTS DOCUMENT SOURCE DOCUMENTS

The QARD integrates and tailors requirements from the 18 basic, supplemental, and non-mandatory appendices of ASME NQA-1 (ASME 1989a) and the other Consensus Standards, NQA-2 (ASME 1989b) and NQA-3 (ASME 1989c) with:

- Appropriate QA provisions from certain articles of the Hanford Federal Facility Agreement and Consent Order (i.e., the Tri-Party Agreement):
  - Article XXX-Quality Assurance of the Tri-Party Agreement
  - Chapter 7.8 of the Tri-Party Agreement Action Plan.
- U.S. Environmental Protection Agency (EPA) requirements and source documents such as QAMS-004 (EPA 1980b) for development of QA program plans, and QAMS-005 (EPA 1980a) for QA project plans, EPA/540/G-87/003 (EPA 1987) for Data Quality Objectives, EPA 540/G-89/004 (EPA 1989a) for guidance in conducting remedial investigation/feasibility studies under Comprehensive Environmental Response Compensation and Liability Act (CERCLA), OSWER 9950.1 (EPA 1989b) for the Technical Enforcement Guidance Document, and EPA-SW-846 (EPA 1986) for test methods for evaluating solid waste, and other EPA guidance documents.
- The U.S. DOE Orders and DOE-RL Orders such as 5600.6b [(DOE 1986) Quality Assurance] and RL 5700.1A [(DOE-RL 1983) Quality Assurance], 5400.1 [(DOE 1988) General Environmental Protection], 6430.1A [(DOE 1989) General Design Criteria], and 4700.1 [(DOE-RL 1989) Project Management System].
- Washington State Department of Ecology regulations such as Washington Administrative Code (WAC) 173-340-350 [(Ecology 1991b) Toxic Control Act Cleanup Regulations], and WAC Chapter 173-303 [(Ecology 1991a) Dangerous Waste Regulations].
- Each requirements of the QARD is source-coded to identify the documents from which the requirements were derived. This allows the user to go back into the source document(s) from which consensus requirements were established. Best management practice (BMP), other consensus standards (OCS), and consolidated and tailor requirement (CTR) are identified in the source code(s) where they are used.

* DOE/RL 90-28, **Environmental Restoration Remedial Action Quality Assurance Requirements**, U.S. Department of Energy, Richland Field Office, Richland, Washington.

** Ecology, EPA, and DOE, 1990, **Hanford Federal Facility Agreement and Consent Order**, Washington State Department of Ecology, U.S. Environmental Protection Agency, and U.S. Department of Energy, Olympia, Washington.

CONFIGURATION

The QARD is configured in three basic parts to facilitate identification and use the appropriate quality management tools for the appropriate work activity. Specific QA elements or functions in each part must be addressed.

The organization of the QARD into three distinct parts is based on the logical separation of management and technical operations; that is, to group together all activities which support common functions, such as procurement policies, and records management, into a single unit management systems (Part I). These common functions establish the framework and infrastructure for undertaking environmental data operations to characterize environmental processes and conditions (Part II), and for designing, constructing, and operating environmental engineering systems (Part III).

Management and Administration, Part I

The elements in the organization level are the organizational structure, policies, procedures, and roles and responsibilities. These elements define the way to establish a quality program for conducting effective environmental data operations. The organization level elements provide a framework or infrastructure to enable consistent quality procedures across similar environmental projects.

Design and Control of Environmental Data Operations, Part II

Part II provides the requirements for planning, implementing, and assessing operations to collect, analyze, and evaluate chemical, biological, ecological, or physical data in the environment. This also includes compiling, modeling, and analyzing environmental processes and conditions by mathematical or computerized methods.

Design and Control of Items, Part III

Part III provides the requirements to ensure effective design, construction, and operations of physical engineering systems, and their components, which remediate environmental contamination or remove pollutants from multimedia discharges.

SUMMARY

The ERRA QARD is at the leading edge of quality systems management for the Hanford Site environmental data operations.

ABBREVIATIONS AND ACRONYMS

BMP	best management practice
CTR	consolidated and tailored requirement
DOE	U.S. Department of Energy
EPA	U.S. Environmental Protection Agency
ER	Environmental Restoration
ERRA	Environmental Restoration Remedial Action
OCS	other consensus standards
QA	quality assurance
QARD	Quality Assurance Requirement Document
RL	U.S. Department of Energy-Richland Field Office
Tri-Party Agreement	Hanford Federal Facility Agreement and Consent Order
WAC	Washington Administrative Code

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COMPLIANCE WITH ASME NQA-1 AND QAMS-005/80 QUALITY REQUIREMENTS UNDER THE ENVIRONMENTAL RESTORATION PROGRAM AT THE IDAHO NATIONAL ENGINEERING LABORATORY

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ABSTRACT

A number of approaches have been advanced within the U.S. Department of Energy (DOE) and DOE contractor organizations in recent years towards reconciliation of DOE and U.S. Environmental Protection Agency (EPA) quality assurance (QA) requirements as applicable to environmental investigation at DOE facilities. The DOE has adopted ASME NQA-1 as the preferred standard for all projects conducted at its nuclear facilities. The EPA, through direct requests in consent agreements or by other means, requires consideration of its QAMS-005/80 guidelines for all environmental data gathering and monitoring investigations under its purview.

It is suggested that one approach to implementing the DOE and the EPA standards exists that by its nature is less prone to the implementation problems and the costs associated with the introduction of new and complex requirements documents. That approach involves a re-examination and reaffirmation of the basic intent of the ASME NQA-1 and the QAMS-005/80 standards, and the establishment of flexible, ASME NQA-1-based program management structures and supporting procedures. Multiple investigations may then be pursued in compliance with detailed secondary planning documents, which may be prepared in compliance with QAMS-005/80 and/or other applicable EPA guidelines to meet the specific needs of individual contract tasks and applicable consent orders. Since it makes the best possible use of existing QA programs, supporting QA and technical procedures, and existing management and training systems, this approach has proved to be both practical and flexible.

INTRODUCTION

Environmental restoration involves the assessment and cleanup of facilities that are no longer part of active operations. Environmental restoration consists of two fundamental activities: 1) remedial actions to eliminate sources of potential releases from inactive waste sites and 2) decontamination and decommissioning of surplus facilities. Remedial action is primarily concerned with all aspects of the assessment and cleanup of waste units. To date, approximately 370 suspected waste disposal units have been identified at the Idaho National Engineering Laboratory (INEL) for investigation. These sites have been divided into 10 Waste Area Groups (WAGs). The Idaho Chemical Processing Plant (ICPP) designated WAG-3 contains 83 of these waste disposal units. In addition to being the principal contractor at the ICPP, Westinghouse Idaho Nuclear Company, Inc. (WINCO) is the primary contractor for environmental restoration activities at the ICPP. The principle subcontractor for environmental restoration activities has been assigned the responsibility of overseeing the drilling and sampling operations at the ICPP. Other key participants to the remedial action effort include the drilling contractor and the contracted analytical laboratory services supporting the ICPP. The Quality Assurance (QA) Program, including some of the functional reporting for the major participants, is described in a later section of this paper.

This paper specifically addresses the integration of QAMS-005/80 (1) and ASME NQA-1 (2) for the remedial action effort of the Environmental Restoration Program at the INEL and has been thoroughly tested by application to all environmental sampling and analysis activities at the ICPP. This approach has been particularly useful for WINCO, where this integration of multiple QA standards involved ASME NQA-1 and a different U.S. Environmental Protection Agency (EPA) QA reference (i.e. not QAMS-005/80).

THE TIERED APPROACH

Many people assume that in invoking QAMS-005/80, ASME NQA-1 is no longer being invoked; thus, it must be proven that ASME NQA-1 is still being implemented. A number of approaches have been advanced within the U.S. Department of Energy (DOE) and DOE contractor organizations in recent years towards reconciliation of DOE and EPA QA requirements as applicable to environmental investigation at DOE facilities. One method for ensuring implementation of both standards is the "two-tiered approach." While this approach is a bit more complicated from a conceptual standpoint, in actual practice we believe it to be straightforward and effective. This tiered approach is graphically illustrated in Fig. 1.

WHY THE TWO-TIERED APPROACH

Before a discussion is given on how the tiered approach was developed and how this approach is used for environmental restoration, it is worth mentioning the three strongest arguments for adopting a two-tiered approach to QA. First, this approach is inherently flexible; second, it is less prone to change as source documents are revised; and last, it models the original EPA system for QA and yet satisfies the DOE system for maintaining ASME NQA-1 as the "preferred standard."

Flexibility

In the preliminary stages of development, it became evident that creating a separate QA Program for environmental

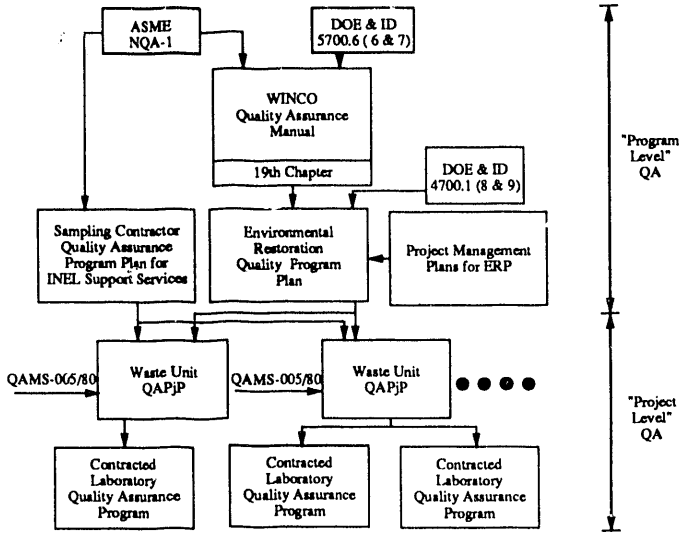


Fig. 1. The two tiered approach to quality assurance.

protection activities (environmental restoration included) was not a viable option. This was due in part to WINCO's size, the costs associated with development and associated training for a new program, and the required time frame for initiating environmental restoration activities. The existing QA Program and associated standard operating procedures would have to be used to support environmental restoration.

As a result, investigations associated with environmental restoration would be conducted in compliance with detailed secondary planning documents prepared in compliance with QAMS-005/80 and/or other applicable EPA guidelines. Inherent to this approach was the fact that subcontractors could just as easily prepare and implement these secondary planning documents for WINCO. What resulted was a logical, practical, and effective approach without any sacrifice to the quality and defensibility of the generated data.

The Standards Change

As alluded to in the introduction, QAMS-005/80 is not the only EPA guideline that directs QA activities at the implementation level. A perfect example is the QA criteria given by both 40 CFR 60, Appendix F (3) and 40 CFR 61, Appendix B, Method 114 (4). While the fundamental principles of these two chapters are similar to QAMS-005/80, a specific new set of criteria is outlined. Under this flexible NQA-1-based structure, where implementation takes place at the level of these secondary detailed planning documents, the impact is minimal, and the program need not be changed.

There also exists the possibility that ASME NQA-1 may not be retained as the DOE-preferred QA standard. The impact of such a change would be more severe than a change to the EPA criteria, but the tiered approach will be less affected. Obviously, changes to the overall program in either case would be significant; however, if correctly prepared, the changes to the second-tier documents would again be minimal or nonexistent.

The EPA Approach

The last and perhaps the strongest reason for adopting this approach was that it models the EPA's approach to QA and yet maintains ASME NQA-1 as the overall standard consistent with the DOE orders.

Under the EPA system, QAMS-004/80 (5) was written to describe the overall QA Program requirements. As part of the development of this QA Program, Quality Assurance Project Plans (QAPjPs) were to be written to assure that "all data generated are scientifically valid, defensible, comparable, and of known precision and accuracy." QAMS-005/80 was written to further define these QAPjPs. Essentially, this led to a two-tiered system with "program-level" and "project-level" documents. Keep in mind that the terms "program level" and "project level" were derived from the EPA's definitions of a Quality Assurance Program Plan and a Quality Assurance Project Plan. Throughout this paper, these terms will be used to illustrate this two-tiered approach to QA. The same type of system has been developed at WINCO, where ASME NQA-1 guides the program-level requirements consistent with the DOE orders, and QAMS-005/80 guides the project-level requirements for environmental sampling and analysis activities.

DEVELOPMENT

The first step in developing this approach was to re-examine and reaffirm the basic intent behind both ASME NQA-1 and QAMS-005/80. While a requirement-by- requirement comparison between both standards will yield large disconnects, the fundamental principles behind both standards are essentially identical as long as QAMS-005/80 is applied only to the activities for which it was intended (i.e., environmental sampling and analysis) and the intent of ASME NQA-1 is applied toward the same type of activities. Once this step can be justified in your own mind, the remaining steps easily fall out. This first step is critical in that it forces one to use QAMS-005/80 as the appropriate standard to implement ASME NQA-1 for environmental sampling and analysis activities.

The second step was to document the philosophy of the previous paragraph. While this step is not mandatory, it has been helpful in presenting WINCO's QA position for environmental protection activities including restoration. After evaluating several options, it was decided this could be best accomplished through a new dedicated chapter to the WINCO Quality Assurance Manual. This 19th chapter provides the mechanism for the generation of QAPjPs in accordance with QAMS-005/80 (or an other appropriate standard) and places the QAPjPs in the appropriate place in the QA hierarchy. In addition, this 19th chapter provides the crosswalk between the ASME NQA-1 "program" and the QAMS-005/80 "projects." This crosswalk is provided through the use of a comparison matrix between the ASME NQA-1 and the QAMS-005/80 criteria.

The final step in the process is to refine the implementation process. While the previous discussion makes a very clear distinction on what QAMS-005/80 is used for, the actual breakdown is not that clean-cut. There are two areas where this deviation occurs. First, one needs to identify the starting and stopping points for environmental sampling and analysis activities within the Environmental Restoration Program.

Second, one needs to identify which activities associated with environmental sampling and analysis could be best handled as standard ASME NQA-1 activities. In either case, we are looking at circumstances that cause a shift in control from the project level (QAMS-005/80) to the program level (ASME NQA-1). The next two sections describe the thought process for determining when QAMS-005/80 is no longer the appropriate standard for environmental restoration activities. Since environmental restoration is not just limited to environmental sampling and analysis, a definitive line was drawn between the two types of activities to more cleanly divide the two-tiered QA approach. Construction-type activities are those activities which by their nature fall under the classic ASME NQA-1 program. Environmental sampling and analysis activities are those that fall under the two-tiered QA approach. These two types of activities are illustrated in Fig. 1.

Shared Components

Look back at the illustration in Fig. 1, specifically at the shared elements region. With the two-tiered approach to QA, a transition must be made between the project level and the program level. Conceptually, this may seem complicated, but the process is straightforward. In actual implementation, this simply involves referencing the standard QA procedures that apply to all activities. A perfect example of this transition is the corrective action program for environmental restoration. If a condition adverse to quality arises during environmental restoration, regardless if it involves an environmental sampling and analysis activity or a construction-type activity (see above), the system for taking corrective action is identical in both cases and is handled at the program level. As one might expect, at the project level, this program-level system (i.e., corrective action) is merely cited by reference.

Where Sampling and Analysis Begins and Ends

Another obstacle that must be confronted is benchmarking where sampling and analytical activities within the Environmental Restoration Program begin and end. Before environmental sampling and analysis activities begin, one must consider the program-level QA requirements. The same holds true for the close of environmental sampling and analysis activities. This is the point where the QAPjP is no longer applicable or only partially applicable to the environmental restoration effort. A simple example of this process is described in a later section.

ENVIRONMENTAL RESTORATION QUALITY ASSURANCE PROGRAM

The best way to describe the Environmental Restoration QA Program is to describe the quality-implementing documents associated with environmental restoration. Fig. 2 illustrates the QA hierarchy for environmental restoration at the ICPP. Previously, the philosophy of the QAMS-005/80 and ASME NQA-1 integration was explained. This integration represents the upper portion of Fig. 2, specifically the program-level portion.

Now, the waste unit QAPjPs and the analytical services provided to environmental restoration will be discussed, followed by a discussion of some of the program-level documents written specifically for environmental restoration.

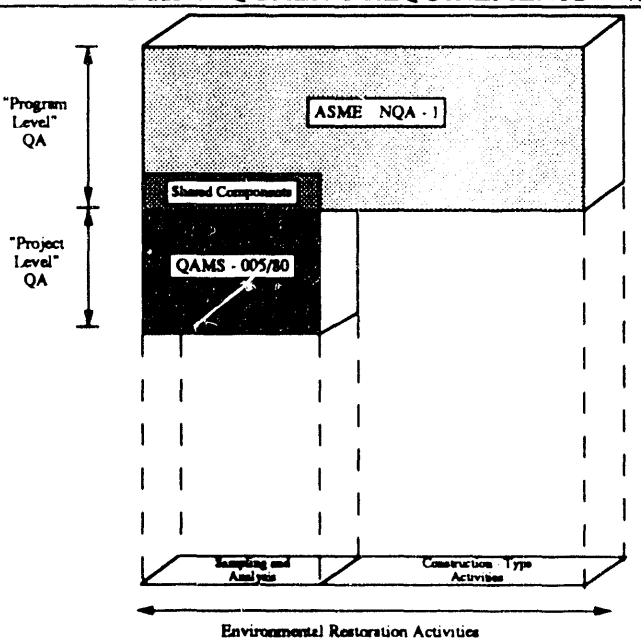


Fig. 2. Quality assurance hierarchy for environmental restoration.

Waste Unit QAPjPs

The waste unit QAPjPs serve as the focal point for all quality activities associated with environmental sampling and analysis for each waste unit or group of similar waste units. As discussed earlier, these documents are prepared in accordance with the appropriate implementing standard in the two-tiered QA system, namely QAMS-005/80. Interpretations of QAMS-005/80 requirements and expanded guidelines provided by other EPA guidance documents [such as SW-846, "Test Methods for Evaluating Solid Waste" (10) or EPA/540/G-89/004, "Guidance for Conducting Remedial Investigations and Feasibility Studies Under CERCLA" (11)] are also considered in the preparation of the waste unit QAPjPs. These documents are prepared by the sampling contractor and approved by a project manager and a QA officer in both organizations. These QAPjPs along with their referenced standard operating procedures define the lowest hierarchy document for the sampling effort. Examples of environmental sampling and analysis activities standard operating procedures referenced by these QAPjPs include drilling, sampling, and logging of soils, and chain-of-custody procedures. Examples of program-level standard operating procedures referenced by these project-level QAPjPs include QA audit, calibration, surveillance, and inspection procedures.

Furthermore, these same QAPjPs define the requirements that are to be contractually imposed on the analytical laboratory(ies) for that particular waste unit.

Analytical Laboratory Quality Assurance Programs

The project-level QA requirements are passed on to the contracted analytical services via the waste unit QAPjPs. The analytical laboratories are responsible for incorporating these unit-specific requirements into their own respective QA Programs. The laboratory QA Programs are prepared in accordance with SW-846, "Test Methods for Evaluating Solid Waste," which specifies that a QAMS-005/80 type of system be established. These "laboratory" QAPjPs fit into the environmental restoration two-tiered QA hierarchy for analytical

services in much the same manner as the "waste unit QAPjPs" do for sampling services.

Control of analytical services provides an excellent venue to explain the tiered approach to QA. QAMS-005/80 poorly addresses the mechanisms by which analytical services should be procured; ASME NQA-1, on the other hand, is fairly strong in this area. As was discussed in a previous section, this is another case where a shift occurs from the project level to the program level, and evaluation of these services occurs under the program-level criteria (ASME NQA-1). Prior to award of contract (i.e., prior to where sampling and analysis begins), each laboratory's QA Program is evaluated against the criteria specified by the waste unit QAPjPs and through joint on-site evaluation of each analytical laboratory.

Program-Level Documents Written Specifically for Environmental Restoration

Two other key documents exist that direct environmental restoration activities at the ICPP, namely the Environmental Restoration Quality Program Plan (QPP) and the Quality Assurance Program Plan for INEL Support Services. Both of these documents define the program-level requirements that are directly applied to environmental restoration. Each major participant (WINCO and the sampling contractor) has developed a parallel ASME NQA-1-based document to pass down the QA requirements to the second level in the tiered approach to QA. In Fig. 2, both documents are shown driving the waste unit QAPjPs, which form the basis for environmental sampling and analytical QA. Since environmental restoration is not solely limited to environmental sampling and analysis, both of these documents have been written to guide any construction-type activities that may arise as environmental restoration proceeds.

CONCLUSION

Conceptually, the two-tiered approach to QA may appear complicated, but in actual practice, the process is very straightforward. The biggest obstacle to overcome is accepting that the intention of both standards for environmental sampling and analysis activities is identical, and as such, use of QAMS-005/80 is not only justified but appropriate. Treat QAMS-005/80 as a method to implement ASME NQA-1 as it pertains to environmental sampling and analysis rather than a standard to replace ASME NQA-1.

In summary, the way to treat QAMS-005/80 is identical to the way an ASTM or ASQC specification has always been treated under a traditional ASME NQA-1-based program. For example, performing a hydrostatic test in accordance with ANSI B31.3, "Chemical Plant and Petroleum Refining Piping," (12) is not substituting ASME NQA-1's "Test Control," but rather it is supplementing. Furthermore, performing environmental sampling and analysis in accordance with QAMS-005/80 is not substituting ASME NQA-1, but rather it is supplementing.

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APPLICATION OF CLASSIC ENGINEERING TECHNIQUES (VALUE ENGINEERING AND OBSERVATIONAL METHOD) AT THE WELDON SPRING QUARRY

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ABSTRACT

In July of 1987 the Weldon Spring quarry was listed on the Environmental Protection Agency National Priority List as the highest priority Federal facility site. The Weldon Spring Site Remedial Action Project applied the principles and techniques of Value Engineering (VE) and the Observational Method to remedial planning efforts at the quarry. VE sessions resulted in modifications of the scenarios developed during the Remedial Investigation/ Feasibility Study (RI/FS) process in preparation for conceptual design activities for the removal of waste from the quarry.

The Observational Method, a technique developed to manage uncertainties, was used to guide both environmental and engineering planning to ensure that the waste removal activities will be carried out in a safe and environmentally responsible manner.

INTRODUCTION

While the complexity of environmental remediation projects is certainly greater than most traditional engineering endeavors, many of the general types of problems and uncertainties are not unique. Our engineering predecessors pioneered techniques for managing difficult sites and situations, and these techniques can be applied today to many of the major problems faced by professionals engaged in environmental restoration activities. Two such techniques are Value Engineering (VE) and the Observational Method of planning and designing. The Weldon Spring Site Remedial Action Project (WSSRAP) has applied VE to several topics, including contracting strategy and waste management issues such as treatment, storage, and disposal of asbestos-containing material; sludge processing and management; and consolidation of debris resulting from structure dismantlement. This paper focuses on the use of VE principles in planning and preliminary engineering for remediation of a quarry at the Weldon Spring site. The paper also addresses use of the Observational Method to plan, design, and implement removal, transport, and temporary storage of 73,000 m^3 (95,000 yd^3) of heterogeneous bulk waste contaminated with natural series radionuclides and nitroaromatics.

PROJECT DESCRIPTION

In April 1941, the U.S. Department of the Army acquired approximately 7,000 hectares (17,000 acres) of land in St. Charles County, Missouri, for construction of the Weldon Spring Ordnance Works. From November 1941 through January 1944, the Atlas Powder Company operated the ordnance works for the Army to produce trinitrotoluene (TNT) and dinitrotoluene (DNT) explosives.

In 1955 the U.S. Atomic Energy Commission (AEC), a predecessor of the U.S. Department of Energy (DOE), constructed a feed materials plantnow referred to as the chemical plant on 83 hectares (205 acres) of the property for the purpose of processing uranium and thorium ore concentrates. A nearby quarry, the Weldon Spring Quarry, which had been used by the Army since the early 1940s for disposal of chemically contaminated (explosive) materials, was transferred to the AEC in July 1960.

The AEC used the quarry to dispose of uranium and thorium residues (both drummed and uncontained), radioactively contaminated building rubble and process equipment, and TNT and DNT residues from cleanup of the former ordnance works. Based on historical data and characterization results, an estimated 73,000 m^3 (95,000 yd^3) of contaminated materials is present in the quarry.

In July 1987 the quarry was listed on the National Priorities List (NPL), and in September 1990 the U.S. Environmental Protection Agency (EPA) signed a Record of Decision (ROD) for the removal, transport, and temporary storage of bulk wastes from the quarry.

Design packages have been developed for each phase of work described in the ROD. Contracts are currently being awarded for this work, and the bulk waste excavation is scheduled to begin in August 1992.

VALUE ENGINEERING

Value Engineering is an organized team study technique that combines objective and subjective analysis for problem identification and solving. This approach has been used in manufacturing circles for many years and has become a mandatory analysis technique with several Japanese firms.

Mr. Larry D. Miles is credited with developing the "functional approach" which is the heart of Value Engineering. Miles developed this approach during World War II in order to make the best use of available resources. He applied his program at General Electric, eventually saving approximately $200 million over a 17 year period.

Value Engineering sessions are designed to promote team building and creative thinking as well as to provide the motivation and education to anticipate and solve complex problems by analyzing them at their most fundamental functional level. A typical VE session consists of several phases beginning with the selection of an item or items for study. The item is then defined by its function which is described by a transitive verb followed by a direct object noun. A classic example is the function of a roof, which is to "protect interior." This information can be presented graphically using a function analysis system technique (FAST) diagram which ensures that the logic is consistent with associated functions identified during evaluation (see Figure 1).

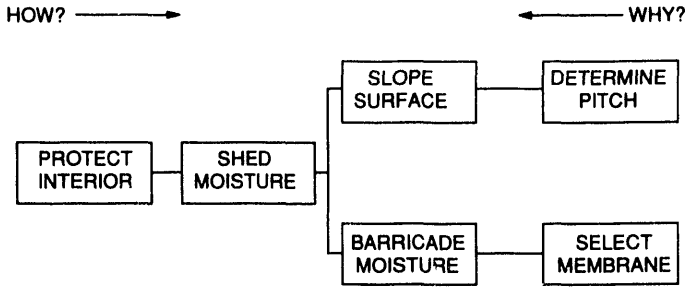


Fig. 1. Fast diagram for a roof (1).

A speculative phase is then intiated to "brainstrom" alternative ways of accomplishing the function. It is important for the team to promote creative solutions and to list every idea for subsequent analysis. The next step is criteria development. The criteria are evaluated and ranked by importance. The ranked criteria each have an associated numeric value which is eventually used as a relative weight for comparison against other alternatives in a matrix analysis. Normally, this analysis establishes a significant spread between the most desired and the least desired alternatives, and only the most desired are carried forward to the next step, the subjective phase.

The subjective phase is simply an analysis of alternatives on the basis of experience. The advantages and disadvantages of each alternative are thoroughly discussed, the alternatives are re-ranked accordingly, and the preferred alternatives are identified.

Finally, cost analyses of the best alternatives can be prepared for comparative purposes. The results are then presented to decision makers for approval and implementation.

APPLICATION OF VALUE ENGINEERING STUDIES

The WSSRAP used value engineering techniques to develop and analyze alternatives for conceptual design within the framework of the RI/FS process for quarry bulk waste management. VE training was provided to several members of the WSSRAP staff by Mr. William L. Kelly, P.E., C.V.S., of Value Engineering Services Transworld (VEST) of Walla Walla, Washington, using his book, *You and Value Whatnot*, as a manual.

The preferred alternative presented in the Feasible Study (FS) called for removal of the bulk wastes, transport by truck to the chemical plant site, and placement in an engineered temporary storage area. The FS assumed that the waste would be stored in a covered pile.

A VE analysis was conducted for all three components of the preferred alternative presented in the FS. However, for presentation purposes the following summarizes only that portion of the VE analysis concerning the storage of material susceptible to wind blown dispersal.

The VE team consisted of seven individuals including a trained "facilitator" versed in VE techniques, procedures, and methodology. The team developed a FAST diagram and focused on those functions with the greatest apparent impact on design. The following criteria for temporary storage of fine grained material were developed.

- Structural integrity
- Health and safety
- Environmental impact
- Accessibility
- Schedule
- Life-cycle cost
- Waste minimization

Reasonable alternatives carried forward from the speculative phase were analyzed against the previously determined criteria in matrix form. This yielded the following preferred alternatives for covered storage of the bulk waste in question:

- Steel panel bin
- Permanent steel container
- Reinforced concrete bin
- Roller compacted concrete
- Geogrid membrane bin
- Roller compacted soil bin
- Pile

After the objective appraisal was completed, the advantages and disadvantages of each alternative were reviewed on the basis of the experience of each team member. The results indicated that three alternatives steel panel bins, reinforced concrete bins, and roller compacted concrete-were preferred and should be evaluated by the conceptual designers.

Other critical functions, including waste excavation, sorting, and hauling, were evaluated similarly. The preferred alternative for each of these functions was compiled in a system matrix (Table 1) to aid the conceptual designers.

OBSERVATIONAL METHOD

In planning for the removal of the bulk wastes from the quarry, it was important to recognize the associated uncertainties. Site conditions and the nature of the waste, which consists of a heterogeneous mixture of demolition debris, concrete rubble, process equipment, and containerized and uncontainerized wastes, precluded a complete characterization of the in-place material. Because the precise excavation conditions and the effects of the operation cannot be completely anticipated, an observational approach, or "Observational Method," is being utilized to manage uncertainty as part of the cleanup strategy.

The Observational Method provides a structured approach to managing uncertainty. Planning is based on available data and realistic assumptions of field conditions. Reasonably conceivable deviations in these conditions are assessed, mechanisms by which to identify their occurrence are defined, and plans to address or mitigate them are developed. This approach minimizes the need to design for worst-case conditions, which can be overwhelming when considerable uncertainty exists.

The observational method was pioneered by two geotechnical engineers, Karl Terzaghi and R.B. Peck, who were concerned with the uncertainty of subsurface conditions related to the design and construction of earth structures. Potential application of the observational method to Superfund projects was proposed by S.M. Brown, D.R. Lincoln, and W.A. Wallace in a paper titled "Application of Engineering Under Uncertainty to Remediation of Hazardous Waste Sites (2)." The method has since been incorporated into the EPA's Office of Soild Waste and Emergency Response (OSWER) Directive 9355.3-06, RI/FS Improvement Phase II, Streamlining Recommendations.

TABLE I

System Matrix

FUNCTION	PREFERRED ALTERNATIVE 1	2	3
Excavate Waste	Multiple Bench Top Advance (TA)	Multiple Bench Floor Retreat (FR)	Single Bench (FR) Single Bench (TA)
Sort Waste	Grizzly*, Screen*, Magnet, Selective Handling, etc.		
Establish Route	Single lane with Turnout (U.S.F.S. Road)	Two lane	Single lane with Highway 94 return
Haul Waste	Roll-Off Box, Tanker Roll Off	Dump-Truck, Barrels	
Store Waste	Steel Panel Bins, Reinf. Conc. Bins, Roller Compacted Soil Cement		

NOTE: * Required only with Roller Compacted Soil Cement

Utilization of this method at the Weldon Spring Quarry, focuses on the remedial design and remedial action (RD/RA) phase of the project. The principles used to implement the method are consistent with previous work related to RI/FS applications. The following discussion describes the implementation of the approach and presents additional guidance for RD/RA application on other environmental restoration projects.

As previously discussed, a VE study was conducted which refined the RI/FS options for implementing the RA. Planning for the RD/RA phase of the project was initiated on the basis of these refinements. All planning related to the physical aspects of removing the waste (equipment, operations, material properties, productivity) was developed in a Conceptual Design Report (CDR), and planning related to dealing safely with the various types of contaminants and hazards encountered (environmental monitoring, health and safety, contingency plans) is taking place as part of a comprehensive Operational Environmental, Safety, and Health (ES&H) Plan for this action.

Engineering Planning

The Conceptual Design Report describes and differentiates among known site conditions, expected conditions, and potential variations. Reasonably foreseeable variations (such as the degree of dewatering of the waste, the ability of equipment to work an excavation face, the stability of the highwall adjacent to a nearby state highway, and the productivity of the excavating equipment) were examined and categorized according to the types of response or mitigative measures required (see Table 2).

The fundamental difference between the traditional engineering approach and the observational approach for RD/RA activities is the systematic process of "brainstorming" and documenting potential deviations. The advantage of this approach is that the list of deviations can be distributed for peer review and reviewed by others to facilitate discussion and ensure that all reasonable deviations have been identified.

The CDR also identifies how the various assumptions will be verified in the field by measurement (such as water level monitoring) or direct observation (such as material heterogeneity) for comparison against the forecasted conditions. Cost estimates are provided for various operational scenarios (such as alternative types of excavating equipment) and contingency designs (such as stabilization of the highwall).

A logical question at this point in the process relates to whether or not a final design deliverable must be developed in advance for each identified deviation. In applying the observational approach to this type of work, it is recommended that the deviations be assigned a relative probability of occurrence (i.e., low, moderate, or high) and an assessment be made to determine how much lead time is available to respond should each deviation occur. In this way, one can conclude that a final design package should be available prior to initiating work for those deviations with a high probability of occurrence and a short response time. Conversely, deviations with-low probabilities of occurrence and long response times need only a conceptual-level contingency design. Implementation of this approach requires a flexible contracting strategy.

Environmental Planning

The observational approach was also used in the assessment of environmental planning which focuses on managing uncertainties related to the waste characteristics and potential occurrences (see Table 3). The Quarry Operational ES&H Plan:

- Summarizes the activities expected during water treatment operations and waste excavation, transportation, segregation, and placement in temporary storage.

TABLE II

Engineering Uncertainties

Expected Conditions	Potential Deviations	Mechanisms to Identify Deviations	Contingency Design	Probability of Occurence	Response Lead Time
Stable High Wall	• Removal of toe support • Increased traffic and vibrations	• Direct Measurement	• Rock bolt • Wire mesh • Benches	Low	Short
Adequate Dewatering	• Unable to dewater certain areas of the quarry	• Monitor well water level readings • Direct observation	• Drainage trenches • Dewatering wells	High	Long
Stable Working Face	• Waste will not support equipment	• Operator feedback • Degree of dewatering • Settlement/sloughing/ slumping	• Alternative excavation method • Excavate thinner lifts	High	Short
Excavating Equipment Effective	• Inability to remove or extract • Inability to sort • Inability to maneuver	• Direct observation	• Alternative excavation method	High	Short
Buried Access Road	• Unusable access to quarry floor	• Direct observation	• Alternative excavation method	Moderate	Moderate

TABLE III

Environmental Uncertainties

		Expected Conditions	Potential Deviations	Engineering Controls	Probability of Occurence	Response Lead Time
Vapors	Radon	Above 3 pCi/l progressively lower	Levels higher expected	• Water Sprays • Reduce surface area • Surface sealant (50 - 85%)	High	Long
	VOCs	Below 5 ppm		• Mechanical • Ventilators • Covers (80 - 95%)	Moderate	Short
Dust	Radioparticulates	Below respiratory action levels	Concentrations exceed respiratory action levels	• Water sprays • Surface sealant • Covers	Moderate	Long
	Nitroaromatics				Low	Short
Gamma		Exposure rates at most tens of mrem/hr	Levels higher than expected	• Limit working area • Remote excavation	Low	Long
Explosives		Concentrations less than 10%	• Concentrations higher than 10% • Hot spots	• Water sprays • Oil/water sprays	Low	Short
Fire		• Currently under analysis • Possibility for ignition	• Pyrophorics • Oxidizers	• Dry chemicals • Cover stockpile	Moderate	Short
Groundwater		• Gradient reversal • Little chance for migration	• Preferential pathways • Rapid transport	• Interceptor wells • Cut-off wall • Shut down municipal well(s)	Low	Long

- Identifies the expected hazards, including concentrations of contaminants and levels of exposure.
- Plans health and safety and personal protective equipment requirements based on expected contaminants and concentrations.
- Identifies potential deviations to the expected conditions.
- Defines action levels for implementing plans to mitigate any increases in contaminant concentrations.
- Develops incident response plans for implementing engineering controls.
- Develops contingency plans to address emergency situations.

Methodology similar to engineering planning was used to ensure the potential deviations are completely evaluated and to establish how far to carry the incident response plans with respect to final design deliverables. With a flexible contracting strategy, the critical planning relates to ensuring that the excavation contractor has the proper expertise and equipment on hand to respond to short lead-time incidents and deviations.

These methods have proven to be a valuable asset at the Weldon Spring site. The project is committed to identifying and implementing these and other innovative solutions until final remediation goals are achieved. In the meantime, remediation of the Weldon Spring Quarry will present an opportunity to apply these time-tested techniques.

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LABORATORY-SCALE TESTS OF A CHEMICAL BARRIER FOR USE AT URANIUM MILL TAILINGS DISPOSAL SITES

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ABSTRACT

A chemical barrier is a permeable mixture of reactive materials that chemically extracts contaminants from groundwater passing through it. One application is as a repository liner to protect an underlying aquifer from contamination. This paper concerns the development of a barrier consisting of a layer of $FeSO_4$ overlying a layer of $Ca(OH)_2$ to be used as a liner for a uranium mill tailings repository. Batch tests were performed to determine the minimum amount of $FeSO_4$ and $Ca(OH)_2$ required to remove molybdenum and uranium, respectively. This barrier design was tested using a laboratory-scale column that allows sampling along the flow path. A redox front was observed propagating through the column coinciding with the precipitation of ferrous iron by contact with $Ca(OH)_2$. Dissolved molybdenum and uranium were successfully removed from solution for 6 and 9 days, respectively. Chemical mechanisms for removal of uranium include reduction to UO_2 and precipitation of $CaUO_4$ caused by elevated pH. Molybdenum is extracted by the reduction to Mo_3O_8 or MoS_2, or precipitation of $FeMoO_4$.

INTRODUCTION

Passive groundwater remediation is an alternative to pump-and-treat methods. Many pump-and-treat projects have failed to adequately restore the groundwater (1). In addition, the public is demanding more restrictive regulations governing landfill designs. *Prevention* of groundwater contamination is generally more acceptable and economical than treatment or removal.

A promising preventive technology is passive chemical barriers (Fig. 1). A chemical barrier is a permeable mixture of reactive materials that can be used as a repository liner to protect an underlying aquifer from contamination. Groundwater contaminants are removed by chemical extraction as they pass through the barrier.

The U.S. Department of Energy (DOE) is responsible for the remediation of about 30 million tons of uranium mill tailings under the Uranium Mill Tailings Remedial Action Program (UMTRA) and Surplus Facility Management Program (SFMP) (2). Regulations mandate groundwater protection from contamination for periods of 200 to 1,000 years (3). Passive chemical barriers may be applicable to these sites. In this paper, we present results of an on-going study to evaluate the feasibility of a chemical barrier for the Monticello, Utah, uranium mill tailings repository.

The barrier design presented in this paper consists of a layer of $FeSO_4$ (ferrous sulfate) overlying a layer of $Ca(OH)_2$ (lime). These materials were selected from a large variety of materials that were screened for their ability to remove the contaminants of concern. Results of these initial batch tests are discussed in another paper (4).

$Ca(OH)_2$ has been used to remove contaminants from waste waters and mill effluents (5). A previous study showed that when $Ca(OH)_2$ was mixed with Gunnison, Colorado, uranium mill tailings, uranium mobility was significantly reduced while molybdenum mobility increased (6). These results were confirmed in our laboratory using Monticello uranium mill tailings.

Contaminants of Concern

Uranium mill tailings contain high concentrations of a wide variety of contaminants including U, Mo, Se, As, ^{226}Ra, ^{230}Th, Cu, Zn, Pb, Cr, SO_4, and NO_3. Because of the wide range in reactive pathways, it is unlikely that a single material can be found that will favorably affect all potential contaminants. Studies of stabilizing chemicals for all of these contaminants would require an enormous number of experiments at great cost. Therefore, an essential part of this study was to survey groundwater contamination at uranium mill tailings sites, in particular at Monticello, and determine which of the contaminants posed the most serious threat to humans because of mobilization into groundwater supplies.

The results of this survey show that uranium is by far the most likely contaminant that will be released to the groundwater. Molybdenum is probably the second most mobile contaminant. While radium-226 is a serious health threat even in low concentrations, there is substantial evidence that radium-226 is relatively immobile in groundwater systems. As a result of these observations, our experimental strategy was to focus on controls primarily for uranium with a secondary emphasis on molybdenum. Once a barrier is designed that meets performance guidelines for uranium and molybdenum, it will be tested against all other potential contaminants.

METHODS

Two types of experiments were conducted: batch tests and a column test. Batch tests consisted of combining the test material with an aliquot of a synthetic uranium mill tailings pore fluid (SPF-1). The synthetic pore fluid composition was formulated to resemble a pore fluid sample from the Monticello East Pile tailings (Table I). The mixture was then shaken on an orbital shaker table.

The column test used a 10-centimeter-diameter acrylic column (Fig. 2). The column was comprised of 10 sections; each section consisted of a solids chamber and a water sampling chamber. Each of the bottom five solids chambers was filled with a mixture of $FeSO_4$ (6.91 grams) and sand (648 grams); each of the top five was filled with lime (6.91 grams)

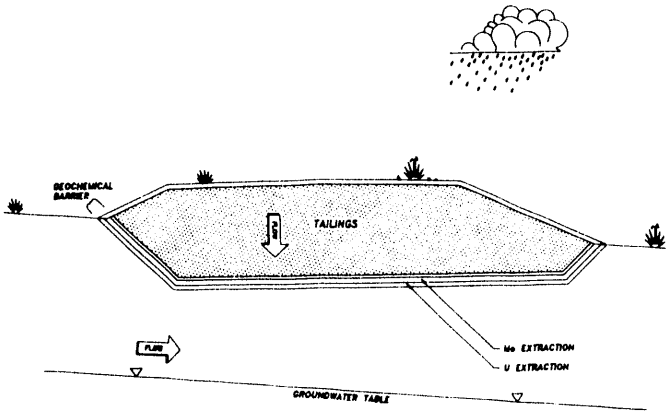


Fig. 1. Chemical barrier concept.

and sand (648 grams). Each water sampling chamber was equipped with a port to allow sampling of the fluids at intervals along the flow path. Filters (230 mesh) were placed between all chambers.

Synthetic pore fluid SPF-2 (Table I) was pumped through the column from the bottom to the top for 11 days. The average flow rate was 1.3 liters (L) per day. The ports were numbered from 1 to 10 starting at the bottom of the column.

All samples were filtered through a 0.45-micron filter. The pH and Eh were measured using glass combination electrodes. Batch test samples were measured for pH and Eh immediately after filtering. In the column experiments, the pH and Eh were measured without exposure to the air. The molybdenum content of all samples was measured using the ternary complex photometric method. Our detection limit for molybdenum was 0.05 milligrams per liter (mg/L). To test for matrix interferences, distilled water was mixed with $FeSO_4$, filtered, and spiked with known amounts of molybdenum. Results of these spiked waters showed no major interferences by $FeSO_4$ with the molybdenum determinations. The uranium contents were measured by laser-induced fluorescence using a Scintrex, Model UA-3 Uranium Analyzer. Our detection limit for uranium was 0.0005 mg/L. Standard addition techniques were used to correct for any quenching, temperature, and matrix effects. No correction was greater than 15 percent. Molybdenum and uranium concentrations were periodically

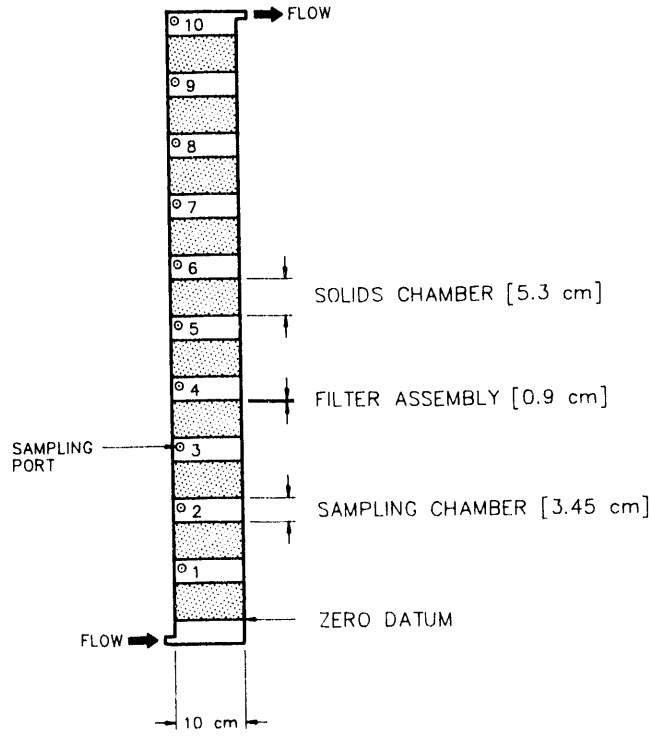


Fig. 2. Experimental column.

checked against Inductively Coupled Plasma Mass Spectrometry determinations and known standards. Our standard error for both uranium and molybdenum was about 10 percent.

RESULTS

Results of Batch Tests

Two series of batch tests were conducted to determine the minimum amounts of $FeSO_4$ or $Ca(OH)_2$ required to extract the contaminants. Each experiment within a series contained 200 milliliters (mL) of synthetic pore fluid (SPF-1) but a different amount of test material. The results for $Ca(OH)_2$ show that the uranium in 200 mL of SPF-1 was effectively extracted by a minimum of 0.15 grams (g) (0.75 g/L) and that the most efficient pH for uranium removal was about

TABLE I

Comparison of Synthetic Pore Fluids SPF-1 and SPF-2 With Pore Fluid Collected From Lysimeter LYS82-29[a]- (in milligrams per liter [mg/L]; ^{226}Ra in picocuries per liter [pCi/L])

Pore Fluid	Na	K	Ca	Mg	SO_4	Cl	Alk[b]	As	U	V	Mo	Pb	^{226}Ra	pH
LYS82-29	3529	23	340	64	6300	1000	1940	0.30	13	1.6	9.64	NA[c]	NA	7.5
SPF-1	3680	23	340	65	6300	1000	1902	1.00	30	1.6	8.89	2.0	20.0	7.8
SPF-2	3654	0	301	0	5920	1000	1902	2.00	30	0	8.89	0	0	7.8

[a]Pore Fluid collected from the Monticello Millsite East Pile on October 29, 1984
[b]Alkalinity is expressed as mg/L of $CaCO_3$.
[c]NA = not analyzed.

10.9 (Table II). Approximately 1.0 g of $FeSO_4$ per 200 mL of SPF-1 (5.0 g/L) was required to extract most of the molybdenum (Table III). The dissolution of $FeSO_4$ produced an acidic environment with an Eh of around 550 millivolts (mV).

TABLE II

Effect of $Ca(OH)_2$ on Extraction of U From 200 mL of SPF-1 (shake time = 75 hours; initial concentration: U = 30 mg/L)

Amount of $Ca(OH)_2$ (g)	Final pH	Final U (mg/L)
0.45	12.49	0.44
0.40	12.42	0.26
0.35	12.35	0.23
0.30	12.22	0.27
0.25	12.00	0.30
0.20	11.71	0.37
0.15	10.88	0.07
0.10	9.75	29.3

TABLE III

Effect of $FeSO_4$ on Extraction of Mo From 200 mL of SPF-1 (shake time = 167 hours; initial concentration: Mo = 8.89 mg/L)

Amount of $FeSO_4$ (g)	Final pH	Final Eh (mV)	Final Mo (mg/L)
10.00	2.38	592	< 0.05
5.00	2.52	549	< 0.05
0.98	3.42	491	< 0.05
0.12	7.01	404	2.85

Results of the Column Experiment

The spatial distributions of Eh, pH, uranium, and molybdenum in the column fluid for days 3, 4, 5, 8, and 10 are shown in Fig. 3. The days are determined from the day that contaminated fluid was first pumped into the bottom of the column. The column was not completely filled with water until the beginning of day 4. A front with low Eh values followed by high pH (12.5) values developed in the column. The pH and Eh values in the $FeSO_4$ sections (ports 1 through 5, Fig. 3) were never less than 6 or greater than 110 mV, respectively. Dissolved molybdenum decreased from the bottom to the top of the column. Dissolved uranium decreased slightly from the column bottom to the low Eh front where it dropped sharply.

The water turned yellow-orange upon contact with $FeSO_4$ due to ferric iron. The intensity of this color decreased as more water passed through the column. Dark green material developed above the contact of $FeSO_4$ and $Ca(OH)_2$. Within the solids chambers, this material formed distinct bands with sharp boundaries similar in appearance to roll fronts observed in uranium ore deposits. The green material formed columns and mats within the water chambers. Concurrent with the green material front was an extremely reduced environment (Eh as low as -336 mV; day 4, port 7).

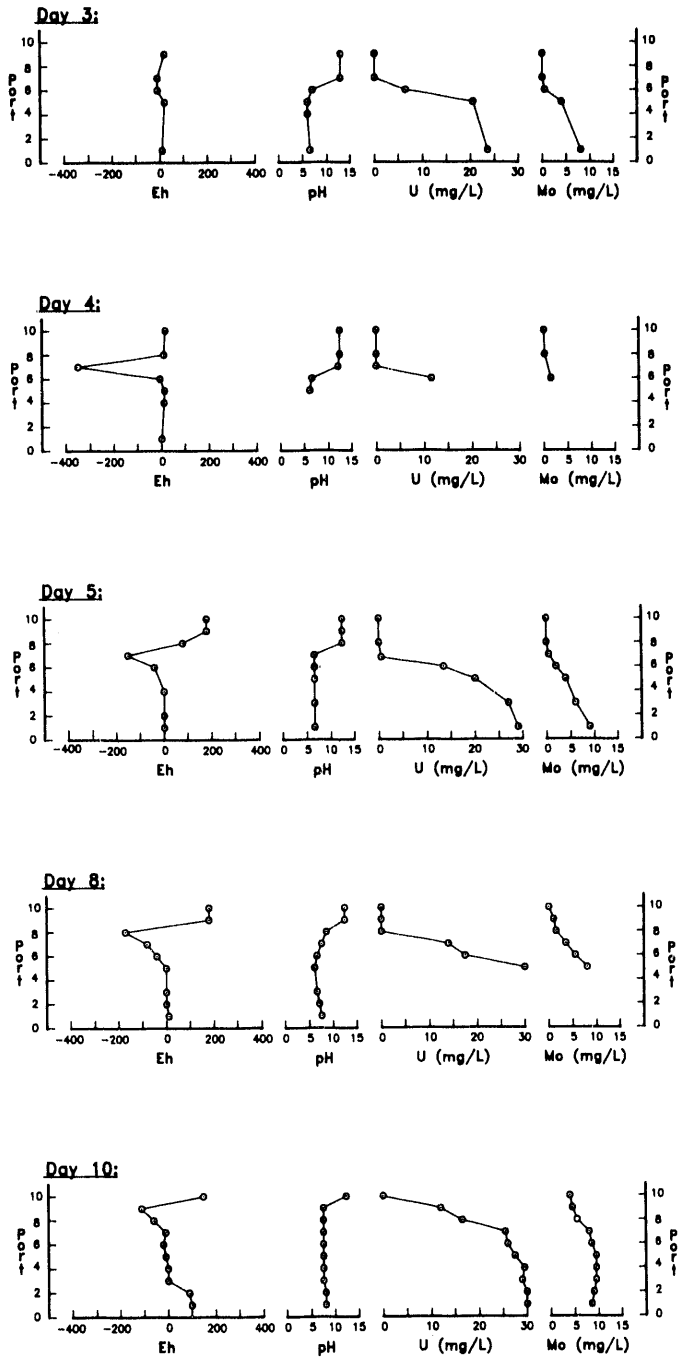


Fig. 3. Spatial-temporal distribution of Eh, pH, uranium in solution and molybdenum in solution.

Ahead of these fronts was a zone in which the pH increased from about 6 or 7 to 12.5 due to saturation with $Ca(OH)_2$. With time, the green material, Eh, and pH fronts moved up the column. The green bands, once formed, remained; no dissolution was observed.

Investigation following completion of the experiment revealed that upon exposure to the atmosphere, the green material immediately turned red. This material is X-ray amorphous. The material is similar to substances referred to as "green rust"(7).

The molybdenum and uranium contents at the top of the column (port 10) are shown in Fig. 4. Molybdenum was below our detection limit of 0.05 mg/L through day 6. The uranium content was below 0.020 mg/L through day 9. Approximately

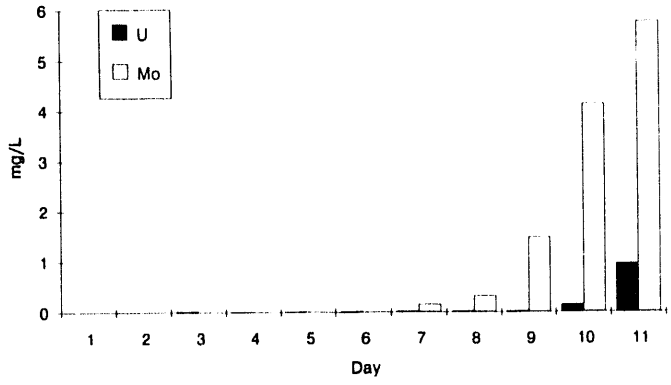


Fig. 4. Results obtained from port 10 (top of the column).

5 L and 8 L of contaminated fluid passed through the column by day 6 and 9, respectively.

DISCUSSION

Chemical Mechanisms

Mechanisms that can cause the extraction of uranium and molybdenum in the column include sorption, precipitation, and co-precipitation. Ferrous iron and $Ca(OH)_2$ are major components of the chemical system. Chemical gradients imposed by these major components determined the fate of Mo and U.

Iron (II) was released into solution by the dissolution of $FeSO_4$ in the lower portion of the column. A small amount of this Fe^{2+} was oxidized and precipitated as ferric oxyhydroxide, producing the reddish-orange coloration in the lower portion of the column. Dissolved Fe^{2+} migrated up the column and contacted $Ca(OH)_2$. The $Ca(OH)_2$ produced a front with a sharp rise in pH that caused ferrous hydroxide ($Fe(OH)_2$) to precipitate. The ferrous hydroxide formed the dark green mineralization described previously. Near the front, the Eh of the fluid was lowered as ferrous iron was oxidized to ferric iron. The $Ca(OH)_2$ layer continuously dissolved causing the high-pH front to migrate up the column with time. Layers of green ferrous hydroxide remained behind.

All Eh values measured in the column were higher than the stability field of $Fe(OH)_2$ (Fig. 5, point LE). However, the Eh at the front was probably lower than our measured values; we were unable to measure the Eh exactly at the redox front. A lower Eh environment than measured would allow for precipitation of the observed $Fe(OH)_2$. The Eh increase seen above the front is probably due to O_2 that had diffused from the top of the column or through the joints.

Redox potentials at or near the front were probably low enough for Mo to have precipitated as a reduced phase (for example, Mo_3O_8 or MoS_2). In support of this mechanism, there is a positive correlation between dissolved Mo concentrations and Eh (for example, ports 5, 6, 7, and 8 on day 8; Fig. 3). An alternative mechanism that could explain the Mo distribution is the precipitation of ferrous molybdate ($FeMoO_4$). Hem (8) has suggested the formation of ferrous molybdate to explain the abundance of Mo in some iron- rich natural waters. In Fig. 5, solubility contours for $FeMoO_4$ are superimposed on the stability fields for iron hydroxides. The data from day 5 shown on Fig. 5 show that the chemical conditions in the lower portion of the column (ports 1, 6 and 7) could cause $FeMoO_4$ precipitation and a substantial decrease in dissolved

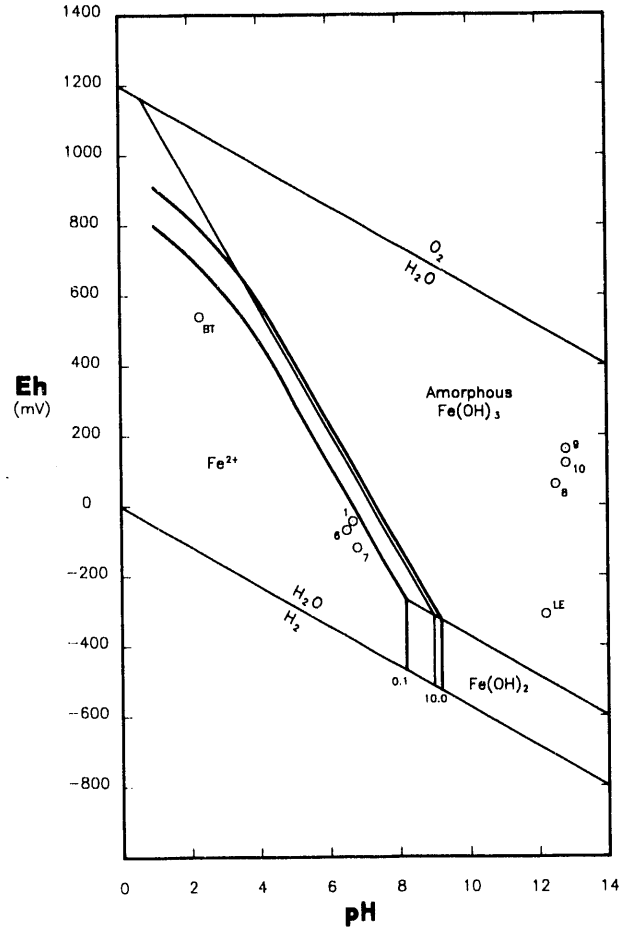


Fig. 5. Eh-pH diagram for iron hydroxide and ferrous molybdate. The thicker lines indicate Mo concentrations of 0.1 and 10.0 mg/L in equilibrium with $FeMoO_4$. Data from day 5 at column sampling ports 1,6,7,8,9, and 10 are shown. Point LE is the lowest Eh determination observed in the column. T = 25°C, P = 1 bar, total $Fe^{2+} = 1.0 \times 10^{-6}$ moles/L. No correction was made to activity coefficients for ionic strength.

Mo. Precipitation of $FeMoO_4$ ceases once the fluid contacts $Ca(OH)_2$ (ports 8, 9, and 10; Fig. 5).

The Eh-pH gradients associated with the chemical front were also responsible for the extraction of dissolved uranium. Low-solubility uranium solids would have precipitated in response to either the sharp decrease in Eh or the sharp increase in pH near the front. Many uranium (IV) solids have very low solubilities. Rai et al. (9) describe amorphous hydrated UO_2 solids that could limit uranium concentrations to about 0.003 mg/L in the neutral to high pH range. Batch experiments in our laboratory have shown that $Ca(OH)_2$ causes precipitation of a yellow uranium-bearing solid from uranyl nitrate solutions. Formation of this solid caused a decrease in dissolved uranium from 30.0 to as low as 0.070 mg/L. We presume that the precipitate is $CaUO_4$.

Data from Rai et al. (9) for amorphous UO_2 and from our preliminary determination of $CaUO_4$ solubility were used to construct an Eh-pH diagram (Fig. 6). Data from the lower part of the column (ports 1, 6, and 7) for day 5 suggest a trend of decreasing uranium concentrations due to the formation of amorphous UO_2. The further decrease in uranium concentration from port 7 (U = 0.756 mg/L) to port 8 (U = 0.010 mg/L) may be due to the precipitation of $CaUO_4$ (Fig. 6). These two precipitation mechanisms (caused by low Eh and high pH) are

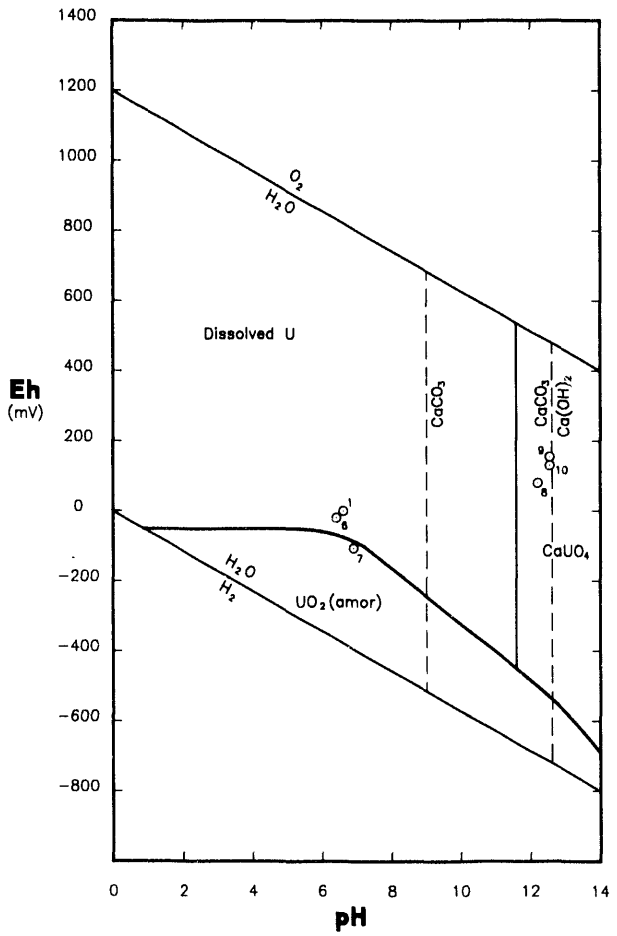


Fig. 6. Eh-pH diagram showing stability fields for Amorphous UO_2 and $CaUO_4$. The fields for calcite ($CaCO_3$) and portlandite ($Ca(OH)_2$) as shown for reference. T = 25°C, P = 1 bar, total dissolved Ca = 1.89×10^{-2} moles/L, total dissolved C = 1.0×10^{-5} moles/L, total dissolved U = 4.20×10^{-7} moles/L (0.1 mg/L). Data from day 5 for column sampling ports 1,6,7,8,9, and 10 are shown. No correction was made to activity coefficients for ionic strength and no reduced carbon species were considered. Log K for $CaUO_4$ (-24.9) was estimated from a single solubility experiment; Log K for amorphous UO_2 is from Rai et al. (1990).

controlled by the iron and lime systematics as discussed previously. Since they both occur at nearly the same location in the column, it was not possible to differentiate between them.

Although not apparent from the column data, batch tests indicated that acid is produced from reactions with $FeSO_4$ (Table III). Acidic water increases the dissolution rate of $Ca(OH)_2$ and, thus, increases the quantities of $Ca(OH)_2$ required for a barrier. The acid production is probably the result of oxidation to ferric compounds, for example:

$$4FeSO_4 + O_2 + 10\,H_2O = 4Fe(OH)_3 + 4SO_4\text{-}2 + 8H^+$$

Acid production in the column can be inferred from the rate of propagation of the $Ca(OH)_2$ dissolution front. Based on the solubility of $Ca(OH)_2$ in pH 7 water (1.6 grams per liter [g/L]), the dissolution front should have migrated to port 7 by day 10. The front, however, progressed to port 10 (Fig. 3), indicating that more than 1.6 mg/L had dissolved. The increased solubility is probably due to acid production in the $FeSO_4$ layers. Acid production (as expressed by low pH) was not observed apparently because most of the $FeSO_4$ had dissolved prior to our first measurements on day 3.

Economic Considerations

A chemical barrier for use at the Monticello uranium mill tailings repository must be functional throughout the period that transient water is draining from the repository at a relatively high rate. Transient water is defined as construction water (used for dust control during the 2-year construction period) and precipitation added prior to the construction of the repository cover. Given the current repository design criteria, transient water is likely to pose the most significant problem in meeting regulated contaminant release limits. Proposed regulatory groundwater limits for uranium and molybdenum at uranium mill tailings disposal sites are 30 pCi/L (0.043 mg/L assuming a natural isotopic abundance) and 0.10 mg/L, respectively (3). It is not necessary, however, for the chemical barrier to reduce concentrations to those low levels. Dilution by aquifers that underlie the barrier as well as the position of the regulated point-of-compliance must also be considered when evaluating the effectiveness of the chemical barrier.

The water composition at the top of the column (Fig. 4) can be used to gauge the overall effectiveness of the chemical barrier. The column was effective in controlling the transport of uranium and molybdenum for about 9 days (~ 8 L) and 6 days (~ 5 L), respectively. Since a total of 34.55 grams (g) of each active chemical was used, about 4.3 g of $Ca(OH)_2$ and 6.9 g of $FeSO_4$ were required to treat a liter of contaminated fluid. The amount of required $Ca(OH)_2$ is 5.8 times higher than in the batch tests while the required $FeSO_4$ is essentially the same. Acid, produced in the $FeSO_4$ layer, increased the dissolution rate of $Ca(OH)_2$.

The total amount of transient water is estimated at 527 million liters. In the absence of $FeSO_4$, the amount of $Ca(OH)_2$ required to effectively lower uranium concentrations is estimated as 0.75 g/L of pore fluid (Table II). Treatment of all the transient water requires about 395 metric tons of $Ca(OH)_2$. At a material price of $60 per metric ton, the total cost for $Ca(OH)_2$ is $24,000. In the column experiment, however, the production of acid by $FeSO_4$ increased the amount of required $Ca(OH)_2$ by about a factor of 5.8; thus, the cost for $Ca(OH)_2$ is about $140,000. The amount of $FeSO_4$ required to effectively lower molybdenum concentrations from both batch and column results is about 5 g/L of pore fluid (Table III). The total cost for the required $FeSO_4$ is approximately $800,000 ($295 per metric ton). The above costs do not include the cost of transportation and barrier construction.

The cost of $Ca(OH)_2$ for removing uranium is low. The cost to also remove molybdenum by this design is more expensive because of the cost of $FeSO_4$ and the additional $Ca(OH)_2$ required to counteract the acid produced by the $FeSO_4$. We are presently testing other materials that can remove molybdenum without the undesirable effect of acid production.

Other Considerations

Other considerations for this chemical barrier design that need to be evaluated include (1) the effect of high pH and high calcium concentrations produced by $Ca(OH)_2$, (2) the degeneration of $Ca(OH)_2$ by reactions with silicates to form calc silicates and with carbonate to form calcite, (3) the effect of chemical changes on permeability and mechanical strength, and (4) the oxidation of $FeSO_4$ to ferric oxyhydroxidies.

SUMMARY AND CONCLUSIONS

This paper presents an initial laboratory evaluation of a chemical barrier design for use beneath the Monticello uranium mill tailings repository. This design consists of a layer of $FeSO_4$ overlying a layer of $Ca(OH)_2$. Laboratory- scale column tests demonstrated that this design is effective for removing uranium and molybdenum. Uranium and molybdenum are the primary pollutants to the groundwater supplies in the vicinity of a uranium mill tailings repository. Use of a multiport column that allows sampling along the flow path permitted interpretation of the processes that remove the contaminants. A low redox front was formed by the oxidation of ferrous iron. This front was preserved due to precipitation of $Fe(OH)_2$ under the elevated pH conditions caused by $Ca(OH)_2$ dissolution. Strong chemical fronts produced by these and other chemical reactions hold promise for controlling contaminant migration by chemical manipulation of the subsurface environment.

Essential to accurate prediction of barrier performance is an understanding of the fundamental chemical reaction mechanisms that remove the contaminants. Further experiments are planned to understand and model these processes. A field demonstration consisting of a scaled-down repository will be conducted to determine if a large-scale chemical barrier performs similar to the laboratory-scale model. Economic and technical considerations suggest that materials other than $FeSO_4$ should be investigated for molybdenum extraction. We are presently evaluating other materials. Results are encouraging that an economical chemical barrier can be designed that will substantially reduce the risk of groundwater contamination.

ACKNOWLEDGEMENTS

This work was supported by the U.S. Department of Energy Office of Environmental Restoration and Waste Management at the Grand Junction Projects Office (GJPO) under DOE Contract No. DE-AC07-86ID12584; the Monticello Remedial Action Program; and the GJPO Exploratory, Research, and Development Program.

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THE GRAND JUNCTION, COLORADO, UMTRA PROGRAM: ENGINEERING DESIGN AND MANAGEMENT OF MORE THAN 4,000 REMEDIAL ACTION DESIGNS

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ABSTRACT

Uranium mill tailings from the Climax Mill in Grand Junction, Colorado, were available to the public during the 1950s and 1960s and were widely used as a sand substitute and as backfill material in more than 4,000 construction projects throughout the area. These later became known as "Vicinity Properties" and through the 1978 Uranium Mill Tailings Radiation Control Act were the U.S. Department of Energy's responsibility to clean up. This paper discusses the uniqueness of the project and the distinctive engineering management and engineering design approaches implemented to permit successful completion of more than 4,000 remedial action designs.

HISTORY OF THE URANIUM MILL TAILINGS REMEDIAL ACTION (UMTRA) PROGRAM

From the early 1940s, uranium ore from multiple sources in the United States was processed by private companies under contracts with the Manhattan Engineer District and the U.S. Atomic Energy Commission. As these uranium ore bodies were depleted and the demand for processed uranium decreased, many of the mills were deactivated. Large quantities of processed ore residue, or tailings, from the milling operations were left behind. These uranium tailings still contained much of the radium (a radioactive element) available in the raw ore and are a source of low-level radiation (1).

Uranium milling processes followed conventional metallurgical industry practices of the time. Tailings were deposited either in ponds or stockpiles (depending on the uranium extraction technique employed) adjacent to the mills and were allowed to dry. Some of these dried piles were unprotected and significant windblown losses occurred. Additionally, some tailings piles were accessible to the public for withdrawal and, in some locations, the tailings were used as a sand substitute or as backfill material in construction projects (1).

The Climax Mill in Grand Junction, Colorado, was one of these uranium ore processing sites. In the 1950s, Grand Junction was prospering from an uranium boom while the uranium mill tailing stockpiles at the Climax Mill were growing larger and larger. The Climax Mill decided to relieve their stockpiles by allowing the public free access to the stockpiles with the understanding that these piles contained only low-level amounts of radiation that were not thought to cause any detrimental health effects. The availability of this "free" material was an excellent way to lower building costs and local contractors took advantage of the opportunity during a period of increased construction and building activity. The tailings were used extensively in the construction of residences, schools, churches, hotels, hospitals, public land improvements, and commercial buildings in a variety of ways such as

- Sand substitute in concrete and mortar mixes.
- Bedding sand for utility lines and concrete structures.
- Backfill material inside and around foundations.
- Backfill to level sites and fill excavations and natural depressions.
- Sand substitute in children's sandboxes and to temper clay soils in gardens.
- Replacement where sandy material might be used.

By the late 1960s, medical research determined there were potential health hazards associated with uranium mill tailings, primarily from the potential inhalation of radium decay products (radon and its daughters). Transfer of tailings materials to properties with habitable structures was a primary concern. Consequently, the Colorado Department of Health mandated that public access to uranium mill tailing stockpiles cease.

Each identified property where tailings were used is referred to as a "Vicinity Property." Twenty-four sites in one eastern state and nine western states consist of more than 8,000 suspected vicinity properties that fall within the UMTRA Project; more than 6,900 of these vicinity properties are within the Grand Junction, Colorado, area.

In 1972, Congress passed Public Law 92314 to provide funds for a cooperative State and Federal program for the cleanup of structures located on selected vicinity properties in Grand Junction, Colorado (1), which was the Grand Junction Remedial Action Program (GJRAP). In November of 1978, Public Law 95604, the Uranium Mill Tailings Remediation Control Act was enacted with the Department of Energy as the responsible party (1). The UMTRA Program (also known as the Grand Junction Vicinity Properties Project) was to clean up additional structures and grounds of all remaining vicinity properties not covered by GJRAP.

FOCUS OF THIS PAPER

To achieve cleanup, each vicinity property progresses through a remedial action process that begins with inclusion in the UMTRA Program and ends with the property being certified clean as a completed remedial action project (see Fig. 1). After a property is recommended for inclusion by Oak Ridge National Laboratory (the Inclusion Survey Contractor) and approved for inclusion by the Department of Energy's Grand Junction Projects Office, a "cradle-to-grave" concept is invoked under the guidance of several Chem-Nuclear Geotech, Inc., Project Managers. (Chem-Nuclear Geotech, Inc., is the operating contractor for the Grand Junction Projects Office.) At the time of inclusion, each property is scheduled through the various stages of the remedial action process

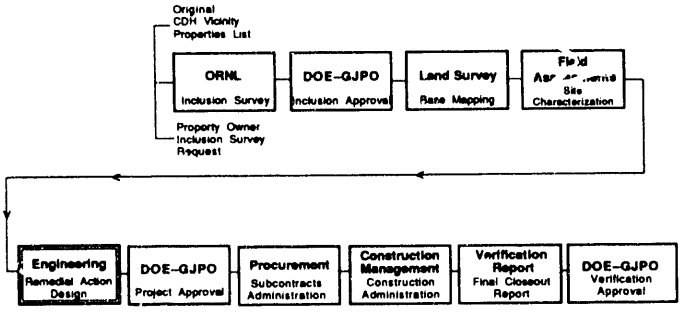


Fig. 1. UMTRA vicinity property remedial action process (cradle to grave).

to enable each functioning organization responsible for a portion of the process to plan future work loads. The Project Managers follow assigned properties through the process and facilitate timely completion by working with the functional organizations to solve problems that require resolution.

This paper focuses on engineering management, engineering design, and some of the Company interfaces that were necessary for the Engineering organization to produce more than 4,000 constructible remedial action designs within a production schedule that mandates completion of decontamination by June 30, 1993.

PARAMETERS OF UMTRA DESIGN

During the implementation of the UMTRA Program in Grand Junction, several parameters influenced the project structure and required consideration. Some of these parameters were apparent at the start of the project, while others materialized as the project progressed. Each parameter influenced the way business was conducted and included

- United Nuclear Corporation (UNC) Geotech took over the responsibility of the Grand Junction UMTRA Program from Bendix Field Engineering Corporation in October 1986 (UNC was sold to Chem-Nuclear Geotech, Inc. [Geotech], in July 1990). The core work force stayed with UNC during the transfer; however, the new management initiated substantial adjustments in the early stages of a project with an intensive schedule.
- Production was scheduled to increase from 39 to a peak of 913 remedial action designs per year as shown in Fig. 2. This effort meant the existing staff level needed to be increased significantly, considering the dramatic increase in production.
- The project comprised more than 4,000 individual properties with similarities but each needed scrutiny to determine property-specific characteristics.
- Geotech's contractual client, the Department of Energy (DOE), provided 90 percent of the UMTRA funding and, therefore, provided the primary project direction. However, the individual property owners also became "clients" in the sense there was a moral obligation to provide good serviceable engineering design even though the property owner would not pay for the project. A subtle conflict of interest existed in which the "payer" would not be the ultimate "user."
- The Colorado Department of Health (CDH) provided 10 percent of the UMTRA funding and, therefore, had to concur with the proposed remedial action. CDH also served as the UMTRA "watchdog," ensuring that each remedial action design adequately addressed the potential health concerns of the property owner.
- Engineering was only one part of the process. Design delays were not acceptable and would cause Company-wide schedule implications.
- The majority of the remedial action designs were not highly technical in nature; however, design personnel with technical expertise (engineers and architects) were needed so their knowledge could be used when required.
- The remedial action design approach and format had to be consistent to avoid confusion by users (DOE, Procurement, Construction Management, construction subcontractors, etc.).
- Many of the construction subcontractors, as required by DOE, were small business set asides. This resulted in small unsophisticated construction subcontractors who were not accustomed to building engineered designs according to detailed plans and specifications.
- Many property owners were not construction oriented and did not believe there was a health problem associated with uranium mill tailings.
- Many buildings requiring remediation were in such poor condition they had no value except to the property owners who would have to replace them.
- Many vicinity properties contained do-it-yourself home improvements that were code violations. Code violations within areas of tailings contamination would have to be fixed as required by the local building department prior to remedial action construction and, in some cases, could be very expensive fixes.
- Many property owners saw the UMTRA Program as a federally funded community betterment project and would try to incorporate their home improvement plans into the remedial action design.

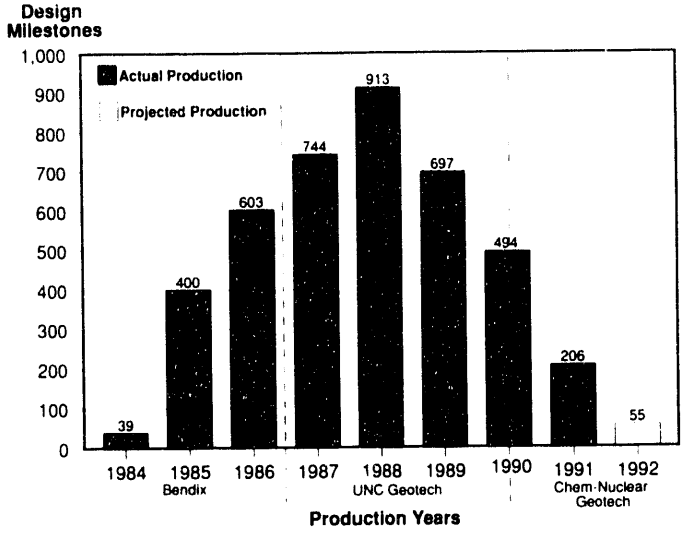


Fig. 2. Grand Junction UMTRA milestone production record by year.

APPROACHES TO UMTRA ENGINEERING MANAGEMENT

The Grand Junction UMTRA Program is primarily a dirt-moving job that generally does not require complicated treatment technologies or high-level technical design. The designs usually represent remodeling projects where surface improvements and the associated contamination beneath the surface improvements is removed with backhoes, skid loaders, and other small earth-moving equipment. The remaining excavation is backfilled with clean material and the surface improvements are restored to their original condition and location. This explanation represents the basic concept for 80 percent of the remedial action designs that have a heavy civil engineering component and involve primarily exterior contamination. The other 20 percent of the designs concern interior contamination that requires architectural and structural design expertise.

Because of the nature of the design work and the required production schedule, the UMTRA Program was more of a management problem than an engineering design problem. The efficient engineering management of these designs was crucial to the project; schedules of all functional organizations had to be coordinated to meet the overall project scope and not impact other organizations. The following sections describe management issues specific to the Engineering organization and the strategies used to deal with these issues.

Lack of Previous Remediation Experience

Prior to the UMTRA Project, the DOE had no actual experience with large-scale remediation projects. This meant that the required design formats and related documentation formats were not defined at the start of the project. Policies and procedures were not defined, and, in many cases, the need for these policies and procedures had not been identified. Regardless, production schedules were set and the work had to be done.

Design formats, policies, and procedures were in a constant state of evolutionthere was always a better and more efficient waywhich made the Engineering organization a dynamic environment. Just when a procedure was established, someone would identify a better method. The design staff had to be flexible and communication within the organization was crucial. Weekly meetings for the design staff were held to share information and conduct training sessions. Set agendas were available to the staff before each meeting and meetings had a 1-hour limit. The entire Engineering organization also had weekly meetings for dispersing information. These organizational meetings included the design staff as well as the office support staffall the personnel necessary to meet production goals.

Appropriate Personnel Staffing

The uniqueness of UMTRA required a flexible Engineering management team with foresight who could plan and adapt to the project's daily changes and implement the daily changes. Both technical and nontechnical personnel were necessary to complete the project. However, architects and engineers were appropriate for the design work . With the required production levels, design professionals with consulting experience proved to be the most valuable. Personnel with this experience were accustomed to meeting deadlines and staying on schedule to keep clients happy.

Maintenance of Design Staff Levels

An efficient design staff consists of design professionals with a variety of experienceranging from new graduates with no experience to personnel with professional licenses and many years of experience. In trying to obtain this proper mix, there was difficulty in keeping new graduates on board. The new graduates were not satisfied with the nontechnical designs given to them and wanted experience with technical designs that would develop their professional expertise. On the other hand, design professionals with several years of experience had more appreciation for the management challenges of the UMTRA Program and could, therefore, tolerate the nontechnical designs as long as there was an occasional technical challenge.

Monthly Milestone Requirements

To keep the entire UMTRA Program on schedule, monthly production goals or "milestones" were established for each organization. These goals and their associated costs were incorporated into the Company's validated Cost Schedule Control System (CS^2) and created a "contract" atmosphere within each organization to complete work within budget and set schedules. A specific number of designs had to be submitted to the DOE each month per the monthly milestone schedule. Ideally, the individual designs submitted were supposed to coincide with the Company's cradle-to-grave schedule for each specific property. However, monthly milestone requirements were heavy and a competitive spirit was present to the extent there was a lot of pride in not missing any monthly goals. When these conflicting goals met head to head, the monthly milestone goal always prevailed. It was more important to keep the flow of properties moving by performing the amount of work contracted for in CS^2 rather than worry about whether a specific property design was completed. The respect developed for CS^2 was a key component to keeping the project on schedule and within budget.

The nature of design requires that the detailed problems of the design be worked out one by one. Most of these problems are not always apparent at the onset of design and often take longer to resolve than expected. Additionally, UMTRA was a voluntary project and property owners could and would refuse to participate at any time. Because of these uncertain factors, it was necessary to overschedule by about 10 percent. Each month, 10 percent more properties than were actually needed to meet the requirements were assigned to the design staff. This allowed properties to "drop out" without being detrimental to the monthly project goals.

To meet the monthly goals, the design staff actually doing the work had to commit to a schedule. This was accomplished by distributing the properties and then asking the design staff to set specific schedules within parameters established by the manager. These schedules were recorded and managed to ensure that the staff fulfilled its commitment. The goal was to avoid completing and submitting all of the designs at the end of the month and to strive toward submitting an even flow of work to the DOE on a weekly basis. The nature of design makes this goal easier said than done because it is often difficult to predict how much time an actual design will take to complete.

Limited Time for Complex Designs

With 50 to 80 designs being processed per month, the need for consistent designs completed by a single design group had to be balanced with the reality of staffing up to provide that consistency. The design staff was highly capable of performing the more complex designs, but complex designs take more time and the old 80/20 rule came into play. It did not make sense to use 80 percent of the design staff to design 20 percent of the remedial actions nor did it make sense to more than double the design staff to handle 100 percent of the required designs. To provide the highest degree of design consistency, the simpler designs consisting of mostly exterior contamination were processed in house and designs requiring the removal of primarily interior contamination were subcontracted to local architecture/engineering(A/E) design firms. Several staff members were responsible for overseeing and monitoring the A/E design services to meet schedules.

Using AutoCAD as a Design Tool

Computerized drafting was well suited to the UMTRA Program because it allowed the electronic transfer of drawing information, generated by other organizations such as Land Survey and Field Assessments, to Engineering for incorporation into the design drawings thereby eliminating the need to redraw information. It also took advantage of the similarities and repetition that carried over between the individual designs and eliminated unnecessary redrawing of information used more than once. Not using computerized drafting would have made it difficult to handle the amount of drafting work that was required without employing additional drafting personnel. The UMTRA Program started using computer-aided drafting and design (CADD) in 1985 when CADD was relatively new to the industry and there were few trained CADD operators. Experienced CADD operators with production experience were virtually non-existent. All aspects of using the system, from operation to management, were on a steep learning curve.

One of the primary questions was whether CADD should serve only as an expensive drafting tool or could it be used more efficiently as a design tool. Use as a design tool would eliminate some of the iterations of rough sketches and redlines that usually pass between a designer and a drafter and the associated interpretation problems associated with those iterations. A semester CADD training program was set up in conjunction with Mesa State College (in Grand Junction) to train design engineers and architects. College-level training was chosen because of its cost effectiveness and the belief that slow training over a longer duration results in higher retention levels and provides a greater depth of knowledge than the typical training seminars that condense everything into 3 or 4 days. The training was not specifically tailored to the needs of the UMTRA Program but instead provided general CADD user training that avoided user "tunnel vision" and promoted exploration of the numerous possibilities of the CADD software.

Need for Design Consistency

With the volume of designs being produced every month, there was a need to funnel the designs through a central focal point to maintain consistency and present the client, DOE, and the other downstream design users similarities in format, presentation, and design approaches. The individuality of the design professionals responsible for the technical aspects of the designs and the sheer volume of material being produced did not provide the consistent critiquing necessary to satisfy the downstream users of the "product."

A group within Engineering, referred to as Technical Coordinators, provided this consistency. This group did not have technical design expertise but supplied a valuable editing service to polish the final product and help avoid embarrassing situations that could have resulted from minor errors and omissions. The Technical Coordinators also provided a secondary benefit that ensured designs were understandable. If the Technical Coordinators did not understand a design, there was a high degree of probability the design would not be understandable to others who would ultimately implement or examine it. In addition to editing services, the Technical Coordinators handled many design-related nontechnical tasks that allowed the designers to focus on design.

Incorporation of Construction Experience into Designs

The Construction Management organization contributed valuable experience into the design loop. Design professionals are often oblivious to the type of construction details that are important to personnel in the field and that make a design more constructible. A system of complexity indexing was developed to assign each property a complexity code at the start of the design process. The complexity code indicated the degree of involvement required to complete remedial action. For example, a property with interior contamination was more complex than a property with only exterior contamination beneath a concrete driveway, which was more complex than a property with only exterior contamination in areas containing no surface improvements. It was decided that only the more complex designs involving interior contamination would benefit from this construction feedback. These complex designs were scheduled for constructibility reviews with Construction Management at the completion of design and before submittal to the DOE. In addition, Construction Management representatives also accompanied Engineering representatives on the initial site visit to these complex properties for familiarization with the property before design review.

Streamlining Paper Work

Each remedial action design has a certain amount of paper work that is assembled and submitted with the final design to DOE. Assembling this paper work was initially a cumbersome and laborious task that detracted from design activities. Eventually, this paper work evolved into a series of boilerplate forms that permitted the designer to essentially fill in a few blanks, give the form to a word processor, and receive a completed document ready for submittal. These boilerplate forms had enough flexibility to communicate important issues of the design to DOE.

Tracking the Status of Design Package Accumulation and Reviews

Each design goes through a review process where miscellaneous pieces of paper work are accumulated before final submittal to the DOE. Keeping track of the status of this review can be confusing with so many pieces of information being processed each month. An origination form was developed and attached to the design package when the design was

initialized. This origination form travels with the package throughout the design process. As each part of the process is completed, the person responsible for each stage indicates completion by initialing the form. This method documents each stage of the process and allows a quick assessment of the work remaining before the design package can be submitted.

Issues That Delay Design

During the design process, many issues emerge that are beyond the control of the design staff and require assistance from other organizations within the Company or require DOE participation for functions that the Company is not contractually allowed to perform. These issues often delay design completion for months, necessitating that other properties be substituted to maintain production levels. Examples of issues that the UMTRA Program has experienced include

- Out-of-code situations that require correction by the owner prior to remedial action.
- Determination of adequate owner compensation for businesses that have to be shut down during remedial action.
- The need to further investigate and characterize tailings that appear to be mixed with hazardous wastes.
- The need to further investigate and characterize asbestos areas that might be disturbed during remedial action.
- Determination of how leaking underground storage tanks would be handled and the liabilities of respective owners.
- Strong property owner design preferences that conflict with the intent of the UMTRA Program.

To solve these miscellaneous issues, an issue resolution team was established to meet on a weekly basis. The team consists of representatives from several of the key functional organizations responsible for resolving specific problems as they occur. These representatives have the authority to determine an appropriate course of action and implement that action. Identified problems are given to the team and entered into a data base for tracking. Weekly, the team reviews each issue property, assigns action items and associated completion dates, and records the weekly progress of each issue resolution. A summary of the resolved issues is maintained for monitoring purposes.

Construction Management Support During Construction

Design changes and other Engineering support are required elements of ongoing construction activities. Balancing requests for support from Construction Management is difficult when such a high priority is placed on maintaining design production schedules. A form was developed to formally request additional Engineering services and ensure that Construction Management receives adequate support to avoid costly construction delays. The request form documents the request and when the service is needed. This request is logged into a tracking system and assigned to a design professional for completion. The tracking system can be accessed to ensure that all requests are fulfilled.

APPROACHES TO UMTRA ENGINEERING DESIGN ISSUES

Many issues affect engineering design more directly and were tailored to meet the needs of the UMTRA Program. Some of these issues and the approaches used in dealing with them follow.

Construction Specifications

General practice in the engineering and architectural industries is to have a unique set of construction specifications for each set of design drawings. The logistics of producing a unique set of specifications for each remedial action in the UMTRA Program was overwhelming. Because each remedial action had similar components, it was possible to develop a general set of specifications that applied to the majority of the designs. These general specifications covered a broad range of conditions that were continually required in multiple designs. The construction subcontracts were constructed to permit application of only those items in the general specifications that were applicable to the specific remedial action; nonapplicable specifications were to be ignored. Writing a generic specification to cover a broad range of conditions can be difficult and can result in a conservative specification. However, the construction subcontracts were set up so that the drawings could override any conditions in the specifications if necessary. Supplemental specifications were written if the general specifications did not adequately cover a situation. Use of general specifications eliminated the need to write and submit individual specifications to DOE for each remedial action design and ultimately resulted in the construction subcontractors only needing one set of general specifications for all UMTRA field construction projects.

Engineering Cost Estimates

Each remedial action design requires an engineering cost estimate. Because many components of every remedial action are similar, a boilerplate format was created using a Lotus™ 1-2-3 spreadsheet for all engineering cost estimates. The spreadsheet design provides DOE with identifiable costs for contiguous areas within the remedial action design package and summarizes the quantities of contaminated material removed. The boilerplate format was designed for flexibility to incorporate unique costs associated with a specific project.

Design Accuracy

In any remodeling project it is difficult to know exactly what the subsurface conditions are without X-ray vision. A balance must be made between the cost of subsurface investigation during the engineering stage versus the cost of construction change orders that result from inaccurate educated guesses about the expected conditions. Regardless of the amount of subsurface investigation, there is still a chance that surprises will occur during construction. As-built drawings did not exist for contamination locations and as-built construction drawings usually were available only for commercial buildings. These conditions resulted in a 90 percent probability that some aspect of the design would be inaccurate, whether it was the calculated quantities of contamination to be removed or an inaccurate educated guess about a building's construction. These inaccuracies could not be eliminated but were mitigated by careful management. Historical research was conducted on larger properties to determine

where and how tailings were used on the property. Probing questions were asked of the property owners for smaller properties to elicit any information that could be incorporated into the design.

Skeptical Property Owners and Their Remodeling Wishes

Each designer of a remedial action on a specific property always has a one-on-one contact with the property owner during a site visit to assess field conditions and owner preferences that might affect the design. Many owners are skeptical of the UMTRA Program and air their feelings to any and all Geotech employees. A designer uses all of his public relation skills in dealing with a property owner to obtain the necessary design information without jeopardizing the production schedule. This is not always possible and delays requiring substitution of another property occur.

Many property owners skeptical of the value of the UMTRA Program become less skeptical if they can see an opportunity to remodel or improve their property. The mission of UMTRA is to remove radioactive contaminated mill tailings *not* to improve properties. However, within certain guidelines it is possible to satisfy the goals of both the DOE and the property owner. Generally, if the property owner wants to make improvements within a contaminated area and the requested improvements do not cost more than restoring the property to its original condition, the requested improvements are incorporated into the design. Many owners are satisfied with these guidelines but some situations involve more serious negotiations requiring substantial DOE input and often delay design completion for months.

Negotiated Interpretations of Building Code Requirements

Initially, the local building department strictly interpreted the requirements of the building code and viewed the UMTRA Program as an opportunity to finally rectify many pre-existing code violations that were either unknown but suspected by the building department or were known but politically unenforceable because of the financial burden on the property owner if correction was required. In many cases, the remedial action could have proceeded by working around the code violation without jeopardizing the safety of the workers and without spending substantial amounts of money to correct the violations at government expense. A series of interface meetings between Geotech and the local building department, combined with time, eventually softened the building department's initial position. More flexibility was allowed in meeting the intent of the code rather than strict interpretation of the code. Remediation was allowed to proceed with the proper permits in place as long as the situation was not worsened and with the understanding that after remediation was complete, the building department would take appropriate action with the property owner regarding correction of the code violation.

CONSIDERATIONS FOR FUTURE REMEDIAL ACTION PROJECTS

As the UMTRA Program reaches its final stages, it is recognized that there is still room for improvement, but it is also recognized that the project will be effectively completed within the allowable time and budget. Several items that future remedial action contractors might consider as they plan a remedial action project are

- Aggressively deal with issues that hinder design completion at the start of the program rather than waiting until the resolution of the issues becomes critical to completion schedules. When there is so much readily available work, problems tend to be addressed later. Simple problems often become critical problems through procrastination.
- Integrate individual organization micro-scheduling sub-systems into the Company-wide scheduling system to ensure that everyone is working with the same information and to eliminate surprises. This integration also eliminates the unnecessary effort of cross-checking different systems to verify information.
- Establish project production accounting so that an organization still has monthly production requirements but does not receive credit until the next critical phase downstream of that organization is completed. The process of delaying credit facilitates a stronger team effort, promotes assisting other organizations, and encourages involvement with a project until completion.

CONCLUSION

The U.S. Department of Energy Grand Junction Projects Office Engineering organization has successfully completed 4,095 of an expected 4,150 designs for remedial action of uranium mill tailings contamination; 3,908 of these designs have been constructed. The Grand Junction Projects Office and Chem-Nuclear Geotech are extremely proud to be on the verge of completing one of the largest environmental remediation projects every attempted in the country.

ACKNOWLEDGMENT

This work was supported by the U.S. Department of Energy Office of Environmental Restoration and Waste Management under DOE Contract No. DEAC0786ID12584.

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ARCHITECTURE AND ENVIRONMENTAL RESTORATION: REMEDIATING URANIUM MILL TAILINGS FROM BUILDINGS

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ABSTRACT

The U.S. Department of Energy (DOE) Grand Junction Projects Office (GJPO) manages the Uranium Mill Tailings Remedial Action (UMTRA) Program in Grand Junction, Colorado. This program is a congressionally mandated clean up of by-product waste that resulted from the extraction of yellow cake from uranium ore. The by-product waste, a fine sand commonly called "mill tailings," is contaminated with low-level radioactivity. These mill tailings were available to the community for use as construction material from approximately 1952 to 1966; their use as bedding material for concrete slabs, utilities, backfill materials, concrete sand, and mortar created unique remediation problems that required innovative solutions.

This paper describes how design personnel approach the remediation of structures, the evaluation of the buildings, and the factors that must be considered in completing the remediation design. This paper will not address the health risks of the tailings in an inhabited space, the remediation of exterior areas, or the process of determining where the tailings exist in the building.

BUILDING REMEDIATION BASICS

The GJPO UMTRA Program comprises 4,150 identified residential, commercial, and industrial properties. Approximately 25 percent of these properties have mill tailings in or under buildings. The remediation design process begins when the radiological department of Chem-Nuclear Geotech, Inc., (Geotech), the remedial action contractor for the DOE/GJPO, provides the engineering department with documentation on the location of the mill tailings within the building. Because of the physical characteristics of the mill tailings sand, usually the tailings are located under the concrete floor slab, but it is not unusual to find the tailings in crawl spaces, in the concrete of building foundations and structural members, in the mortar of structural and non-structural brick, rock veneers, masonry fireplaces, or as utility line bedding material.

The two basic problems with mill tailings within buildings are gamma emissions and radon gas. The approach to remediation design is influenced by which problem is present, or if both problems are present. Gamma emissions in excess of acceptable limits are remediated by removing the source material (mill tailings). The radon gas is remediated by removing the source or venting the structure.

INITIAL BUILDING EVALUATION

Once the radiologically contaminated areas are identified in documents, an initial site visit is scheduled by Geotech personnel with the property owner. During this visit, the property and the structure are thoroughly evaluated based on the following information.

- *The history of the structure.* The date the structure was built will indicate construction materials and methods, such as plaster or gypsum drywall finishes. Also, any building initially constructed prior to 1953 or built after 1966 typically will not have tailings under the major structural components, but there are exceptions to this rule-of-thumb. Remodels and utility upgrades have resulted in mill tailings in pre-1950s buildings.
- *Previous uses of the structure.* Because of the Grand Junction area's boom and bust cycles, buildings have the possibility of major use changes. Buildings that were originally gas stations, but are now convenience stores, are especially prevalent. This also indicates the possibility of petroleum or hazardous wastes in the area. Industrial buildings also have questionable previous use histories.
- *Locations and extents of remodels.* Vastly different construction practices between remodeled areas are the norm; sometimes only one remodeled area is contaminated while the rest of the building is not.
- *Building construction practices.* Double-wythe brick load-bearing walls were typically used for commercial construction during the time of mill tailings involvement. If the mortar is contaminated, determining whether the wall is load bearing or merely a brick veneer is a major concern in the remediation design, because a double-wythe wall requires roof shoring to replace it. Some smaller commercial metal buildings were not built with structural steel reinforcing tie bars in the slab; some do not have steel reinforcement in the slab at all, requiring additional reinforcement when the concrete floor is saw cut and replaced.
- *Building materials.* During the time of mill tailings availability, asbestos products were a common building material. Identification of asbestos materials is paramount in the areas to be remediated. Vinyl asbestos tile is common, and asbestos-contaminated pipe insulation, building siding, transite pipe, and heating system joint compounds are also routinely encountered.
- *Code Violations.* All apparent code violations are noted. If the structures were built to existing codes in the 1950s and 1960s, some of those codes are outdated. Three-wire electrical systems are required now, but two-wire installations are commonly found. Because many structures were built or remodeled by

the owner without building department oversight, these structures may have sagging floors and roof joists, improper electrical and mechanical systems, substandard or non-existing foundations, or general structural deterioration that renders the building unsafe for major structural removal and replacement.

- *Unsafe conditions for remediation.* Unsafe conditions are a top priority to note and design for safe remediation. Confined crawl space access, emergency egress, live electrical wires hanging at head height or lying in the grass, crawl space furnaces without combustion air, buildings that pose an immediate threat to anyone entering, basic biological threats like leaking sewer pipes or trash of questionable content are all possibilities to be addressed. It is not uncommon to find open gasoline containers or other volatile fluids in closed garages. Even gas tanks under commercial interior floor slabs have been encountered.

DETERMINATION OF DESIGN CRITERIA

When the building evaluation is complete, the analysis of remediation options begins. Projects that have high gamma emissions are designed for removal of the source. The building systems that must be disturbed or removed to gain access to the source are analyzed.

Projects with high radon gas concentrations are analyzed for source removal or venting the gases to the exterior. Source removal is the preferred option in the UMTRA program, although complexity and cost on some projects direct the design towards venting. Some projects combine both options if total source removal is not reasonable.

The building evaluation also determines which design option is chosen: removal or venting. Some building components cannot be removed efficiently and safely. Contaminated concrete foundations are the main component that may remain if the building has high levels of radon gas but acceptable levels of gamma emissions. In this situation, radon gas is lowered to acceptable levels by designing the most reasonable radon venting system.

The cost of remediation is a design consideration. The decision to leave the contaminated foundation and install a venting system is based on estimated construction cost versus probability of success. Durability of the venting system is also a consideration in the design criteria. All installed radon venting systems are passive because they do not use an electric motor-driven fan to assist venting. Designs consider prevailing wind direction and the slight negative pressure created by a wind turbine. This eliminates the replacement of electric motors every couple of years, a cost the owner would have to assume when the UMTRA program is completed.

REMEDIATION DESIGN

Buildings that contain unacceptable levels of gamma-emitting tailings have only one design option: removal of the source. Other solutions such as shielding of inhabitants from the source, or justification and application for supplemental standards are unacceptable to the program because the programmatic regulations require permanent remediation of radiological hazards and health risks.

If tailings were used for backfill under the concrete floor slab, the process is to (1) vacate the building through relocation, phase-out, or shut-down of the business, (2) remove remaining items to storage, and (3) remove the floor slab. The walls are shored in place on steel jacks, as are other items which would be costly to remove, such as boilers and water holding tanks. The mill tailings are removed and new backfill is placed along with a new concrete floor slab. After concrete curing, the finishes are replaced, owner items are returned, and the owners are relocated into the remediated building.

If foundation walls are contaminated beyond the acceptable gamma emissions limit, a determination is made on which option is less expensive: replacing the foundation, or a fair-market buyout and demolition of the building. If foundation replacement is the preferred option, the building is supported while the foundation is excavated, removed, formed, and replaced. The structure may or may not be moved off the foundation, depending on the utilities and condition of the structure.

Contaminated structural columns and fireplaces are treated similarly. Some structural columns contain contaminated concrete. In other cases, steel pipe contaminated during mill processing was used as structural steel supports inside houses. These supports are removed and replaced with wood or new steel columns, depending on the column loading and esthetics. Fireplaces and stone veneer floors, especially those constructed from random rock or flagstone, pose aesthetic problems and owner concerns. Thirty years ago there was an established masonry work force in the valley; labor was inexpensive and materials were readily available. Many of these fireplaces, floors and veneers were skillfully constructed and beautifully pieced together. Many owners do not want to lose the character and visual effects (much less the resale value) of this type of construction. In such cases the veneer is mapped, dismantled, cleaned of contaminated mortar, and rebuilt using the existing rock and pattern.

RADON VENTING SYSTEMS

The radon gas problem is unique to the UMTRA program, because it is caused by a source introduced into the living environment in the form of tailings used as building materials. Simple removal of the tailings is usually the cure for the radon problem. However, at times, all the mill tailings cannot be removed, or there is a pathway for exterior radon gas to migrate into the structure through sewer or water lines. The Grand Valley also has large deposits of Mancos shale, which is a radon gas emitter. Radon gas mitigation design usually follows four scenarios.

1. Replaced concrete slabs have a subslab perforated Polyvinyl Chloride (PVC) radon venting system installed. This system is much like a French drain, but is located on the interior perimeter of the slab. A PVC riser is connected to the subslab system, extended through the living space, and terminated above the roof with a wind turbine. This system creates a slight negative pressure in the subslab venting system that becomes a receptor for the radon gas.
2. The design to remediate a contaminated basement wall in a habitable area may involve installation of a "plenum wall." A plenum wall consists of 3- inch perforated metal studs furred out against the contaminated wall; a plenum is created by wrapping the top and sides with 6-mil plastic, 1/2-inch plywood, and 1/2-inch gypsum board. This plenum creates an air space between the contaminated concrete wall, which is emitting radon

gas, and the living space. The plenum space is then connected to the subslab radon venting system with sheet metal or PVC mini ducts cast into the floor slab that allow the gas to enter the subslab venting system. The slight negative pressure in the plenum space then captures the radon gas.

3. A contaminated foundation stem wall in a crawl space has two possible remediation options. The first is insulating and ventilating the crawl space. All gaps in the floor between the crawl space and living space are caulked with foam and the habitable floor space is insulated from the crawl space side with batt insulation. Water pipes are wrapped with preformed rigid tubular insulation, and heating ducts are wrapped with rigid foam insulation. Rim joist vents are installed to provide massive air exchanges through the crawl space area. This design is intended to provide sufficient air exchanges to dilute and expel the radon gas from the crawl space before it enters into the living space. The design is complicated by various factors that may be part of the building, such as heating duct floor penetrations and crawl space furnaces. Designing proper cross ventilation with strategic placement of the rim joist vents is sometimes an impossible task on remodeled or expanded residences.
4. Installation of a stem-wall plenum is a second remediation option used if sufficient cross ventilation cannot be achieved or if the furnace cannot be effectively isolated. This plenum is similar to the basement foundation plenum wall but is constructed of dimensional lumber and foil- faced insulation board. Again, this design is intended to create an air space to capture the radon gas emitting from the contaminated stem wall, thus preventing the gas from entering the crawl space area. This design is labor intensive to install as the workmen must construct this plenum wall in the limited headroom of a crawl space, and usually around furnaces, pipes, ducts and other crawl space barriers. For this reason, a stem-wall plenum is considered only when insulation and ventilation is not reasonable.

CONCLUSION

Remediation of residential, industrial, or commercial buildings requires attention to the dynamics of the structure and its use. The people working or living in a building must be given consideration, because a remediation solution which is a hindrance to the inhabitants will be altered, dismantled, or unmaintained, leading to failure of the remedial action. With proper building evaluation, problem analysis, and thoughtful design solutions, successful remediation of structures is accomplished without creating a burden to those who live or work in the building.

ACKNOWLEDGEMENT

Work supported by the U.S. Department of Energy Office of Environmental Restoration and Waste Management at the Grand Junction Projects Office under DOE Contract No. DE-AC07-86ID12584.

IMPLEMENTATION PLANNING FOR REMEDIAL DESIGN AND REMEDIAL ACTION AT THE DEPARTMENT OF ENERGY'S MONTICELLO MILL TAILINGS NPL SITE

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ABSTRACT

The Monticello Mill Tailings Site (also known as the Monticello Remedial Action Project) is located in San Juan County, Utah, within the city of Monticello. Mill tailings and associated contaminated material remain on the millsite as a result of uranium and vanadium milling operations. The U.S. Department of Energy (DOE) is the responsible party with respect to site remediation. The Record of Decision for the Monticello Mill Tailings Site, completed on the September 20, 1990, requires the DOE to commence substantial, continuous physical on-site remedial action within 15 months of the completion of the Record of Decision. A plan was required to meet the 15-month start-up requirement in addition to the requirements for review by oversight agencies as stated in the Federal Facility Agreement for the site.

Development of a plan to meet project schedule objectives was conceived through a Value Engineering (VE) session. This session was designed to bring representatives from the involved agencies and their contractors together for a "team approach" to project planning. As a result of this effort, 48 key issues were identified as important to the development of the project. In addition, two approaches aimed at streamlining the remedial design effort were formulated at the session: the concept of regulatory agency reviews of working-level discussion documents and the phasing of remedial design/remedial action activities.

INTRODUCTION

The Monticello Mill Tailings Site (also known as the Monticello Remedial Action Project) is located in San Juan County, Utah, within the city of Monticello (Fig. 1). Mill tailings and associated contaminated material remain on the millsite as a result of uranium and vanadium milling operations. A Federal Facility Section 120 Agreement with the U.S. Environmental Protection Agency (EPA) and the State of Utah, pursuant to the Superfund Amendments and Reauthorization Act of 1986, became effective on February 24, 1989. As stated in the Agreement, the U.S. Department of Energy (DOE) is the responsible party with respect to present and past releases at the millsite. Responsibility for oversight of activities performed under the Federal Facility Agreement will be shared by the Environmental Protection Agency and the State of Utah. A Hazard Ranking System score for the millsite resulted in the inclusion of the Monticello Mill Tailings Site on the U.S. Environmental Protection Agency's National Priorities List (NPL) on November 16, 1989.

The Record of Decision for the Monticello Mill Tailings Site was completed on September 20, 1990. This action initiated the requirement of the Superfund Amendments and Reauthorization Act of 1986, Section 120, for Federal facilities to commence substantial, continuous physical on- site remedial action within 15 months of the completion of the Record of Decision.

The 15-month requirement made it necessary for the Department of Energy to develop a remedial design and to implement remedial action within the stipulated timeframe. This had to be accomplished within the framework of the Federal Facility Agreement that stipulated additional timeframes for review and approval of remedial design documents by the Environmental Protection Agency and the State of Utah prior to their implementation. It became imperative for the Department of Energy to develop a streamlined approach for project implementation to meet the 15-month requirement, in addition to the requirements of the Federal Facility Agreement.

This paper presents the process used by the Department of Energy to develop the plan that was implemented to meet the 15-month requirement and the implementation plan. The implementation plan had to meet the project objectives discussed in the following section.

Project Objectives

The Monticello Mill Tailings Site must meet the following project objectives for successful implementation:

- Develop a design for the remediation of the Monticello Mill Tailings Site that demonstrates compliance with applicable and relevant or appropriate requirements (ARARs) established in the Record of Decision,

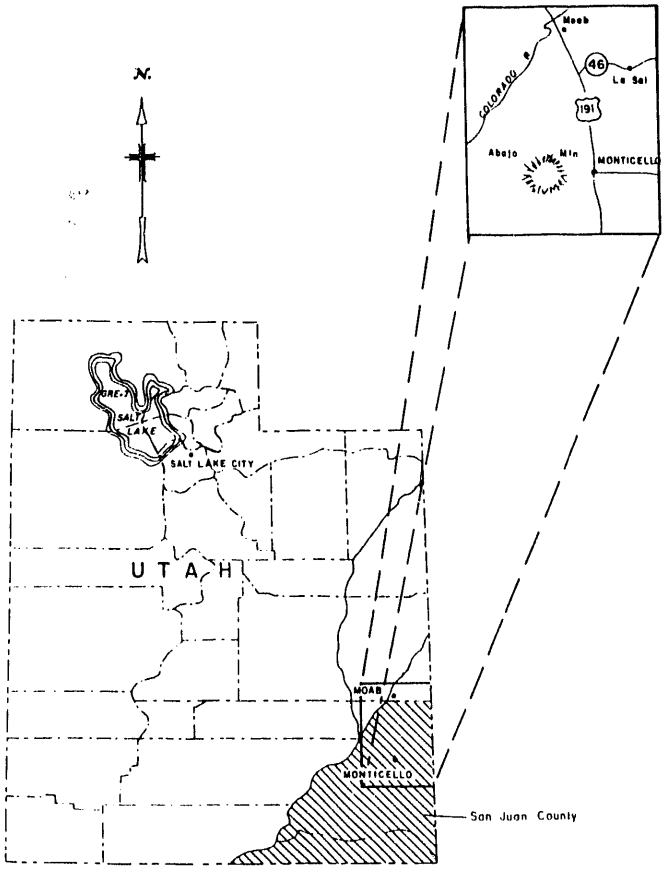


Fig. 1. Monticello, Utah, regional location map.

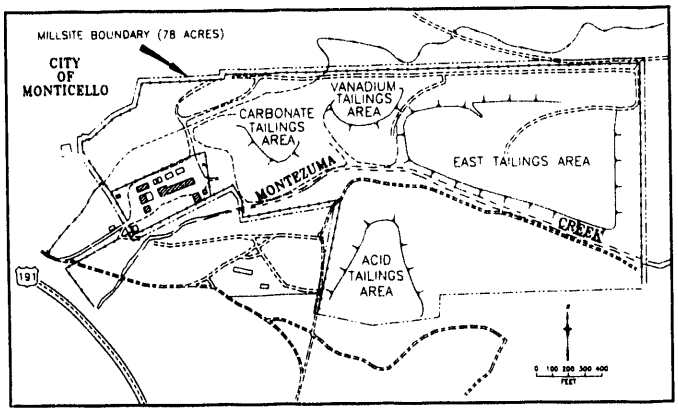


Fig. 2. Monticello millsite plan.

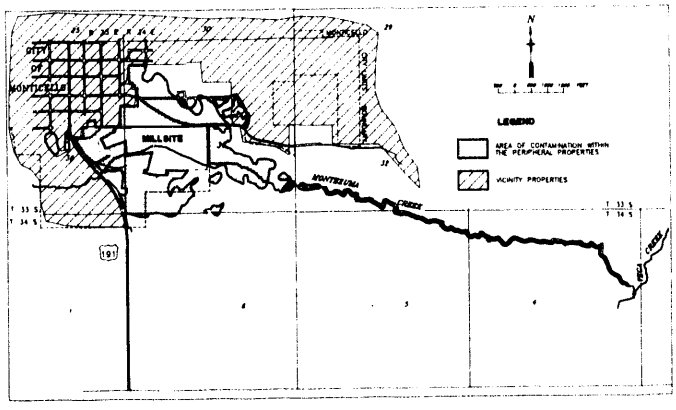


Fig. 3. Monticello vicinity properties and area of contamination within peripheral properties.

- Develop a schedule that allows for review and concurrence of the remedial design as required by the Federal Facility Agreement,
- Develop a plan for implementation of the remedial design that allows for the start of remedial action within the 15-month timeframe.

BACKGROUND

Project Scope

Remediation activities for the Monticello Mill Tailings Site require the removal of an estimated 1.9 million cubic yards of uranium and vanadium mill tailings to an on-site repository. Most of the tailings are contained in tailings piles on the millsite; however, tailings were transported by wind and surface water to properties peripheral to the millsite. The remedial action design will address the plan for removal of the tailings. This design must demonstrate that compliance with ARARs will be achieved.

Site Description

The Monticello Mill Tailings Site includes the millsite and peripheral properties. The Department of Energy owns the millsite, a 78-acre tract within the city of Monticello (see Fig. 2). An estimated 1.4 million cubic yards of mill tailings is present in the tailings piles, and an estimated additional 100,000 cubic yards of material is present on other areas of the millsite.

During the period of mill operation, private land to the north and south of the existing site was leased for the stockpiling of ore. The former ore-stockpile areas and areas contaminated by airborne-tailings particulate matter or surface-water-transported contaminants cover approximately 300 acres around the millsite and contain an estimated 300,000 cubic yards of peripheral property material that requires remediation (Fig. 3).

Additionally, an estimated 100,000 cubic yards of contamination exists on the Monticello Vicinity Properties (Fig. 3). This contamination consists of both airborne-tailings particulate matter and material used as fill or construction material on the properties. The Monticello Vicinity Properties Project was listed on the National Priorities List in 1986 and is being remediated pursuant to a Record of Decision dated September 1989.

The tailings piles are located within the floodplain of Montezuma Creek and are partially in contact with a shallow alluvial aquifer underlying the site. This alluvial aquifer is not presently used as a drinking-water source; however, it does have a potential for agricultural use. A deeper aquifer, known as the Burro Canyon aquifer, is a drinking-water supply. Analyses of samples from monitoring wells in the Burro Canyon aquifer show no evidence of contamination. Two aquitards, the Mancos Shale and part of the Dakota Sandstone, separate the Burro Canyon aquifer from the overlying alluvial aquifer under most of the millsite.

Montezuma Creek, which flows through the millsite, is a small perennial stream. Low-flow conditions prevail in the late summer, fall, and winter months. Within the project area, base flow in Montezuma Creek is maintained year-round by ground-water discharge from the alluvial aquifer and by releases from Monticello Reservoir, located approximately 1-mile upstream from the millsite.

Project Description and History

The Atomic Energy Commission bought the Monticello milling operation in 1948. Uranium milling commenced in September 1949 and continued until 1960, when the mill was permanently closed. Part of the land was transferred to the Bureau of Land Management; the balance of the site remained under the control of the Atomic Energy Commission and its successor agencies, the U.S. Energy Research and Development Administration and the Department of Energy. The land transferred to the Bureau of Land Management was recently returned to the Department of Energy.

In the summer of 1961, the Atomic Energy Commission began to regrade, stabilize, and vegetate the tailings piles. The plant was dismantled and excessed by the end of 1964. Some of the plant was buried on the millsite. Photographic evidence suggests that contaminated soil was used as fill material to partially bury the mill foundations.

The Department of Energy, under the authority of the Atomic Energy Act, initiated the Surplus Facility Management Program in 1978 to ensure safe caretaking and decommissioning of Government facilities. In 1980, the millsite was accepted into the Surplus Facility Management Program and the Monticello Remedial Action Project was established. In February 1989, the Federal Facility Agreement established that the activities at the Monticello Mill Tailings Site must comply with the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) of 1980, as amended by the Superfund Amendments and Reauthorization Act (SARA) of 1986. In February 1990, the Department of Energy completed the Remedial Investigation/Feasibility StudyEnvironmental Assessment for the millsite. The Monticello Mill Tailings Site Declaration for the Record of Decision was approved by all parties in September 1990, establishing the selected remedy.

Selected Remedy

The remedial work at the site is organized into the following three operable units (OUs) to facilitate remedial design and remedial action:

- Operable Unit I: Mill Tailings and Millsite Property
- Operable Unit II: Peripheral Properties
- Operable Unit III: Ground Water and Surface Water

A separate Record of Decision will be prepared for Operable Unit III because the remedy selected for remediation of ground water and surface water depends on the removal of contaminated material from the millsite and from the peripheral properties. The Record of Decision will be completed after the collection of additional surface- and groundwater monitoring data following tailings removal from the millsite and the peripheral properties.

The alternative selected for Operable Unit I involves excavation and removal of contaminated materials to an on-site repository located south of the existing millsite. Removal will be by conventional earthmoving equipment; transport of tailings and other materials will be entirely on site. The use of dust-control measures and access restrictions will protect public health and the environment during remedial action activities. To control runoff, diversion structures will be built and collected water will be treated as appropriate. Tailings disposal will occur on and contiguous to the existing millsite in a repository covered with a clay and multimedia cap. Design of the repository will comply with 40 CFR 192 ("Health and Environmental Protection Standards for Uranium and Thorium Mill Tailings") performance standards.

The alternative selected for Operable Unit II requires removal of tailings to meet the principal relevant and appropriate standard, 40 CFR 192. Contaminated materials will be transported to an interim storage area and then relocated with the millsite materials to the repository. Removal of contaminated materials will be either by conventional construction techniques or by environmentally sensitive removal techniques. The environmentally sensitive techniques, such as hand excavation or use of high-suction vacuum equipment, could be used in areas with mature dense vegetation that would require decades to re-establish the native tree species.

The remedial designs prepared for the selected remedies for Operable Units I and II must demonstrate compliance with ARARs identified in the Record of Decision.

DISCUSSION

Approach Used to Develop Plan for Meeting Project Objectives

Development of a plan to meet project objectives was conceived through a Value Engineering (VE) session. This session was designed to bring representatives from the involved agencies and their contractors together for a "team approach" to project planning. This facilitated session started with a "think tank" approach to identify the issues that needed to be addressed to design and implement the project. This allowed each team member to put individual concerns and concepts "on the table." As a result of this effort, 48 key issues were identified as important to the development of the project. These key issues were then ranked by the team according to how critical they were to project progress. In addition to identifying critical issues, this phase of the session served to establish a comparable level of understanding of the scope of the project for all team members.

Once the critical key issues were identified, the VE team worked to resolve the issues. Resolved issues included the need to phase the design and remedial action to meet schedule constraints and the use of "working-level discussion documents" as a mechanism for resolution of regulatory compliance issues. A commitment was made to prepare a Remedial Design Work Plan incorporating the team's concepts on project phasing and to identify the required design documents and their contents. In addition, the VE team made commitments to prepare working- level discussion documents addressing key regulatory issues.

Besides resolving the tangible issues, the VE session provided the mechanism for building a team approach to project planning. This team-building effort enhanced the ability to communicate between the involved team members, which included Government agencies and contractors.

Schedule for Remedial Design and Remedial Action

The schedule for remedial design and remedial action for the Monticello Mill Tailings Site is phased to meet the CERCLA Section 120 requirement for Federal facilities to initiate substantial continuous, physical on-site remedial action within 15 months after signing the ROD. In addition, the phase approach meets the Environmental Protection Agency's "bias for action" strategy advocated in Office of Solid

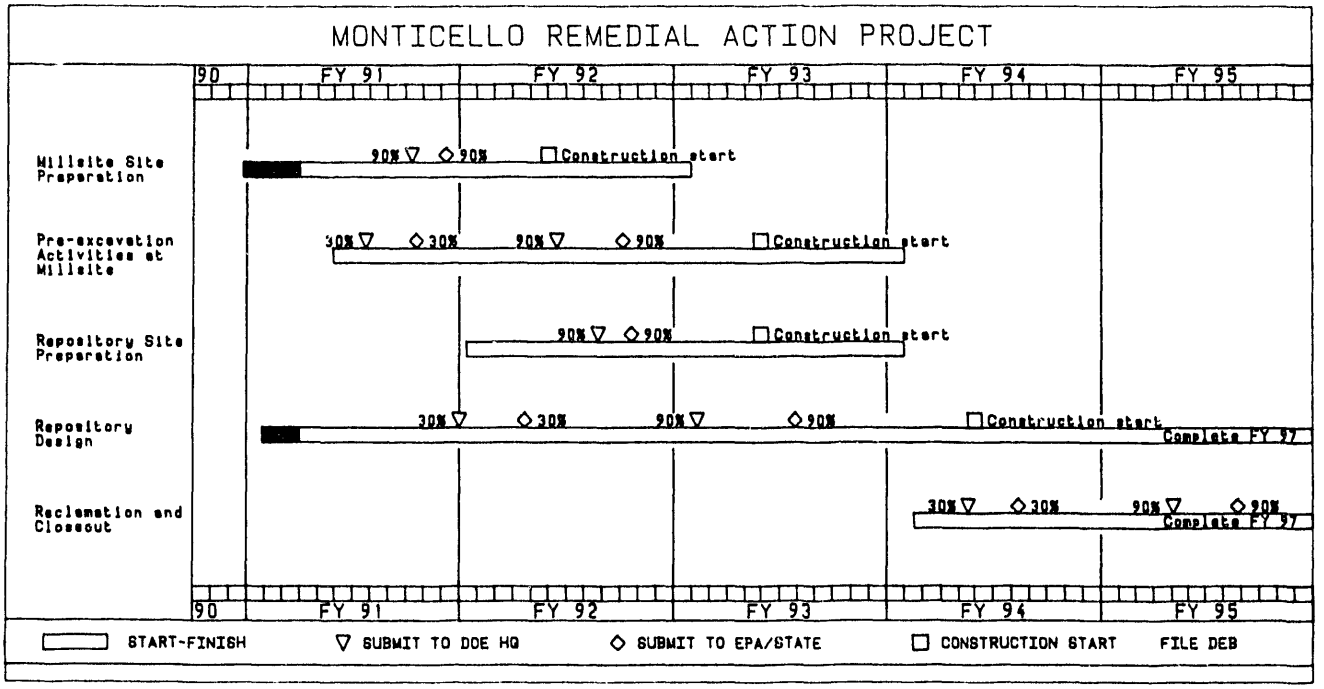


Fig. 4. Monticello remedial action project schedule.

Waste and Environmental Restoration Directive 9355.5-20, "Guidance on Expediting Remedial Design and Remedial Action." Operable Unit I of the project was divided into three general phases: Phase 1 Site Preparation, Phase 2 Removal of Tailings and Construction of the Disposal Site, and Phase 3Reclamation of the Millsite and Borrow Areas. Fig. 4 depicts the schedule for the three phases.

Phase 1 was further divided into three subphases: (1) Millsite Site Preparation, (2) Pre-Excavation Activities at the Millsite, and (3) Repository Site Preparation. Design of each subphase requires the preparation of 30 percent and 90 percent design documents. This level of phasing at the onset of the project allows for the preparation of focused design documents and for focused remedial action activities. Preparation of design documents for Phase 1 will require less time than Phases 2 and 3 documents because of less-complex engineering and regulatory compliance requirements. This phased approach allows for the implementation of remedial action within the required regulatory timeframes and is also a reasonable approach to construction.

Phase 2 requires the resolution of many significant regulatory requirements, particularly repository design. The preparation and review and approval of the 30 percent and 90 percent design documents for this phase are anticipated to require 2.5 years. If the design for all phases was one document, remedial action could not be implemented within the required regulatory timeframes. Design of Phase 3 activities was split out from the Phase 2 activities to reduce the scope of the Phase 2 design documents.

The schedule identifies the preparation time for design documents and the review-and-approval cycle. The need for an established review and approval process is critical to meet the remedial action schedule. The timeframes shown on the schedule for review, comment resolution, and final concurrence reflect the requirements of the Federal Facility Agreement for the Monticello Remedial Action Project.

The draft *Remedial Design Work Plan* for the Monticello Mill Tailings Site includes this schedule and describes the contents of the design documents. The Environmental Protection Agency and the State of Utah are currently reviewing the *Work Plan*. When the *Work Plan* receives final approval, commitments will be established for document preparation and submittal and for document review and approval to meet the objectives for project scheduling.

Working-Level Discussion Documents

The VE team identified many complex regulatory issues that are integral to the development of the Phase 2 design. The Department of Energy has prepared the following working-level discussion documents on each of these issues, providing the technical rationale for DOE's proposed compliance position:

- *Technical Approach for Designing the Monticello Repository Cover*
- *Ground Water Compliance Strategy for Engineering Design*
- *The Use of Engineering Controls in the Disposal of Low Level Radioactive Uranium Mill Tailings*
- *Point-of-Compliance for Ground-Water Monitoring at the Monticello RepositoryRegulatory Interpretation*
- *Compliance with Applicable or Relevant and Appropriate Requirements for Peripheral Properties*
- *The Level of Effort Used to Decontaminate Radiologically Contaminated Building Materials and Mill Equipment in the Remedial Design for the Monticello Mill Tailings Site*

Each document evaluates issues that required analysis of site-specific conditions, evaluation of regulatory requirements, and development of a specific position to achieve compliance. The documents were submitted to the Environmental Protection Agency and the State of Utah for review

and comment. Meetings were held to discuss the reports and to determine further actions necessary to assess compliance.

As a specific example of the use of these documents, the *Point-of-Compliance for Ground- Water Monitoring* document is discussed in further detail. The point-of-compliance (POC) is the location(s) at which a monitoring well(s) must be installed to determine if seepage from the repository has degraded ground-water quality. The requirements of the State of Utah regulations and the Federal regulations are different, and both are ARARs.

Determination of the POC is critical to the design of the repository. The design effort must assess changes in ground-water quality as a result of seepage from the repository. The design must demonstrate that changes in ground-water quality will not exceed established ground-water quality criteria at the POC. If this demonstration cannot be made, the design must be modified to provide for additional control of seepage.

An understanding of the geohydrologic setting is critical to the determination of the POC. The geohydrology of the proposed repository site is complex and determination of the location of monitoring wells is not straightforward.

The position presented in this working-level discussion document identifies DOE's interpretation of regulatory requirements as they pertain to the current understanding of site- specific conditions. However, uncertainties exist associated with the understanding of the site- specific conditions. Although 69 wells on 200-foot centers were installed on the proposed repository site, location of the POC cannot be agreed upon by the involved regulatory agencies and the Department of Energy.

The discussion document on the POC raised as many questions as it attempted to answer. However, it developed a starting point from which the involved agencies could work together to move forward on establishing the appropriate location(s) of the POC. On the basis of discussions between the Department of Energy, the Environmental Protection Agency, and the State of Utah, additional site characterization is being conducted to obtain the data necessary for the determination.

Discussion and resolution of issues through the use of discussion documents focuses the design process. Several directions can often be taken during design to meet design and compliance objectives. The direction that meets regulatory requirements often is not obvious and is subject to professional opinion. A team can use the working-level discussion documents as a mechanism to determine the direction of the design effort. This subsequently results in the preparation of a design that should meet regulatory requirements. Working-level discussion documents also facilitate the review process because the review agencies are familiar with the design issues.

CONCLUSIONS

The VE session is a productive tool in development of a project plan. It served to bring the involved Government agencies and their contractors together to identify issues significant to the progress of the project and to develop a plan for the resolution of those issues. This team approach also enhanced the communication process between the agencies and their contractors.

The planning approach developed during the VE session includes a phased schedule necessary to meet the requirement for substantial continuous physical on-site remedial action within 15 months. The schedule identifies focused remedial design packages that could be prepared and implemented within the required timeframe. In addition, the schedule specifies the dates for delivery of documents to the Environmental Protection Agency and the State of Utah and the time for review and approval of the designs. Success of the project depends not only on the submittal of the appropriate designs but also their review. The schedule and description of the contents of the documents to be delivered is included in the *Remedial Design Work Plan*. Final approval of the *Work Plan* will establish commitments for document preparation and submittal and for document review and approval.

The use of working-level discussion documents provides a method to focus discussions on regulatory compliance issues and their resolution prior to submittal of design documents. This resolution facilitates preparation of the designs and their review and approval.

ACKNOWLEDGEMENT

Work supported by the U.S. Department of Energy Office of Environmental Restoration and Waste Management at the Grand Junction Projects Office under DOE Contract No. DEAC0786ID12584.

COMPLETED REMEDIAL CLEANUP AT THE DURANGO, COLORADO URANIUM MILL TAILINGS REMEDIAL ACTION SITE: A CASE STUDY

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ABSTRACT

The uranium mill tailings site near Durango, Colorado, is one of twenty-four inactive uranium mill sites designated to be remediated by the U.S. Department of Energy (DOE) under the Uranium Mill Tailings Radiation Control Act of 1978 (UMTRCA). Remedial activities were conducted by the DOE for the long-term stabilization and control of the radioactive materials at the inactive uranium mill site. As required by the UMTRCA, remedial action at the Durango site had to comply with the regulations established by the Environmental Protection Agency (EPA).

The remedial action at the Durango Uranium Mill Tailings Remedial Action (UMTRA) site consolidated approximately 2,400,000 cubic yards of contaminated materials from the uranium mill site and vicinity properties into a single, partially below-grade, disposal cell located approximately 1.5 miles southwest of the mill site. Construction sequencing of contaminated material within the cell considered the concept of reducing radon flux below EPA's standards to levels as low as reasonable achievable. A compacted earthen radon barrier 2.0 feet thick was placed directly over the contaminated material. Additional cover components were sequentially placed above the primary earthen radon barrier to provide the required low hydraulic conductivity to reduce water infiltration and to provide long-term stability.

INTRODUCTION

In response to public concern over the potential public health effects associated with uranium mill tailings and the associated contaminated materials left abandoned or otherwise uncontrolled at inactive processing sites throughout the United States, Congress passed the Uranium Mill Tailings Radiation Control Act (UMTRCA) in 1978. In the UMTRCA, Congress acknowledged the potential health hazards associated with uranium mill tailings and identified 24 sites that were in need of remedial action. The Environmental Protection Agency (EPA) was charged with the responsibility for promulgating radiological and nonradiological standards for remedial action at inactive uranium mill sites. The final standards for inactive mill sites were promulgated by the EPA in 1983. The U. S. Department of Energy (DOE) was authorized to enter into cooperative agreements with affected states or Indian tribal governments to perform remedial actions to bring the radiation levels at sites under their jurisdiction within the EPA standards. The Nuclear Regulatory Commission (NRC) is to concur in the selection and performance of the remedial actions, and at the conclusion of the remedial action, will issue a license for the long-term surveillance of the disposal sites.

The principal hazard associated with the tailings results from the production of radon, a radioactive decay product of the radium contained in the tailings. Radon, a radioactive gas, can diffuse through the tailings and be released into the atmosphere, where it may be inhaled by humans. If the concentration of radon is high enough and the exposure time long enough, cancers may develop in persons living and working near the tailings. If the tailings are not properly stabilized, erosion or human removal of the contaminated materials could spread the contamination over a much wider area and increase the potential public health effects.

This paper reports on the remedial activities at the Durango, Colorado uranium mill site, as performed by the Uranium Mill Tailings Remedial Action (UMTRA) Project Office. The paper also identifies several lessons learned during the remedial action that are transferable to other remedial programs.

PROJECT BACKGROUND

The Durango site is a 126-acre property just southwest of the city limits of Durango, La Plata County, in southwest Colorado (Fig. 1). In general, the site is bordered on the east by the Animas River near the tailings piles and by U.S. Highways 160 and 550 near the raffinate ponds area, on the north by Lightner Creek, and on the southwest by Smelter Mountain. The processing site consisted of the mill site, two tailings piles and, about 0.5 mile to the south, the raffinate ponds areas.

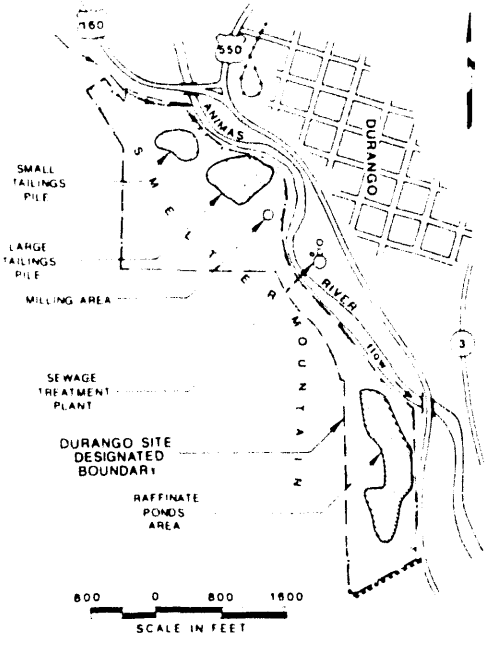


Fig. 1. Durango processing site, Colorado.

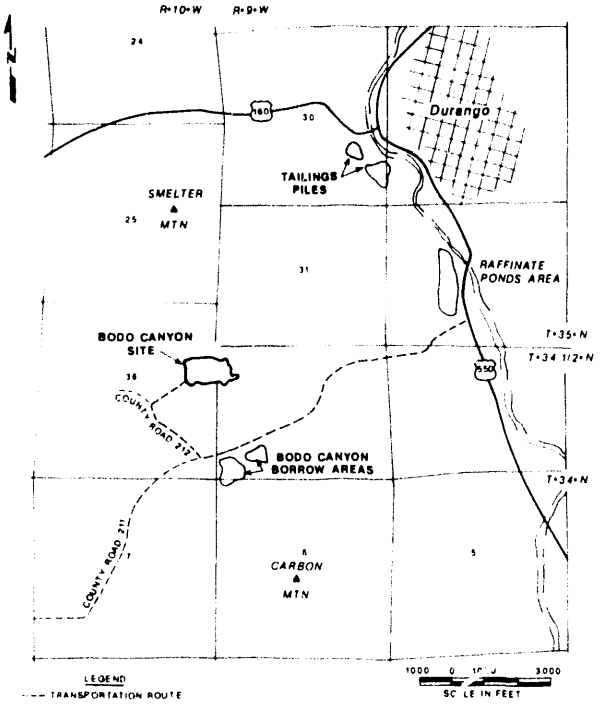


Fig. 2. Location of Bodo Canyon site, Colorado.

The former mill was built in 1942 on the site of an old lead smelter by the United States Vanadium Corporation (USV), a corporation established by the Federal government for the purchase of strategic materials needed during World War II. In 1943, USV began reprocessing vanadium tailings for the recovery of uranium for sale to the Manhattan Project and operated the mill until 1946 when the mill was shut down. In 1949, the Vanadium Corporation of America (VCA) leased and subsequently purchased the site. VCA operated the mill and sold uranium to the U.S. Atomic Energy Commission (AEC) until March, 1963, when the mill was shut down permanently, The site was purchased by Ranchers Exploration and Development Corporation in 1977, which was subsequently acquired by Hecla Mining Company in 1984.

In 1979, the DOE designated the Durango site as eligible for remedial action under UMTRCA. The DOE and the State of Colorado entered into an agreement in 1981 to perform remedial action at this site and other sites in Colorado. The State of Colorado acquired the site for the purpose of remedial action following the signing of the cooperative agreement.

The Bodo Canyon disposal site is on the opposite side of Smelter Mountain from Durango, about 1.5 miles due southwest of the Durango site (Fig. 2). The area is in an ephemeral drainage basin known as Bodo Canyon and encompasses about 80 acres. The sections of land on which the site is located are owned by the State of Colorado and managed as a part of the Bodo Canyon Wildlife Refuge. The area surrounding the disposal site is owned by the State of Colorado either as Division of Wildlife land or as school lands.

At the Durango site the contaminated materials included 1) tailings; 2) subpile soils; 3) surficial materials in the mill yard; 4) windblown materials; 5) vicinity properties; and 6) raffinate ponds. Approximately 2.4 million cubic yards of contaminated materials covered 29.3 acres at the Durango processing site. Depths of contamination ranged from 0.5 foot for windblown areas on Smelter Mountain to at least 60 feet in the large tailings pile. The highest average radium (Ra-226) concentration was 573 picocuries per gram (pCi/g) for 1,407,400 cubic yards of tailings. The lowest average Ra-226 concentration was 48 pCi/g for 395,500 cubic yards of material in the raffinate ponds.

EPA STANDARDS

In developing the standards, the EPA determined that the primary objective for control of tailings should be isolation and stabilization to prevent their misuse by man and dispersal by natural forces such as wind, rain, and flood waters. Accordingly, a design objective of 1000 years was established for the control of the tailings and other residual radioactive materials, to be satisfied whenever reasonably achievable, but in any case with a minimum performance period of 200 years.

The EPA identified a reduction of radon emissions from tailings piles as the second objective in its standards for the control of tailings. An emission limitation for radon of 20 picocuries per square meter per second ($pCi/m^2/s$) on the disposal site or a concentration limit of 0.5 picocuries per liter (pCi/l) outside the disposal site was established as a design standard. These values reduce both the maximum risk to individuals living very near the sites and the risk to the population as a whole.

The EPA evaluated the risk associated with the dispersal of tailings off the site and concluded that the principal risk to man was the exposure to radon daughter products inside buildings. For open lands, the purpose of removing the contamination is to remove the potential for excessive indoor radon-daughter concentrations that might arise from new construction on contaminated land. The 5 pCi/g and 15 pCi/g Ra-226 concentration limits for 15-centimeters surface and subsurface layers were considered adequate to limit indoor radon-daughter concentrations to below a 0.02 working level.

In September of 1987, the EPA proposed new groundwater standards which established specific numerical limitations for designated hazardous constituents related to uranium processing activities. The standards are meant to control future groundwater contamination that may occur from any stabilized disposal cell after remedial action.

REMEDIAL ACTION

The remedial action for the disposal and stabilization of the contaminated materials from the former tailings area, mill facility, and raffinate ponds area was to relocate them to the Bodo Canyon disposal site, approximately 3.5 road miles away. The contaminated materials were consolidated into a single disposal cell. Before contaminated materials could be moved, site preparation at the Durango processing site and the Bodo Canyon site was required. At the processing site, this preparatory work included upgrading the haul roads, construction of access roads across the processing site, construction of a truck-wash station, and construction of a contaminated water storage reservoir. The Bodo Canyon site preparation included construction of a network of surface water runoff controls, stripping and stockpiling 0.5 foot of topsoil from the disposal area, construction of four perimeter embankments, putting down the first section of the clay under liner, building a truck-wash station along with a contaminated water storage reservoir.

Excavation, transportation and placement of uranium tailings and other contaminated materials began in August 1987. Remedial activities were shut down from December 1

thru March 30 due to winter weather conditions and also as a mitigation measure for wildlife. The entire disposal cell is underlain by a two-foot-thick layer of low permeability compacted clay to minimize infiltration of water. Efforts were made to place materials with relatively low Ra-226 concentrations over material with higher concentrations. The exact construction sequencing of contaminated material within the cell considered the concept of reducing the radon flux below the EPA's standards to levels as low as reasonably achievable. Placement of uranium tailings and other contaminated materials was completed by November 1989.

The cover for the disposal cell is designed to meet EPA standards for radon flux, protection of groundwater, and longevity. The cover is designed to resist degradation, minimize infiltration, minimize biointrusion, meet radon protection standards, and withstand differential settlement throughout its design life. To meet all of these criteria, the cover consists of multiple layers.

The radon/infiltration barrier on the topslope is comprised of bentonite matting over unamended low permeability clay. This layer was placed over the relocated, contoured, and compacted contaminated materials and will inhibit radon emanation and the infiltration of water into the tailings. The radon barrier material consisted of 0.5 feet of select Bodo Canyon soils, and 1.5 feet of spoil material. Additional cover components were sequentially placed above the primary earthen radon barrier on the topslopes, and consisted of a six-inch-thick drain and filter layer, followed by a 1.5-foot-thick biointrusion layer, a 2.5-foot-thick frost protection/rooting soil, and a final six-inch-thick rock/soil matrix. Native grasses were seeded on the topslope.

To provide the required low hydraulic conductivity to reduce water infiltration, the radon barrier on the sideslopes was constructed of six inches of natural material excavated from the disposal cell location (spoils) followed by 1.5 feet of low permeability clay materials amended with sodium bentonite. Above this composite radon barrier was placed, in order, a six-inch-thick drain layer, a six-inch-thick bedding layer, a 1.5-foot-thick frost protection layer, a six-inch-thick bedding layer, and a 1.0-foot-thick riprap layer.

The disposal cell was designed so that all on-cell runoff will flow off and away from the cell. To protect the toe of the cell against erosion, riprap-lined ditches will conduct surface runoff to two discharge points at the designated disposal site. All areas excavated and disturbed were recontoured to promote positive drainage.

Excavation control monitoring was conducted during remedial action to ensure that the 5 pCi/g and 15 pCi/g above background Ra-226 design standards were met for surface and subsurface soils. Verification sampling prevented both inadequate under-excavation and costly over-excavation. Final verification surveys were performed to document average Ra-226 concentrations on all areas remediated in order to verify compliance with EPA standards.

Independent radiological surveillances and health/safety audits were conducted by the DOE and the Technical Assistance Contractor during remedial action to ensure that all activities were performed to meet Federal, state, and local standards and guidelines. Quality control and assurance requirements and procedures were followed to ensure that adequate cleanup and subsequent verification were properly implemented and documented. Remedial action was fully complete by May 1991.

RISK REDUCTION

The DOE cleaned up the Durango site and associated vicinity properties in accordance with EPA standards, NRC guidelines, and UMTRA Project health and safety requirements. The remedial action was effective in controlling and stabilizing the uranium tailings. The activities were also effective in significantly reducing risk to human health and the environment.

In June 1987, the initial phase of a remedial action radon monitoring program was implemented at and around the Durango processing site. The monitoring program determined background radon concentrations near the site, and determined periodic radon concentration from the processing site. A time-weighted average radon concentration for the Durango area during remedial action was 0.6 pCi/l. At the processing site, the highest measurement taken during remedial action was 45.6 pCi/l. The average radon concentration for remedial action at the processing site was 7.0 pCi/l. Following remedial action, the average radon concentration at the processing site was 0.5 pCi/l. These measurements clearly indicate that the radon concentration at the processing site are within the range considered background levels for Durango. The risk for potential cancers associated with long term exposure to radon was significantly reduced.

At the completion of remedial action the UMTRA Project Office also measured the radon flux on the disposal cell at Bodo Canyon. There were 140 measurements taken over the 61,314 square meter disposal cell. The average radon flux was 0.2 $pCi/m^2/s$, well below the standard of 20 $pCi/m^2/s$. The measurements illustrate the remedial action was very effective in limiting radon emissions from the disposal cell.

In addition to a risk reduction for radon, the disposal cell was designed to control radioactive materials and nonradioactive contaminants in conformance with groundwater protection standards. The Durango disposal cell is designed to meet the EPA maximum concentration limits or background concentrations for designated hazardous constituents in groundwater in the uppermost aquifer.

LESSONS LEARNED

The DOE has finished construction at nine sites by collecting radioactive ore residues and storing them in engineered, above-ground disposal cells at each of the sites. The UMTRA Project has begun to show major results. In an effort to improve the quality of remedial actions, and to reduce costs while maintaining a standard of excellence, the UMTRA Project has begun to compile a record of lessons learned from remedial activities. The purpose is to examine and evaluate past successes and mistakes, and to document these for future reference and orientation.

At the Durango, Colorado, UMTRA site, a report was compiled that focused on lessons learned during the last two years of construction. The major lessons can be grouped into three categories: 1) enhanced communications; 2) working with environmental risk; and 3) engineering features.

Remedial action at the Durango site was of great concern to the local community, and initially there was an ineffective community relations program. The Durango Mill Tailings Task Force (Task Force), made up of local citizens, was

established as a mechanism for local oversight of the remedial action. Several methods were used at Durango to ensure open communication with the Task Force, and the effort was instrumental in obtaining a positive outlook on the project by the Task Force and the local community. The three primary methods utilized in communicating with the Task Force included: 1) a semimonthly status report which provided information on project progress, upcoming plans, project employees, and any unusual occurrences; 2) frequent phone calls to the chairman were made any time there was a significant event or problem; 3) and periodic meetings and site tours were held every few months which provided the task force members an opportunity to express their concerns. The emphasis on communications was essential in obtaining local trust and support.

Many of the problems with remedial action schedule performance lie in breakdowns in communications between staff, rather than an inability to meet schedules. At the beginning of the 1990 construction season at Durango there were many activities in progress which required the input of the DOE, the Remedial Action Contractor, the Colorado Department of Health, and the Technical Assistance Contractor. Coordinating the communication to ensure that all action items were identified and acted upon was often time consuming and ineffective. The UMTRA Project Office initiated a weekly conference call early in the 1990 construction season. The conference call was a practical way to disseminate the required information to all parties in an efficient manner. Typical topics discussed included a status of in progress construction activities, upcoming plans, design changes or problems, status of needed permits, and individual action items. The weekly call proved very successful in providing information to the UMTRA team and in expediting decision making.

An important lesson learned throughout remedial action at UMTRA sites, and one that was apparent at Durango, concerned working with environmental risk. In an environmental project such as UMTRA, there are many changing conditions, both concerning regulatory issues and the type and quantity of contaminated material. Management of the remedial action requires the ability to continue working on the remedial action, while at the same time working out solutions. One example at Durango involved a line of seepage along the eastern side of the disposal cell that was discovered during remedial action. The investigation and analyses of the seepage problem indicated that the potential environmental threat and the surface instability of the slope were sufficient to require action. As the study proceeded during the construction season the principal challenge was to avoid interfering with the construction work. Delaying the project would have a major cost impact, and would itself pose an environmental risk by slowing the relocation of the contaminated materials and construction of the final cover to the disposal cell. The eventual solution involved the installation of a toe drain along the eastern slope of the cell and draining the excess water by gravity to a lined holding pond. This solution kept the side slope dry and allowed construction of the disposal embankment to continue without disruption. It also allowed the drainage to continue for a period of time after the contaminated material had been placed and the cell closed.

A project the size and complexity of UMTRA has opportunities to develop or apply new engineering features to resolve certain issues. Application of these new features can be beneficial to other sites when specific conditions are similar. An example at the Durango UMTRA site involved the protection of the disposal cell during a winter shutdown period. When remedial action is to performed over more than one construction season, protection of the in progress remedial action is required to minimize erosion and potential spread of contamination during winter shutdown. At Durango, a system of earthen berms and plastic lined ditches were temporarily constructed on the disposal cell to direct water off the cell during the 1989/1990 winter shutdown. This planned system for control of runoff helped to eliminate excessive ponding on the cell and minimized erosion on the sideslopes. These activities proved to be an economical and effective method to protect the disposal cell at Durango over the winter.

SUMMARY

Remedial action at the Durango UMTRA site consolidated approximately 2.4 million cubic yards of contaminated materials from the inactive processing site and vicinity properties into a single disposal cell located approximately 3.5 road miles southwest of the mill site. Completed remediation contained the following characteristics: 1) The disposal cell and radon barrier design significantly reduced the surface radon flux to levels below the EPA standards; 2) the disposal cell was designed to control radioactive materials and nonradioactive contaminants in conformance with EPA groundwater protection standards; 3) the disposal site was designed to stabilize and control residual radioactive material for at least 200 years; and 4) the remedial action was conducted to provide reasonable assurance that the concentration of Ra-226 at the mill site did not exceed the background level by more than 5 pCi/g over the first 15 centimeters of soil below the surface, and 15 pCi/g for subsurface layers. The remedial actions were completed in May 1991.

URANIUM MILL TAILINGS REMEDIAL ACTION PROJECT VICINITY PROPERTY PROGRAM

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ABSTRACT

This paper outlines the steps developed by the Uranium Mill Tailings Remedial Action Project Office to assure proper identification, remediation and certification of vicinity properties. In addition, some of the more unique aspects of the UMTRA Project vicinity property program are discussed centering on the voluntary nature of the program, public information efforts and coordinating the work of several different entities. The UMTRA vicinity property program has been extremely successful with over 3800 properties remediated to date.

THE UMTRA PROJECT

The UMTRA Project was mandated by the Uranium Mill Tailings Radiation Control Act (UMTRCA) of 1978 (Public Law 95-604) which directed the Secretary of Energy to designate Title I uranium processing sites. Material was moved from these processing sites and used as construction material and for landfill at properties around the mill sites. These properties which contain residual radioactive material are called vicinity properties. Vicinity properties are homes, businesses, public buildings and vacant lots which were contaminated by the use of tailings as a building material or as fill material. The use of tailings for these purposes is no longer allowed.

The UMTRCA specifies that the remediation of vicinity properties will be accomplished only with the voluntary consent of the property owner. The remediation will be performed at no cost to the owner. This voluntary participation in the UMTRA vicinity property program leads to many unique situations since not all property owners are eager to participate in a government program. In addition, the UMTRA Project is also a cooperative effort between the Department of Energy (DOE) and the affected States. This cooperative remediation effort creates differing pressures from the various States since the States have a role in the remedial action and each has a different interpretation of its role in the project.

To assist in the remediation of vicinity properties, the UMTRA Project Office has developed the Vicinity Property Management and Implementation Manual (VPMIM) which outlines the steps required to be followed for the inclusion, remediation and certification of properties. Controlled copies of the VPMIM were distributed to all Project participants including the Department of Energy (DOE), the States, DOE contractors and the Nuclear Regulatory Commission (NRC). The VPMIM defines each agency's role in the vicinity property program and sets forth DOE policy for the remediation of vicinity properties.

The UMTRA Project was initiated to eliminate the health risks associated with tailings. Vicinity properties contain the largest risk to people since the health effects of tailings are manifested only after long term exposure. The tailings contain over 80 percent of the radioactivity of the uranium ore. The potential for the release of radon gas is greater in the tailings than in the ore because the tailings are a sand like material with greater surface area than the ore. When the tailings are transported and used in and around structures, the radon released from the tailings can become trapped and accumulate inside the structures, many times building up to levels exceeding the Environmental Protection Agency (EPA) standards as set forth in 40 CFR Part 192. Exposure to elevated levels of radon over a long period has been associated with increases in lung cancer. The tailings also release low levels of gamma radiation.

INCLUSION OF VICINITY PROPERTIES INTO UMTRA

The initial group of vicinity properties to be investigated for inclusion into the UMTRA Project were part of the Designated Property List (DPL). The DPL consisted of properties identified through historical research and cursory radiological surveys. In the Grand Junction, Colorado, area, properties included in the Grand Junction Remedial Action Project (GJRAP) (Public Law 92-314, 1972) were also included in the UMTRA Project. The GJRAP only remediated the structures and the land ten feet around them, which left tailings on the open land areas of the properties. The UMTRA Project remediated the other areas of these properties.

With owner consent, these properties were investigated to determine whether contamination was present in excess of the EPA standards. Inclusion surveys were performed on other properties identified by the States or property owners as potentially containing residual radioactive materials. The UMTRA Project has performed in excess of 13,000 inclusion surveys to date. The inclusion surveys are performed by Oak Ridge National Laboratories (ORNL), which is not involved in the actual remediation of the properties. The ORNL also independently verifies that a percentage of the properties in the Grand Junction, Colorado, area meet EPA standards after remedial action. ORNL performs the inclusion surveys to ensure that the inclusion recommendations will not be biased since they have no involvement in the remediation of the properties.

REMEDIAL ACTION DESIGN AND REMEDIAL ACTION AGREEMENTS

Once properties are found to be eligible for the UMTRA Project, detailed radiological surveys are performed. These surveys identify the location and extent of the residual radioactive material on the property and enable the engineering design to be developed. The UMTRA Project uses a document called the Radiologic and Engineering Assessment (REA) to present the detailed radiological survey data. This REA is developed by the RAC and is reviewed and concurred on by the DOE and the affected State.

The EPA standards give the UMTRA Project the ability to leave some material in place under 40 CFR Part 192.22. The application of supplemental standards is permitted for situations where application of the control or cleanup standards would (1) pose a clear and present risk of injury to workers or the public notwithstanding reasonable measures to limit damage; (2) directly produce environmental harm that is clearly excessive compared to the health benefits to persons living on or near the site, now or in the future; (3) result in an estimated cost of remedial action which is unreasonably high relative to the long term benefits, and the residual radioactive material materials do not pose a clear, present or future hazard; (4) result in an unreasonably high cost of cleaning up a building relative to the benefits; or (5) there is no known remedial action method.

In order to justify a request for supplemental standards, the deposit must be fully characterized and documentation specifying the extent of the deposit, the activity level of the deposit and the circumstances requiring the application of supplemental standards must be presented for review by the DOE, State and the NRC. When the supplemental standards are used the remedial action shall come as close to the cleanup standards as possible.

Once a design has been developed and has been approved by the appropriate entities, a Remedial Action Agreement (RAA) is executed with the property owner. The RAA is a contract between the DOE, State and property owner for the remediation of the property. It outlines the intent of the UMTRCA and contains provisions for right-of-entry, restoration of the property, and release of liability by the owner for results of remedial action. Any unique requirements such as reimbursement for lost profits, supplemental feed for livestock, or relocation requirements are listed in the RAA.

The UMTRA Project has developed a generic RAA which is typically used for most properties. Unique or complicated property issues are generally negotiated by the DOE and the State. Every effort is made to avoid delays to the scheduled dates of remedial action during the negotiations.

REMEDIATION ACTIVITIES

Property Types

The UMTRA Project has encountered many unusual conditions and requirements for vicinity property remedial action in order to minimize the impacts of remedial action on property owners. Many properties which are contaminated are active businesses which must either be kept open during remedial action or relocated. Sometimes when the business is kept open during remedial action, impacts to profits are experienced. The UMTRA Project evaluates owner requests for reimbursements due to impacts solely related to remedial action. Normally, these reimbursement requirements are outlined in the RAA.

The UMTRA Project has remediated almost every type of property imaginable. Tailings in excess of EPA standards have been discovered anywhere from vacant land to office buildings, ranches to railroads and swimming pools to gas stations. However, private residences comprise the majority of properties in the UMTRA Project. Every remedial action design is treated individually; however, some types of properties occur with such frequency that the major elements of the remedial action design can be used over and over again thus reducing design development time.

Schedules

The remediation schedule for vicinity properties must be closely coordinated with that of the mill site from which the residual radioactive materials originated. The goal is to remediate all the vicinity properties prior to closing the disposal cell containing the vicinity property and mill site material. The vicinity property remedial action normally precedes the mill site remedial action in order to be complete in time to avoid impacting the mill site construction activities.

Several sites have, or are scheduled to have, the completion of vicinity property remedial action occur the same week that the disposal cell is scheduled to be closed. Both the Durango, Colorado, and Lowman, Idaho, sites experienced this scheduling and it is anticipated to occur in Grand Junction, Colorado, despite over ten years of vicinity property remedial action in that area.

In order to enable all the included properties to be remediated and the tailings to be disposed of in the mill site disposal cells, the UMTRA Project publicizes an inclusion cutoff date for vicinity properties to be included for remedial action. A multimedia announcement is made to the public documenting the deadline for requesting inclusion surveys. After that date the Project cannot guarantee that a property can be remediated. The inclusion survey deadline is calculated to allow time to excavate tailings from new vicinity properties and deliver the tailings to the disposal cell before it is closed.

At all sites, once vicinity property remedial action begins, renewed interest arises in the UMTRA Project as homeowners request inclusion surveys to be sure they do not have tailings on their property. These inclusion surveys generally yield a very low percentage of includable properties (in most cases less than 10 percent) but are valuable because additional properties are discovered and remediated.

Post Cell Closure Policy

Currently, the UMTRA Project is developing a Post Cell Closure Policy to determine how to handle tailings discovered at sites where mill site remedial action is complete and there is no longer a disposal cell available for the tailings. The UMTRCA gives the DOE the responsibility for remedial action of the tailings for a finite period of time, currently 1994 but projected to extended to 1998 in a proposed reauthorization amendment. The Post Cell Closure Policy will address disposal options available until the tailings remediation authority expires. This policy is being developed with input from the States and the public. The States were given a draft of the policy and asked to comment. The comments will be addressed and then public meetings or other mechanisms for soliciting public input will be held at all the UMTRA sites to gather public input. The policy is expected to be complete in early 1992.

Remedial Action Activities

The RAC is responsible for obtaining a qualified contractor to perform the remedial action construction activities. The RAC sends out Requests for Proposals to qualified contractors, receives the proposals and analyzes them for mathematical errors and unbalanced bid items. Once the analysis is complete, the DOE is provided with an award nomination which is reviewed and approved before the contract can be awarded.

The RAC closely monitors the excavation of the residual radioactive material by the construction contractor to ensure that material is removed according to the plans and specifications and the property will meet the EPA standards upon completion of remedial action. In some locations, the State also provides a representative to assure all contaminated material is excavated to meet the EPA standards. The RAC conducts construction management activities including evaluating subcontractor work schedules and status reports, processing subcontract changes, conducting field inspections, and submitting progress reports to the DOE. The DOE provides guidance to the RAC, approves changes, and conducts field inspections.

Excavation control for the UMTRA Project is provided by RAC personnel using either hand held scintillometers or the Opposed Crystal System which analyzes the radium-226 content in soils. The RAC is responsible for assuring that the contaminated material is excavated and the construction contractor does not leave behind residual radioactive material in excess of the EPA standards or excavate clean material unnecessarily. Once the RAC determines that excavation of contaminated material is complete, verification samples are taken to assure EPA standards have been met and the property is returned to its condition immediately prior to the start of remedial action.

The UMTRA Project is only authorized to restore a property to its condition immediately prior to remedial action. The UMTRA Project cannot make improvements to a property. However, it is extremely difficult to replace a ten or twenty year old driveway or structure in exactly the condition it was prior to remedial action. In many instances the property owner obtains a new replacement item either because the original item had to be demolished in order to remove the tailings or the reconstruction had to conform to new, stricter building codes.

The UMTRA Project strives to work with the property owner to accommodate minor changes during restoration of the property. If the property owner wants minor changes to his property at no cost or a savings to the government, these changes are usually accommodated.

In some instances, the property owner will make an agreement with the remedial action construction contractor doing the removal to perform improvements to the property. The improvements are funded entirely by the property owner. The owner can obtain a better price from the subcontractor for the improvements because the mobilization and demobilization costs are already paid by the UMTRA Project for the residual radioactive material removal. The property owner only pays for the actual work that is performed, thus saving money by doing the improvements at this time. These side agreements between the property owner and the subcontractor must not impact the remedial action schedule or the RAC will not allow the improvements to be done.

Verification

The UMTRA Project requires verification that all properties are properly remediated. As detailed in the VPMIM and the RAC field procedures, the RAC takes soil sample measurements to verify the EPA standards have been met before the property is backfilled and restored to its original condition. Previously contaminated areas are sectioned into verification grids and a composite soil sample is obtained from each grid. The radium-226 content of each sample is determined and compared to the EPA standards. Once it has been determined that the remediation has adequately removed the residual radioactive material to below the EPA standards, the construction contractor is given approval to begin reconstruction activities. The Independent Verification Contractor (ORNL) also takes measurements at 10 percent of the Grand Junction properties to provide a further check of the remediation.

The verification measurements are included in the Completion Report describing the radiological condition of the property after the remedial action. Soil measurements for outdoor contamination and gamma levels and radon daughter concentrations for indoor contamination presented in this report are reviewed by the DOE for adequacy and conformation to the EPA standards. If the information is judged to be complete, the property is certified as meeting the EPA standards by the DOE and a certification letter is sent to the owner and the State. The NRC must also review and concur with the Completion Reports of supplemental standards properties before they can be certified.

ANNOTATION OF VICINITY PROPERTY CONDITION

The UMTRCA specifies that the DOE will ensure that the condition of the vicinity properties will be documented so that future purchasers will be informed of their condition. The DOE is developing a rule to be published in the Federal Register dealing with annotation of land records. The UMTRCA requires that a public land record be annotated to describe the status of a vicinity property including the date that remediation took place. The affected States will be tasked to identify the public land records to annotate. It is currently envisioned that properties containing residual radioactive materials through either the application of supplemental standards or through owner refusals to participate in the project will be annotated along with remediated properties.

The States will determine which land record will be annotated and submit a plan to the DOE describing how the annotation procedure will work and how the prospective purchasers of a property will be informed of its status. The DOE will review the plan and work with the State to modify it, if necessary, and provide approval. The costs of the annotation process will be borne by the States.

COMMINGLED WASTE

Several properties, especially in the Grand Junction, Colorado, area, have hazardous wastes not derived from the milling process mixed with the residual radioactive material. The DOE has determined that the UMTRCA does not permit the expenditure of Federal funds for the stabilization of hazardous materials not used in the milling process. The UMTRA Project is currently developing a policy to deal with these commingled wastes. The intent of the policy is to place the financial burden for stabilization of the nonradioactive hazardous material on the property owner. The UMTRA Project will then remove the residual radioactive material after the hazardous materials have been rendered nonhazardous. If the owner does not wish to stabilize this material, the property will be treated as an owner refusal and closed out.

OWNER REFUSALS

There is a group of approximately 250 property owners that refused to participate in the UMTRA Project at various stages. The owners have refused access for inclusion surveys, detailed radiological surveys, remedial action or verification surveys for various reasons. The UMTRCA specified that the

vicinity property remediation would be a voluntary program. The Congress was not envisioning a large number of owners refusing to participate in a free program to remove residual radioactive material from their properties. The UMTRA Project has worked very hard to persuade these owners to reconsider their decision. Owners are contacted several times and provided with additional information regarding the UMTRA Project and radon to allow them to make a truly informed decision concerning their participation. Owners refusing to participate are asked to sign an owner refusal form documenting their decision.

The owner refusal group of properties presents a number of concerns to UMTRA Project managers including the continuing possibility of tailings being spread to other properties and new owners being unaware that tailings may exist on their property. The DOE is determining whether to annotate the land records of refusal properties which are known to contain residual radioactive material in excess of the EPA standards. The Project Office believes this annotation is necessary to document the presence of the tailings and provide prospective purchasers the status of properties which are known to contain tailings.

PUBLIC INFORMATION EFFORTS

The UMTRA Project has made many efforts in the public information and public participation areas in response to the requirements of the UMTRCA. The education of both the real estate community and the general public regarding the purpose of the UMTRA Project and the vicinity property program, hazards of the tailings and the services the UMTRA Project can provide has made completion of remedial action much easier. Vicinity property managers have met with local Realtors associations, addressed special college seminars and given media interviews in addition to meeting with the public in meetings and in a one on one setting.

Vicinity property managers have always tried to present relevant information which could benefit people impacted by the UMTRA Project. Subjects such as annotation of land records, remediation options and ways to obtain specific property information have been presented in addition to a complete explanation of the vicinity property program from inclusion through certification and land record annotation. Additional information is provided to homeowners who live in homes affected by naturally occurring radon. This information details additional steps they can take to lower indoor radon levels that are not caused by tailings. We have discovered that after this information is presented in an area, the number of complaints and dissatisfied property owners decreases and the project is much more effective.

MANAGEMENT ACTIVITIES

Vicinity property contractor coordination meetings are essential in assuring that all the different project participants are knowledgeable of the latest events and policy decisions made by the DOE concerning the project. The Colorado Department of Health (CDH) is the only state representative to participate in these meeting due to its overwhelming number of vicinity properties in Colorado and CDH's involvement with both RACs. Remediation of properties in other states has been much less complicated due to the smaller number of properties involved and the more limited use of tailings at the vicinity properties.

The coordination meetings are held at least quarterly to give all participants the opportunity to discuss topics that have arisen or that need clarification. Items such as commingled waste, supplemental standards, quality improvement efforts, consistency between RACs and comparison and coordination of the project databases are discussed. The meetings are kept to one day in length to minimize disruption to the participant's normal activities.

MK-Ferguson Company is responsible for all of the vicinity properties except those located in Grand Junction, Colorado, and Edgemont, South Dakota, and is managed by the UMTRA Project Office in Albuquerque, New Mexico. Chem Nuclear-Geotech is responsible for the Grand Junction and Edgemont properties and is managed on a day to day basis by the DOE Grand Junction Projects Office (GJPO). The UMTRA Project Office reports to the DOE Field Office, Albuquerque, and the GJPO reports to the DOE Field Office, Idaho. One of the challenges of having two different RACs perform remediation is keeping their field procedures consistent. Further complicating matters is the fact that the RACs are managed on a day to day basis by two different DOE offices.

Over the years the two RACs have developed slightly different field procedures due to their inability to be able to share specific technical information due to its proprietary nature and the different management styles of the DOE offices. In 1988, a vicinity property programmatic review was conducted utilizing outside consultants to evaluate the consistency of the different field procedures and to ensure that both procedures resulted in meeting the EPA standards. Several differences were noted; however, both contractors procedures resulted in remedial actions meeting the EPA standards. A Technical Liaison Committee (TLC) was formed to address these differences and formulate consistent project procedures.

The TLC completed their recommendations in 1989 and the VPMIM was revised via a series of directives issued in 1990 by the UMTRA Project Office and reviewed by all participants. After the implementation of the VPMIM directives, the Colorado Department of Health still believes there are some differences in the field procedures since they work with both the RACs on sites in their state. The DOE is currently reviewing their concerns and is evaluating whether the TLC should be reestablished to address these concerns and ensure consistency.

CONCLUSIONS

The UMTRA vicinity property program presents many challenges in that it is voluntary and owner refusals were not envisioned. The UMTRA Project has developed and refined guidelines for managing all aspects of the vicinity property program from inclusion through certification. The project has placed an emphasis on meeting with the public to make the identification and remediation of vicinity properties easier and to gather suggestions from the public to make the vicinity property remediation less disruptive. The vicinity property program has gained much practical experience in the remediation of properties through the work completed to date. The UMTRA Project is a leader in the remedial action and environmental restoration arena with over 3800 vicinity properties completely remediated out of a total of over 5100 scheduled for remedial action. The UMTRA Project can and should be used as a model for other remedial action projects.

DETERMINING THE "R" IN ALARA: A PARAMETRIC STUDY TO ESTABLISH CLEANUP CRITERIA

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ABSTRACT

This paper describes the use of a tool for establishing criteria for cleanup of low-level radioactive contamination that will result in cost-effective remedial action. Central to this tool is the application of the principles of ALARA (as low as reasonably achievable). ALARA goals are driven by a desire to remediate a site to meet the strictest criteria practicable; to meet economic requirements, waste volumes must be minimized. The result of using this tool is the development of a remedial action program that satisfies ALARA requirements while limiting health and environmental risks to acceptable levels.

Topics discussed in depth include the ALARA process, its principles, and its application to remedial action programs. The paper concludes with a case study in which the tool is applied to establishing cleanup criteria for the Department of Energy's Formerly Utilized Sites Remedial Action Program (FUSRAP).

INTRODUCTION

The Department of Energy (DOE) has adopted ALARA (as low as reasonably achievable) principles for use in the Formerly Utilized Sites Remedial Action Program (FUSRAP). FUSRAP was initiated in 1974 to identify, clean up, or otherwise control sites where radioactive contamination remains from the early years of the nation's atomic energy program or from commercial operations causing conditions that Congress authorized DOE to remedy. As project management contractor for FUSRAP, Bechtel National, Inc. (BNI) has taken an integral role in the development of standard procedures for planning and performing remedial action. The objective of these guidelines is to limit potential health risks from exposure to contaminated materials while remaining within practical economic and operational limits. To evaluate the guidelines according to ALARA principles, a parametric analysis is recommended.

DOE has established radiological protection guidelines for cleanup of residual radioactive material at FUSRAP sites. The guidelines for radioactivity levels and radionuclide concentrations are applicable to sites to be released for public or private use without radiological restrictions. The guidelines are classified as either generic, such as existing radiation standards, or site-specific, derived from site-specific exposure models and data. Levels for radium-226, radium-228, thorium-230, and thorium-232 (four of the most prevalent isotopes found in FUSRAP investigations) are stated in the generic guidelines (1). Consideration of the other prevalent radionuclides, specifically isotopes of uranium, falls in the second category. DOE currently uses the RESRAD computer model to develop total uranium cleanup criteria based on a maximum allowable nonoccupational exposure limit of 100 mrem/yr above background. Other regulatory agencies often disagree with these criteria in favor of lower values. Thus, determination of a cleanup level that is acceptable to those agencies and meets the goals of ALARA is necessary.

THE ALARA PHILOSOPHY

Application of ALARA principles is required in DOE Orders on environmental protection and safety and health and in DOE guidelines for residual radioactive material. Requirements for limiting radiation exposures to as-low-as-practicable levels were introduced in the Energy Research and Development Administration Manual, Chapter 0524, in 1975. These requirements formalized the position practiced within DOE and by its contractors and did not represent a new commitment.

Applying ALARA principles is a process with basically one objective: to attain dose levels that are as far below applicable limits as is practicable and reasonably achievable, taking into account technical, economic, safety, and social factors. No single set of specific and detailed criteria exists as a prescription for achieving the ALARA objective. Instead, general guidance, in the form of broad principles, has been established to acquaint management with ALARA concepts. Therefore, no defined set of dose levels exists for determining when ALARA objectives are achieved. For example, when an area cannot be decontaminated to the derived concentration guideline, a decision must be made as to whether the area can be used without radiological restrictions or whether controls will be required (2,3,4,5).

Applying ALARA principles during remedial action is in many cases more complex than applying them during operating situations. Factors that must be identified and considered when selecting remedial action alternatives include characteristics of the waste stream, pathways of contaminant migration, individual exposure to contaminants, and cost of remedial action over time. The two approaches used for determining ALARA objectives are qualitative or judgmental procedures and quantitative or optimization procedures.

The first, more traditional method for determining ALARA requirements consists of a decision-maker's judging each situation based on an understanding of relevant economic, social, and technical factors. The most important economic factor is the cost of performing remedial action, including costs for planning, operation, labor, materials, equipment, energy, and services over the period of remediation and any subsequent maintenance and monitoring activities. Implementing either a remedial action or a no-action alternative may have positive or negative effects on everyday operations at a site and/or the environment.

Social factors include risks to the people exposed to contamination and perceptions about exposure risks. To meet ALARA objectives, reductions in risks before and after remedial action should be compared to the incremental risk during

the remedial action. Risk studies should identify potential users and individuals in the area near the remedial action site following completion of the remedial action. In addition, risk studies should consider incremental risk from exposure to contaminants to individuals in the same area and to workers during remedial action activities.

Technical factors are primarily related to the techniques used to determine the extent of contamination and the remedial action alternatives (3).

The International Commission on Radiological Protection recommended the use of cost-benefit analysis as a method for balancing cost against benefit to achieve the objectives of ALARA. Cost-benefit analysis is a quantitative technique that compares risk (and therefore costs of health factors related to radiation) with the cost of reducing levels of radiation. This relationship can be expressed as a simple mathematical expression:

$$\text{Benefit} \geq \text{Cost} + \text{Risk}$$

This expression is idealized, and many unknowns and subjective factors complicate its use. Cost-benefit analysis is a procedure for quantitatively determining some of the input to a specific decision concerning radiological protection. In applying this procedure to an ALARA program, the difficulty of determining how to measure costs and benefits becomes obvious. Some investigators have attempted to assign monetary value to the effects of exposure to radiation. The cost/risk ratio for deriving ALARA guidelines is assumed to be $1,000 per person-rem. It is usually assumed that a linear extrapolation of risk versus dosage holds at all levels down to zero (2,3,5). Unlike risk cost, which is defined by a linear relationship, dose reduction cost follows a hyperbolic trend. Larger doses are reduced at low relative costs. As doses become smaller, each additional increment of dose reduction becomes more costly. If both curves (cost of dose reduction and cost of risk) are plotted and summed, a minimum is obtained. The minimum represents the theoretical optimum situation wherein an incremental increase in the cost of protection is exactly balanced by a corresponding incremental decrease in the cost of detriment.

THE TOOL

The tool is an X-Y graph showing the relationship between volume of soil to be remediated and cleanup criteria (Fig. 1). The graph represents a hyperbolic function of the two variables. The y-axis represents the volume of soil to be remediated (but may be modified to represent cost). Cost is inclusive of labor, equipment, material, personal protective equipment, and other related items. The x-axis represents cleanup criteria. Therefore, for varying cleanup criteria, the volume to be remediated and the accompanying costs are determined and plotted.

Managers can use this tool to decide whether to perform cleanup based on the funds available, recognizing that cleanup would not meet required criteria, or to make budgetary plans, based on the graph, to remediate to the criteria. The optimum point for achieving remedial action objectives while meeting ALARA goals based only on cost and cleanup criteria is determined by extending tangents from the two asymptotic regions of the curve to the point of intersection and bisecting the angle thus formed (Fig. 1). Determining volume for varying cleanup criteria will be discussed later. However,

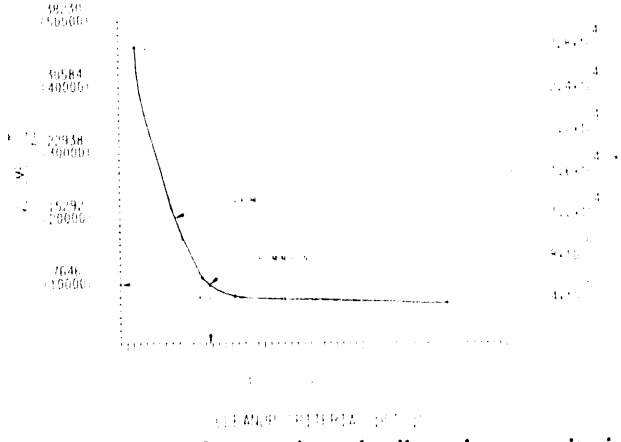


Fig. 1. Volume of contaminated soil vs. cleanup criteria.

controls for health and environmental risks will always be maintained; the safety of personnel performing the cleanup or those who reside near the remedial action site is not negotiable.

As shown in the graph, the volume of soil to be removed drops at a high rate as cleanup criteria are relaxed. The drop in volume is abrupt at the lower end of the range of criterion values, meaning that a slight relaxation could bring about great cost savings. At the upper end, the curve is smoother and great savings cannot be achieved without sacrificing ALARA goals and possibly health and environmental safety. Therefore, care should be taken in generating data for the graph and in using the graph for decision making.

If data are available, risk that correlates to the criteria for which volumes were determined may be shown on the right side y-axis (Fig. 1). A vertical line is extended from the criterion on the x-axis to the risk-versus-criterion curve, and a horizontal line is projected from that intersection to a point on the newly created y-axis denoting the calculated risk value. Risk tends to increase with relaxation of criteria or decrease in volume and to drop with increasing stringency of criteria or increase in volume. Determining risk is a complex task in itself and is beyond the scope of this paper. However, managers could use this graph not only to determine volumes of soil to be remediated for a particular criterion, but also to estimate the related risk that may be incurred in doing so.

GENERATION OF THE TOOL

Generating volume data for varying cleanup criteria is painstaking and time-consuming. It includes the following activities.

Characterization

Work begins with field sampling, logging of field data, and proper packaging and delivery of samples to the analytical laboratory. Locating sampling points systematically to determine the horizontal and vertical extent of contamination is a critical task. After laboratory analysis of the matrix for the contaminants of concern, the data are reported to interested parties. All quality assurance/quality control requirements will be met during this activity.

Laboratory data are checked against field information for correctness and possible reporting errors. The data are analyzed to determine depths and levels of contamination at each sampling location, which are then compared with cleanup criteria.

Volume Calculations

Volume calculations are performed using the software package SURFER (by Golden Software). However, if the input data are not complex, the volume may be calculated without the use of proprietary software. The software program creates a surface that represents the greatest depth of contamination for the area. The volume can then be calculated using the elevation "0" for ground level and the elevation of the SURFER-generated surface. The volume of soil to be removed is generated for each set of cleanup criteria.

APPLICATION OF THE TOOL

When performing remedial action, limiting factors such as availability of storage space, achievability of ALARA goals, minimum cleanup criteria set by governing agencies, acceptable limits of risk for health and environmental factors, cost, and budget must be weighed carefully. The range of acceptability for each factor is determined to effectively evaluate the options for performing remedial action. For example, if storage space is the limiting factor, the manager determines the corresponding cleanup criteria, risk, and cost. If these three factors fall within the acceptable range, then the storage space is sufficient. If not, the manager can implement the ALARA concept by accepting a higher risk for a lower cost. In selecting the more stringent criteria, the manager accepts a higher cost (within the allowable budget) to achieve a lower risk. Generally, the increase in cost will be minimal to certain criteria; costs will increase sharply as the criteria become stricter. Therefore, it is essential to determine an optimum point within the range of minimal cost increase.

CASE STUDY

The 8.1-ha (20-acre) Elza Gate site is located in the eastern portion of the city of Oak Ridge, Tennessee, in what is now known as Melton Lake Industrial Park. In the early 1940s, the site was developed by the Manhattan Engineer District as a storage area for pitchblende (a high-grade uranium ore from Africa) and ore processing residues. In 1946, ownership of the site was transferred to the Atomic Energy Commission (AEC). AEC used the site until the early 1970s, at which time it was vacated. After a radiological survey and appropriate decontamination activities were conducted in 1972, the site was deemed acceptable for use with no radiological restrictions under existing criteria. At that time, the property was transferred to the General Services Administration and then to the city of Oak Ridge. The property was subsequently sold to Jet Air, Inc., and used for the operation of a fabrication and metal plating facility. In 1987, at the request of the Tennessee Department of Health and Environment, Oak Ridge Associated Universities conducted a survey at the site because of the possibility of contamination from the metal plating facility. This survey confirmed the presence of heavy metals and polychlorinated biphenyls. In October 1988, a preliminary radiological survey of the site was conducted by Oak Ridge National Laboratory for DOE; the survey indicated contamination exceeding current guidelines for declaring a site eligible for remediation under FUSRAP. As a result, on November 30, 1988, the entire Melton Lake Industrial Park was designated a FUSRAP site. In 1988, ownership of the site was transferred to MECO, a development company. The site is presently under further development for use as an industrial park (6).

FUSRAP cleanup criteria for radium-226, thorium-230, and thorium-232 radionuclides are 5 pCi/g above background concentrations for the first 6 in. of soil and 15 pCi/g above background concentrations for soil deeper than 6 in. No DOE cleanup criteria have been established for uranium-238, the other radionuclide of concern; a value of 59 pCi/g was calculated by the RESRAD computer model based on several site-specific parameters (7). In an effort to implement the ALARA process, DOE has adopted 35 pCi/g as the uranium-238 guideline based on the tool. Justifiable deviation from this guideline, within reasonable limits of risk and cost savings, is an option, and variation from it with the intent to meet project goals is acceptable.

Volume calculations were performed for the following uranium criteria: 5, 25, 35, 50, and 100 pCi/g. These volume values were plotted on a graph (Fig. 2). Table I shows the calculated values. Relative cost is not shown. The mortality risk for 59 pCi/g has been calculated to be 4×10^{-5} and is shown on the right side y-axis. Values resulting in higher mortality risk were unacceptable according to Environmental Protection Agency and DOE guidelines.

The optimum cleanup criterion was determined by extending the tangents to the asymptotic regions of the curve to the point of intersection and bisecting the formed angle. In this case, the optimum criterion is 27 pCi/g, requiring that 6,881 m^3 (9,000 yd^3) of soil be removed. The risk is slightly decreased.

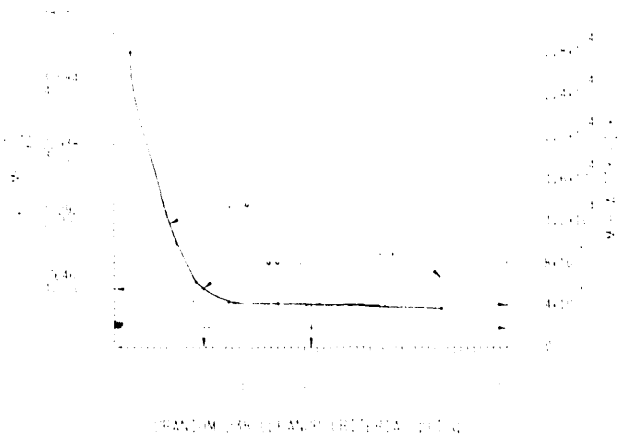


Fig. 2. Volume of contaminated soil vs. uranium cleanup criteria for the Elza Gate Site.

CONCLUSIONS

Certain radionuclides, including uranium, are not addressed in radiological protection guidelines for cleanup of residual radioactive contamination at FUSRAP sites; thus, the options are open to investigation. DOE currently uses the RESRAD computer model to establish a uranium cleanup criterion based on an allowable nonoccupational exposure limit of 100 mrem/yr.

In this paper, a new tool for use in the decision-making process is discussed. A parametric study was performed to establish cleanup criteria for low-level radioactive contamination. A key parameter in the analysis is the volume of material to be removed. The volume becomes a function of the cleanup criteria in that the more stringent the criteria, the deeper the

TABLE I

Volumes of Soil to be Remediated at the Elza Gate Site Under Various Uranium-238 Cleanup Criteria

Cleanup Criteria	Calculated Volumes of Soil	
(pCi/g)	(m^3)	(yd^3)
5	34,407	(45,000)
25	7,570	(9,900)
35	5,352	(7,000)
50	5,046	(6,600)
100	4,511	(5,900)

required excavation. The depth of contamination to be removed varies over the range of the criterion, thereby producing a corresponding range of volumes. The speed of computer-aided volume computation methods makes this calculation feasible and reproducible.

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HANFORD SITE PAST PRACTICE INVESTIGATION STRATEGY

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ABSTRACT

The U. S. Department of Energy (DOE), U. S. Environmental Protection Agency (EPA), and the Washington State Department of Ecology (Ecology) have negotiated a strategy for performing Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) and Resource Conservation and Recovery Act (RCRA) Past Practice investigations in a more streamlined manner with a bias-for-action.

This strategy provides new concepts for 1) accelerating decision-making by maximizing the use of existing data consistent with data quality objectives and 2) undertaking expedited response actions and/or interim remedial measures as appropriate to either remove threats to human health and welfare and the environment or to reduce risk by reducing toxicity, mobility or volume of contaminants. Since the goal of the program is cleanup, much more emphasis will be placed on initiating and completing waste site cleanups through interim measures. While investigations and studies are important in meeting long-range goals, there is now agreement by the parties that an appropriate and significant portion of the near-term funding resources can and should be dedicated to remedial work, where there is sufficient information from which to plan and implement interim remedial measures.

The initial stages of Hanford clean-up will optimize the use of interim cleanup actions when justified and practicable. Existing data will be evaluated as the initial basis for decision-making. If the data are found to be insufficient, additional essential data will be collected to support the IRM in a limited field investigation (LFI). Only data needed to formulate a conceptual model (source to pathway to receptor) and qualitative risk assessment would be obtained. The data quality objectives of the LFI will be established based on the use of the data in deciding on IRMs. The data might not need to be of the same quality needed to support final RODs, since the IRM itself would yield valuable information for supporting the final ROD. As IRMs are completed, the later stages of the program would involve more thorough assessment of cumulative risks and environmental effects. In short, the objective would be to achieve real cleanup, where it is obviously necessary to bring health and environmental risk into acceptable levels in the shortest possible time, in a cost effective manner. This would require that the initial focus of the IRMs is on the most obvious problems and on the most achievable and cost effective solutions.

As the cleanup program proceeds through IRMs in the initial stages of cleanup, the strategy envisions that opportunities for effective IRMs may diminish and the need for more comprehensive investigations leading to final remedy selection will then command an increasing shift of resources to complete characterization for cumulative risk assessments and final remedy selection.

INTRODUCTION

In May 1989, the U. S. Environmental Protection Agency (EPA), the Washington State Department of Ecology (Ecology) and the U. S. Department of Energy (DOE) entered into an Interagency Agreement to provide a legal and procedural framework for cleanup and regulatory compliance at numerous hazardous waste sites at the Hanford Site.

Four subareas of the Hanford Site (the 100, 200, 300, and 1100 Areas) have been included on the EPA's National Priorities List (NPL). Under the Hanford Federal Facility Agreement and Consent Order (Tri-Party Agreement), the more than 1000 inactive waste disposal and unplanned release sites have been grouped into 78 operable units (74 source operable units and 4 groundwater operable units which underlie the source units). The contamination is in the form of solely hazardous waste, radioactive mixed waste, and other Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) hazardous substances. Included within the Tri-Party Agreement are 55 Resource Conservation and Recovery Act (RCRA) treatment, storage, or disposal (TSD) facilities which will be closed or permitted to operate in accordance with WAC 173-303 (RCRA) regulations. Some of these TSD facilities are included in the operable units. The Tri-Party Agreement requires that the cleanup programs at Hanford integrate the requirements of the CERCLA program, the federal RCRA/Hazardous and Solid Waste Amendments (HSWA) program and the state's dangerous waste program. As such, the scope of the agreement includes all actions through CERCLA remedial actions and RCRA/HSWA corrective measures. At the same time it integrates activities related to RCRA interim status compliance, RCRA permitting and RCRA closure activities which apply to the TSD units.

While the EPA maintains authority for CERCLA, Ecology has received authorization from EPA to implement the state's dangerous waste program in lieu of the federal RCRA program. In addition, the state has received authorization to implement the EPA's radioactive mixed waste program. The state does not yet have HSWA authority and that authority remains under EPA. Thus, as a result of the rather complex regulatory involvement coupled with the sheer size of the cleanup program, a major challenge of the Tri-Party Agreement is to coordinate, in a cost effective and timely manner, the different requirements of CERCLA, RCRA corrective action and RCRA TSD activities. In many cases these activities occur at the same physical location.

The experience gained to date on developing the work plans and permit applications has shown the need for rethinking the strategy of RCRA/CERCLA integration beyond that

specified in the Tri-Party Agreement to provide for greater uniformity in the applicability of requirements to the Hanford Site. Due to complexity of the Hanford Site operable units, particularly with regard to characterizing existing mixed waste and hazardous waste contamination, and the need to obtain sufficient quantities of data necessary to provide a high degree of certainty in decision making, the schedules for investigations have become very long, ranging from three-and-one-half years to seven years. For the same reasons, the costs of the RI/FSs showed growth well beyond initial expectations. Further, because there were no plans to provide for any cleanup actions to commence until the Record of Decision (ROD) was issued following the RI/FS, DOE and the regulatory agencies became concerned that too much time and too large a fraction of a limited budget would be spent before evidence of actual cleanup could be demonstrated.

The lessons learned from work plan development also showed that there was a need to more closely integrate source and groundwater operable units such that the information gained from each of the investigations was in sync and available for input into the source and groundwater risk assessments conducted in parallel. Also, since a groundwater operable unit covers an area which encompasses several source operable units, many of which are scheduled for investigation much later in the program, there was a need for early identification of the specific sites within source operable units which are significant contributors to groundwater contamination. It was agreed that these significant contributor sites should be brought forward into the overall investigation and risk assessment for the groundwater aggregate area.

Through the lessons learned in work plan development, all parties to the Tri-Party Agreement recognized that all past practice investigations must be managed and implemented under one characterization and remediation strategy regardless of the regulatory agency lead (as defined in the Tri-Party Agreement) and the applicable regulations (CERCLA or RCRA corrective action). In addition, there was a need to coordinate past practice investigations with RCRA closure activities since some operable units contain RCRA TSD facilities.

The high costs and long schedules associated with traditional past practice investigations have given the parties a new perspective on the need to streamline the RI/FS and RFI/CMS processes. In addition, and perhaps most importantly, the parties have recognized that, since the goal of the program is cleanup, much more emphasis needs to be placed on initiating and completing waste site cleanups through interim measures. While investigations and studies are important in meeting long-range goals, there is now agreement by the parties that an appropriate and significant portion of the near-term funding resources can and should be dedicated to remedial work, where there is sufficient information from which to plan and implement interim remedial measures.

The parties have undertaken an ongoing dialogue over the past year to develop a new strategy for streamlining the past practice corrective action process. This strategy provides new concepts for 1) accelerating decision-making by maximizing the use of existing data consistent with data quality objectives and 2) undertaking expedited response actions and/or interim remedial measures as appropriate to either remove threats to human health and welfare and the environment or to reduce risk by reducing toxicity, mobility or volume of contaminants.

OBJECTIVES

A primary objective of this strategy is to develop a uniform streamlined process to meet statutory requirements and integrate CERCLA RI/FS and RCRA Past Practice RFI/CMS guidance and ensure the protection of human health and welfare and the environment at the Hanford Site through effective cleanup actions (effective both in terms of protection and cost). DOE's responsibilities and authorities under the Atomic Energy Act of 1954 (as amended) are not included in the considerations of this strategy. The strategy must satisfy the Tri-Party Agreement and in turn RCRA and CERCLA requirements. This process will be used in both EPA-lead and Ecology-lead past practice units.

The strategy describes concepts and framework for the RI/FS process, in a manner that has a bias-for-action through optimizing the use of interim remedial actions, culminating with decisions on final remedies on the operable unit and aggregate area scale. The overall process leading to final RODs is described in general terms; however, more details are given regarding the initial stages of Hanford cleanup which focus on reaching early decisions to initiate and complete cleanup projects. These early decisions will maximize the use of existing data coupled with focused short time-frame investigations where necessary. As more becomes known about the contamination problems and associated risks through interim actions and through the early, priority-based investigations and studies, the details of the longer term investigations and studies will be better defined. The parties recognize that the details of most longer-term programs cannot be effectively specified when operable unit work plans are initially written. To define such specifics requires more information, which is expected to be forthcoming as results of the near-term work become available. The parties intend that such definition be provided by mutual consultation and incorporated as future work plan addendums, specific agreed to statements of work, etc., which will be reflected in Appendix D of the Tri-Party Agreement Action Plan.

The strategy recognizes that the RI/FS process is a continuum of activities whereby the effort is defined based upon knowledge gained as work progresses. Thus work plans are intended to, (1) Describe in detail what is known about the operable unit; (2) Describe in detail the agreed-upon focused and priority-based investigations, agreed to when the work plan is submitted for approval; and (3) Describe in general terms the framework and process to be followed for the overall RI/FS (RFI/CMS) process.

The parties intend that this strategy be consistent with the requirements of the NCP and RCRA. The strategy defines the Hanford RI/FS (RFI/CMS) process. While the strategy is intended to streamline investigations and documentation and to promote the use of interim actions to accelerate cleanup, the elements of the investigations and interim actions are in aggregate intended to meet all of the objectives of the RI/FS and RFI/CMS processes.

The initial stages of Hanford clean-up will optimize the use of interim cleanup actions when justified and practicable. Existing data will be evaluated as the initial basis for decision-making. If the data are found to be insufficient, additional essential data will be collected to support the IRM in a limited

field investigation (LFI). Only data needed to formulate a conceptual model (source to pathway to receptor) and qualitative risk assessment would be obtained. The data quality objectives of the LFI will be established based on the use of the data in deciding on IRMs. The data might not need to be of the same quality needed to support final RODs, since the IRM itself would yield valuable information for supporting the final ROD. As IRMs are completed, the later stages of the program would involve more thorough assessment of cumulative risks and environmental effects. In short, the objective would be to achieve real cleanup, where it is obviously necessary to bring health and environmental risk into acceptable levels in the shortest possible time, in a cost effective manner. This would require that the initial focus of the IRMs is on the most obvious problems and on the most achievable and cost effective solutions.

As the cleanup program proceeds through IRMs in the initial stages of cleanup, the strategy envisions that opportunities for effective IRMs may diminish and the need for more comprehensive investigations leading to final remedy selection will then command an increasing shift of resources to complete characterization for cumulative risk assessments and final remedy selection.

The strategy provides for Expedited Response Actions (ERAs) and IRMs that are consistent with both regulatory requirements and the Tri-Party Agreement Action Plan (Sections 7.2.3 and 7.2.4). ERAs would meet the requirements of removal actions and IRMs would meet the requirements of interim remedial actions, as provided in the EPA's National Contingency Plan (NCP) (40 CFR 300). Interim measures as provided in the proposed amendments to 40 CFR parts 264-271(55 FR 30798) could be performed either as ERAs or IRMs as deemed appropriate by the parties. This strategy will be revised to incorporate appropriate RCRA corrective action provisions upon adoption and regulatory review of the final rule.

Investigations for RCRA TSD closures conducted within past practice operable units will be fully integrated into past practice aggregate area management studies, work plans and the investigation and abatement process. These RCRA TSD closure investigations would comply with the substantive applicable requirements of RCRA. Section 6 of the Tri-Party Agreement Action Plan further describes implementation of RCRA at the Hanford Site. At the initiation of the first of either the RCRA TSD closure plan, or the Past Practice aggregate area management study or work plan, the involved parties (which would include DOE and either one or both of the regulatory agencies due to Tri-Party Agreement lead assignments) would meet to coordinate the schedules of the investigations or abatement activities and adjust milestones accordingly. The goal is to gain optimal efficiencies in site investigations by coordinating the field activities, while maintaining a schedule of investigations and abatement measures that assures protection of human health and welfare and the environment, documented in a compliance schedule of the Tri-Party Agreement.

The strategy makes effective use of a process similar to the standard "scoping study" to gather and analyze existing data to allow a more limited and focused remedial investigation process. In this manner, the existing data base would become the basis for decisions, where sufficient data and data quality exist.

In cases where existing data are sufficient, it is appropriate to make the Feasibility Study (FS) process much more efficient by initiating formal evaluations of remedial technologies during "scoping" and, by mutual consent of the three parties, reducing the number of alternatives evaluated. Further efficiencies can be realized in these cases if treatability studies are initiated early in the program. The number of alternative treatment technologies that would be evaluated in both the early case, as provided in this strategy, and in the detailed analysis of alternatives portion of the FS in the normal past practice process, could be limited because: the existence of few known effective and technically feasible remedial technologies available to address the particular site problems; recent abatement experience at similar sites; or applicability of particular applicable or relevant and appropriate requirements (ARARs) which might constrain the number of alternatives capable of meeting ARARs as required by the NCP. Also, for certain types of sites (e.g. large non-hazardous waste landfills), the number of treatment or containment alternatives evaluated might be reduced or eliminated if consistent with the EPA's expectation for remediating that particular type of site (NCP preamble 55 FR 8702-8703;NCP regulatory language, 40 CFR 300.430(a)(1)(iii)).

Finally, the strategy identifies critical programmatic decisions and the timing of those decisions. Such decisions are important to the implementation of the strategy. All of these objectives are in keeping with the ultimate goal of performing cleanup at the earliest possible date in the most effective manner that is technically sound. This is compatible with the stated goals of the EPA streamlining efforts as shown in the NCP and other documents.

An important objective of the strategy will be for the parties to work together in identifying the best mix of ERAs, IRMs and investigations to optimize the use of available resources. The goal of such optimization is to focus on real cleanup while still maintaining a technically sound and cost effective program of investigations which meets the intent of the Tri-Party Agreement.

STRATEGY

Figure 1 graphically depicts the Hanford Past Practice Investigation Strategy. A complete, detailed description of the process is found in DOE/RL-9104, Hanford Past Practice Investigation Strategy, August, 1991.

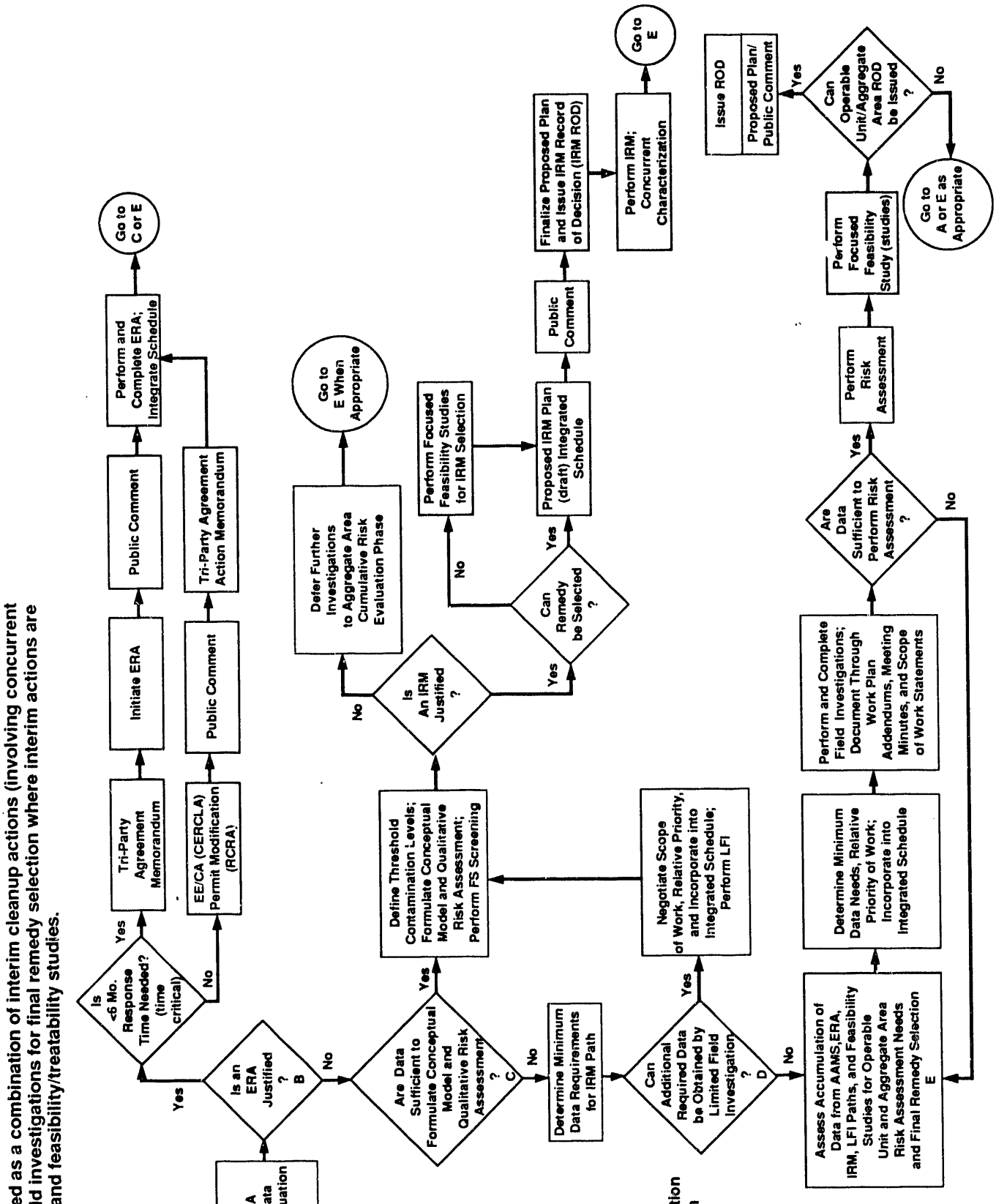


Fig. 1. Hanford past practice RI/FS (RFI/CMS) process.

CHAOS AND REMEDIAL INVESTIGATIONS

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ABSTRACT

Current research into the nature of chaos indicates that even for systems that are well known and easily modeled, slight changes in the scale used to measure the input have unpredictable results in the model output. The conduct of a remedial investigation (RI) is dictated by well-established rules of investigation and management, yet small changes in project orientation, regulatory environment, or site conditions have unpredictable consequences to the project. The consequences can lead to either brilliant success or utter failure.

The chaotic effect of a change in scale is most often illustrated by an exercise in measuring the length of the coast of Great Britain. If a straight ruler 10-kilometers long is used, the sum of the 10-kilometer increments gives the length of the coast. If the ruler is changed to five kilometers long and the exercise is repeated, the sum of the five-kilometer increments will not be the same as the sum of the 10-kilometer increments. Nor is there a way to predict what the length of the coast will be using any other scale. Several examples from the Fernald Project RI are used to illustrate "changes in scale" in both technical and management situations.

Given that there is no way to predict the outcome of scale changes in a RI, technical and project management must be alert to the fact that a scale has changed and the investigation is no longer on the path it was thought to be on. The key to success, therefore, is to develop specific units of measure for a number of activities, in addition to cost and schedule, and track them regularly. An example for tracking a portion of the field investigation is presented. The determination of effective units of measure is perhaps the most difficult aspect of any project. Changes in scale sometimes go unnoticed until suddenly the budget is expended and only a portion of the work is completed.

Remedial investigations on large facilities provide new and complex challenges. Not only are traditional management tools necessary, but innovative approaches and tools are required to achieve repeated successes in a chaotic environment.

WHAT IS A REMEDIAL INVESTIGATION?

At the beginning of a RI two deceptively simple questions are posed: What is the vertical and lateral extent of the contamination? What are the forces controlling the rate and direction of the migration of the contamination? The first step in the RI is to review all the existing data to determine the potential areas which could be the sources of the contamination, compile a list of the potential contaminants and their properties, review what is known about the local geology, and determine where groundwater is and in which direction it is flowing. This information is then used to write a sampling plan that will fill in gaps in the current data or investigate areas where there is no current data.

The initial sampling plan is by its very nature the first change in scale and opens the door to chaos. The site was known at the scale defined by the density of the previous sampling points The sampling plan for the RI will require a new set of sampling points that changes the spacial scale and it will likely require a quarterly monitoring of existing and new wells which will be a change in the time scale. Although the plan will have been written to answer specific questions, the initial installation of wells, soil sampling in source areas, groundwater sampling, and surface water sampling will reveal unexpected results. These results may indicate that the nature and extent of the contamination is different from what the initial data suggested or that the forces controlling migration are more complex than the initial geologic model suggested.

In order to manage cost and time as prudently as possible, a well-written sampling plan will include at least two phases of investigation. Although it is not possible to predict the magnitude of the second phase, it is almost a certainty that changing the scale in the first phase will reveal unsuspected conditions and result in an additional sampling program.

Figure 1 illustrates the sampling cycle that is repeated until the conclusion is reached that enough data has been collected. The cycle consists of doing field work, laboratory analysis, and an evaluation of the results to determine if all the questions that the plan was to address were answered sufficiently. If the answer is yes, then the sampling is complete; however, it is usually the case that some answer is not quite complete. The leading edge of a groundwater plume may have gone farther than expected. A contaminant concentration may have been much higher than expected or shown up in what was to be a background well. Therefore, a second sampling plan is developed and the cycle is repeated. Each repeat of the cycle is for a more specific question or to provide detail to a generally defined problem.

Eventually it is determined that there is enough data to proceed with the feasibility study. No one could say how many wells would be enough at the start of the project and there are probably a few places where it would not hurt to have one more well. However, all parties finally agree that the net benefit of a few more wells or samples is not worth the schedule impact.

FERNALD SITE

The geology of the RI site in the vicinity of the Fernald Environmental Management Project (FEMP) near Fernald, Ohio, is relatively simple. The regional bedrock is Upper

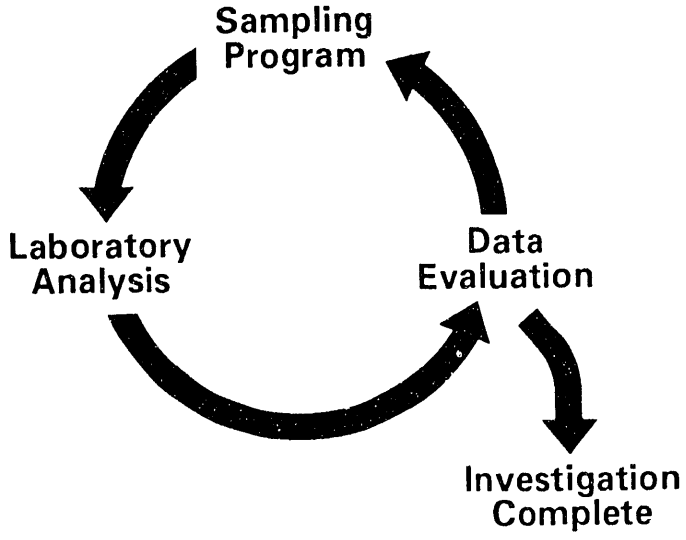


Fig. 1. Sampling cycle.

Ordovician shale that is essentially impermeable. Pleistocene rivers carved valleys in the bedrock that are roughly 60 meters deeper than the present land surface. As the early continental ice sheets retreated, these valleys filled with well-sorted outwash to form the major aquifers in southwestern Ohio. In some areas the aquifers are capped by till which includes sand and silt lenses in generally very low-permeability clay rich material. The heterogeneous material overlying the outwash in the aquifer is referred to collectively as glacial overburden. The Fernald site is located over a buried valley approximately three kilometers wide. The Fernald facility rests on glacial overburden that ranges from eight to 15 meters thick.

Perched groundwater has been found throughout the glacial overburden. Although it has not been demonstrated that perched groundwater flow carries contaminants over long distances, the potential for flow based on water table measurements is generally from the northeast to the southwest. The upper six to nine meters of the underlying sands which comprise the aquifer is unsaturated and many of the wells that are screened at the water table breath with changing weather conditions. Groundwater flow in the aquifer is controlled by the geometry of the buried valleys and the location of recharge sites.

Figure 2 shows the general features of the Fernald site. The FEMP covers 425 hectares of relatively flat land, with the Production Area taking 48.5 hectares in the north-central part. The Great Miami River flows generally from north to south, passes to the east and south of the Fernald site, and receives all groundwater and surface water from the site. Paddys Run and its tributaries collect virtually all of the surface water from the site. Paddys Run and its tributary, the Storm Sewer Outfall Ditch, have eroded through the glacial overburden and their beds are the aquifer sand deposits. As a result, these streams contribute recharge water directly to the aquifer as well as transport runoff to the Great Miami River.

Fernald Groundwater Investigation

At Fernald there were several phases of additional drilling that began to be developed after the first two quarters of groundwater sampling data became available from the 97

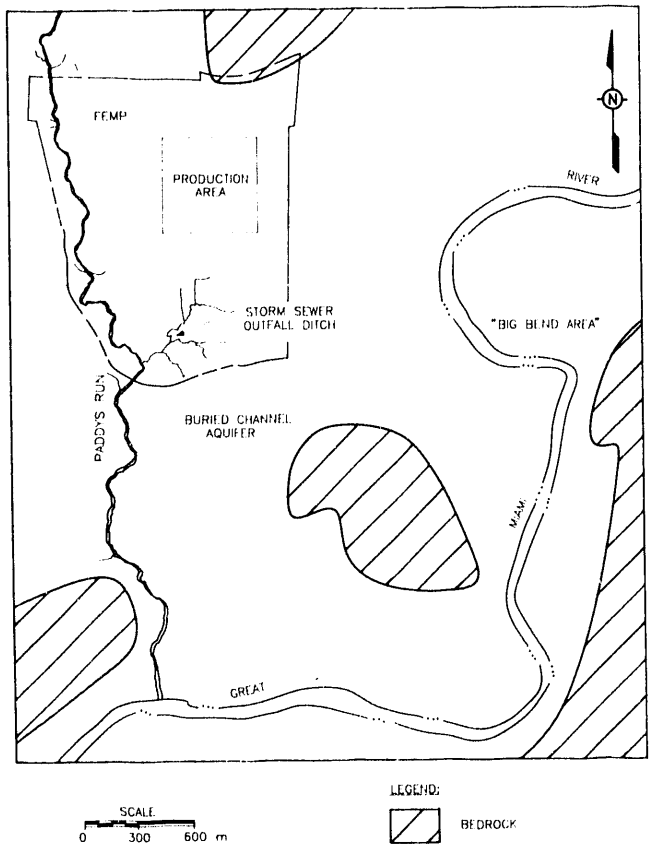


Fig. 2. Surface water hydrology.

wells called for in the initial RI work plan. The additional phases included 24 wells on the FEMP, 10 south of the FEMP on private land, 31 wells on and off the FEMP, and a current proposal for 21 additional wells on the FEMP to establish details about the boundary of the uranium plume and background water quality. The monitoring wells are on a spacing that has wells no closer than 100 to 150 meters, with some more than 300 meters apart. The drilling program utilized two to four cable tool drilling machines working at the same time in relatively open areas providing easy access. Well depths were 10 to 67 meters with the majority of the wells in the 25- to 40-meter range. All wells were completed with 100-mm stainless steel screen and casing.

A significant change in scale of the investigation occurred when the production of uranium products ceased and the EPA insisted on a full investigation of the Production Area. Since this was an operating facility at the beginning of the RI, the RI/FS Work Plan did not include any detailed drilling and sampling activity in the Production Area. In March of 1989 the Production and Additional Suspect Areas addendum to the RI Work Plan was implemented. This work plan initially included about 150 borings up to six meters deep on a 76-meter grid and 100 borings next to specific suspected sources such as underground tanks, process sumps, and historic spill areas. This drilling program utilized three hollow-stem augers working simultaneously in and around process buildings, tank farms, and storage pads. Any boring that encountered perched groundwater in the glacial overburden was converted to a 50-mm piezometer to allow water level measurements and perched groundwater sampling for radionuclides.

While the general level of effort sounds similar to the initial well installation program in terms of numbers of rigs and the sampling depths were much shallower, the effort required to conduct this phase of the investigation was unpredictably greater than expected. The logistics of access, higher levels of ambient contamination and hazards due to production operations, underground electrical and natural gas lines, and stored materials, all resulted in a change in the magnitude of management effort required to conduct the program.

There were two other major scale changes. The obvious one was the compression of sampling density from wells on an irregular 100- to 150-meter spacing to borings (many of which were completed as piezometers) on a 76-meter grid or less. The initial findings from this program have predictably resulted in additional sampling on a finer scale to determine the nature and extent of pockets of mixed waste in the surface soil and the extent of contamination in the perched groundwater in the glacial overburden. This change in the scale of the boring frequency and the increase in the number of soil samples analyzed from each boring also greatly increased the amount of data to be stored, sorted, and reported.

The perhaps less obvious scale change was in the level of management effort required to keep the program on schedule. The same number of drilling machines were operating as had been used in the monitoring well installation program, so that was not really a scale change. The paperwork to properly clear a site for drilling a six-meter boring in the Production Area was much greater than that required to put a 60-meter well in an open pasture. Many borings that were installed inside buildings could only be drilled on the second shift when all power in the facility could be turned off because of the uncertainty of the location of buried electrical lines. Many borings within buildings required multiple attempts because buried piping, footers, or other obstructions not located on facility drawings were encountered by the drill.

The challenge was to accurately report weekly progress to the DOE and monthly progress to the EPA on activities that were difficult to schedule and subject to delays from a wide variety of causes outside of the contractor's control. Figure 3 illustrates one of the effective tools that indicated if the over-all boring program was on schedule even though individual drilling teams were not always able to stay on schedule. This also illustrates the effectiveness of turning a change in scale into an advantage. In order to provide accurate, frequent reporting, results must be measured at a scale that is finer than the one being reported to. In this case, reporting on a weekly basis required tracking on a daily basis.

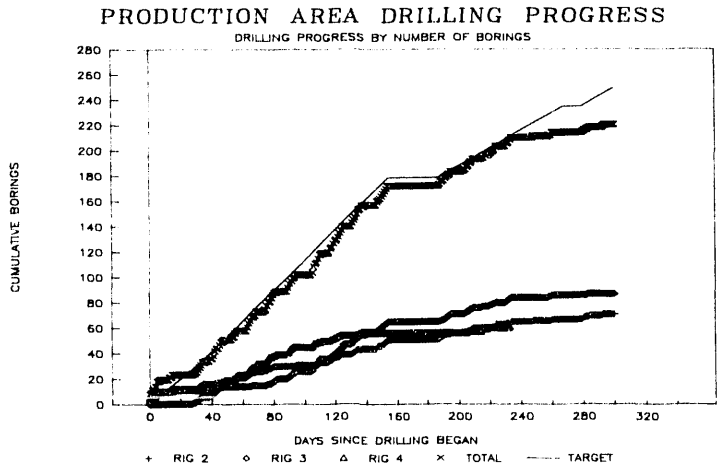


Fig. 3. Borings per day per drill rig.

Figure 3 shows how the program was tracked on a borings-per-day scale. A completed boring was defined as one where the drill rig had moved off the site. This thwarted the tendency of the drilling team to say "the boring was complete" when they had reached their target depth. That statement always sounded good but it left out the time still required to either backfill the hole with grout or install a piezometer. This definition provided a specific and consistent unit of measure with which to track progress. In chaotic situations it is imperative that progress be based on some specific measurable result.

As Fig. 3 shows, each drill rig was tracked to determine the overall progress. The individual performance of each drill was very different because the level of difficulty for each boring location varied considerably. The overall program remained on track because task leaders could assign the drilling site assignments so that all the drill rigs were not on difficult locations at the same time. The final few borings at the end of the program were the ones with the most difficult access problems. Although they were not completed within the planned time frame, they also did not delay the majority of the data analysis for the investigation. Thus an overall success was achieved because the impact of possible unexpected delays was minimized.

Long-Term Monitoring Programs

The establishment of a long-term monitoring program is a scale change that can cause unpredictable changes in the investigation. These scale changes are often made by Mother Nature, who is truly in charge of the situation, which is exactly why long-term monitoring is required. The RI is fundamentally trying to determine how natural conditions are influencing the migration of the contamination. It is essential, therefore, to continue sampling the wells or a selected subset of them to establish the baseline conditions against which to measure progress during the remedial activity, and establish the natural variability of concentration levels, water levels, and flow directions. The scale change here is the time frame over which monitoring data exists.

It is important to know the dynamics of the natural system before an artificial force is imposed on the natural system. If the magnitude of natural variations have been established, then when the remedial action does not perform as expected, it can be determine if the failure is in the design or is simply due to natural variations. The only important question after a groundwater remedial action is started is "How soon can it be turned off?" If the remedial system cannot be effectively managed during its operation, it will be very difficult to convince the agencies that the remediation is complete or even making progress.

At Fernald there were two unpredictable consequences of the establishment of a long-term monitoring program. The first was from the water-level measurements in groundwater monitoring wells. The second was a consequence of continuing the water quality sampling beyond the initial year of quarterly sampling required under the RI Work Plan.

Monthly water level measurements were initiated in January 1988 and still continue even though the sampling plan

called for only four quarters of groundwater sampling from the wells. It turned out that the year of quarterly groundwater sampling was also a record dry year for the Fernald area and there was little or no surface water flow in Paddys Run, an intermittent stream that flows along the western edge of the Fernald site (Fig. 2).

Paddys Run is the principal pathway by which uranium has reached the regional aquifer. The bed of Paddys Run and its tributary, the Storm Sewer Outfall Ditch, is the sand which contains the regional aquifer. Therefore, contaminated surface runoff from the waste pit area and the Production Area enters Paddys Run and recharges the aquifer. This mechanism was known at the start of the RI/FS from previous studies. What was not known was the magnitude of the recharge and the impact this recharge has on groundwater flow directions.

Figure 4 shows the water table contours for September 1989 when there was no flow in Paddys Run. Groundwater is moving in the buried channel aquifer to the east in the northern part of the site and to the south-southeast in the southern part. The approximate location of the groundwater divide between these two flow paths is shown with a heavy dashed line. Figure 5 shows groundwater contours for May of 1990. There is a distinct mound under Paddys Run where recharge was occurring. The effect of the recharge is to shift the groundwater divide to the west and change the orientation of the divide.

In the waste pit area the transient effect is to drive groundwater flow more to the northeast, resulting in uranium contamination in wells that were installed to provide background water quality. Under the southern part of the FEMP the shift in the location of the groundwater divide means contamination at any given location is moving to the east part of the time and to the south part of the time. The resulting arcuate flow path of a particle of contamination is not easily predictable from any one set of water-level measurements, since the path is a result of the frequency and length of the transient effect produced by recharge from Paddys Run.

The second impact of the long-term monitoring is on the perceived distribution of uranium contamination in groundwater. In 1988, when most of the RI samples were collected, southwestern Ohio experienced a severe drought. During 1989 weather conditions were normal and in 1990, the area experienced the wettest year on record. In late 1989 and early

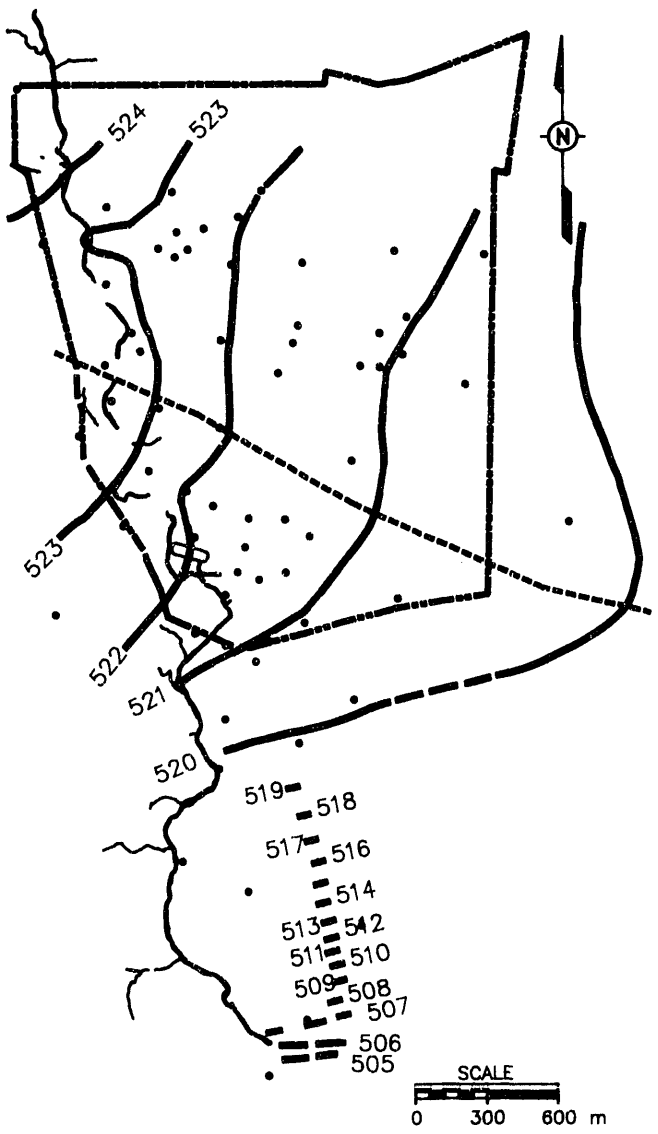


Fig. 4. Groundwater elevations, September, 1989.

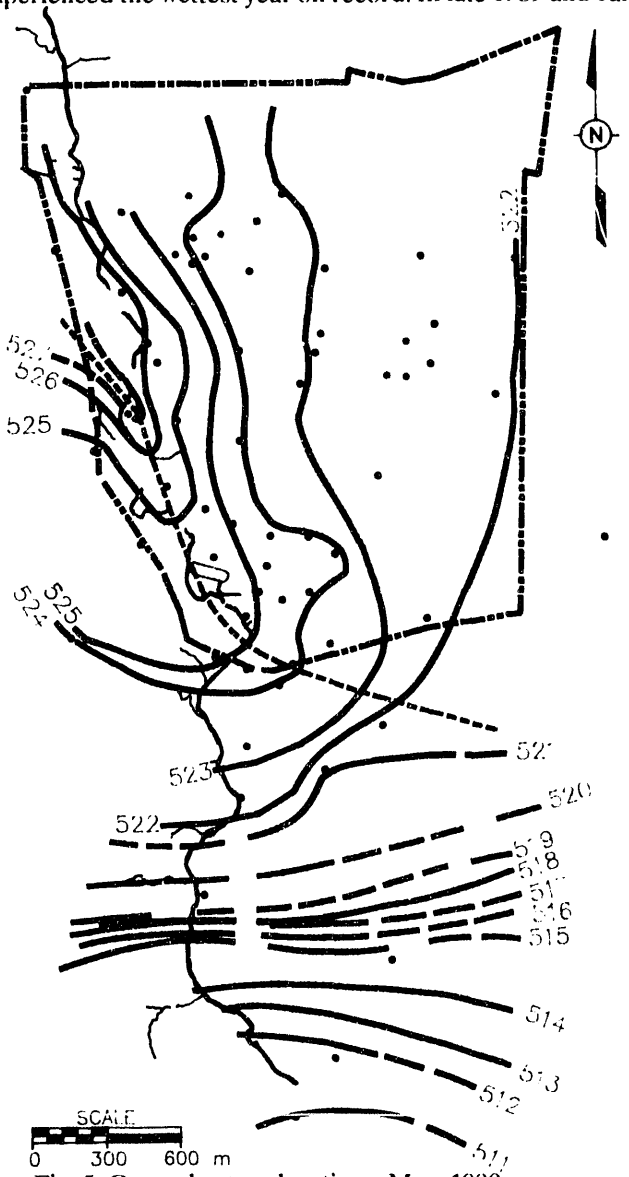


Fig. 5. Groundwater elevations, May, 1990.

1990 uranium values began to rise in a number of wells; some of these wells were supposed to be background and some were supposed to be beyond the leading edge of the plume. This unpredictable result is the reason for the current proposed plan to install the additional 21 wells to determine once again the boundaries of the plume.

Groundwater Modeling

The SWIFT III groundwater modeling code used for the site is a steady-state three-dimensional model and flow has been calibrated on groundwater measurements in a very large area spaced over several years. Using a time interval measured in years, the transients produced by Paddys Run are not significant. The modeled direction of groundwater and contaminant flow are consistent with this time interval of the measurements used in the calibration. Model-predicted contaminant concentrations are also consistent with average values over a multi-year time frame. Therefore, the model is useful for predicting contaminant migration over the time spans required for the risk assessment. It is also extremely useful in determining the location and impact of various extraction-well scenarios for the feasibility study. It shows the impact of the recovery wells for average conditions over a number of years.

The potential for a chaotic impact occurs when an attempt is made to relate the monthly water levels or a single water quality sample to the predicted values from the model. In trying to compare model predictions, which are based on steady state or average conditions, to specific measurements that include transients, the match is not always good. The difficulty becomes especially critical during the early operation of a groundwater remediation program. The weekly results of the remedial action will not precisely match the predictions from the model which are based on a time frame measured in years. It is at this point that the model is often unjustifiably and unmercifully attacked and discredited, when in fact the remedial action has not progressed long enough to generate the necessary data to allow its performance to be compared to the model prediction. During this critical start-up period, the performance must be compared to data collected on a similar time frequency prior to start up. The monthly water level data and the quarterly water quality data from the long-term monitoring program are the best tools for determining the early effectiveness of the remedial action.

OTHER CHAOTIC IMPACTS

For the Fernald RI, chaos came into play when the decision was made to divide the site into five operable units. The effort to decide what data should be included in each operable unit RI Report was only the tip of the iceberg. The increase in the number of authors involved in RI reports and managing their diverse opinions as to style, let alone content and data interpretation, required far greater time, energy, and management skill than producing one massive RI.

The chaotic impact was not limited to the RI contractor. Both the DOE and the regulatory agencies were impacted by the five-fold increase in the number of documents as well. Because of the need to review these documents they were faced with the need to expand their review staffs. The inherent difficulty was to find people who have a knowledge of the site and the critical issues surrounding the site. The impact of involving new people in the review process was that each of them not only had an opinion about the quality of the report, but added questions regarding why the investigation was conducted the way it was. Given that the Work Plan was developed and negotiated in 1986 and 1987, there are a number of things that would have been planned differently if done today.

The impact of the "extra comments" regarding why things were done the way they were was felt by the reviewing agencies as an increase in the volume of comments that had to collate, type, and distribute within the scheduled review time. The impact of the "extra comments" on the documents' authors was to further tax the knowledgeable technical staff who were the only ones with the background to respond to the comments, resolve conflicting comments, and revise a report based on the comments within a strictly set time frame.

This is only one example of how what seemed to be a logical decision that would simplify the organization and timeliness of the feasibility study, resulted in unforeseen impacts on all parties involved in the RI portion of the project.

CONCLUSION

Chaos is present in all aspects of a RI. The key to managing chaos is first recognizing that work is being conducted on some measurable scale and recognize when the scale changes. This requires tracking activities on a finer scale than the one used for reporting. When a decision is made to initiate or terminate an activity, a careful analysis should be conducted to determine what scales are being changed in the process.

The whip of chaos will not go away, but what can be determined is which end of the whip is being held on to and then doing something about it.

REMEDIAL ACTION ASSESSMENT SYSTEM (RAAS) - A COMPUTER-BASED METHODOLOGY FOR CONDUCTING FEASIBILITY STUDIES

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ABSTRACT

Because of the great complexity and number of potential waste sites facing the U.S. Department of Energy (DOE) for potential cleanup, the DOE is supporting the development of a computer-based methodology to streamline the remedial investigation/feasibility study process required for DOE operable units. DOE operable units are generally more complex in nature because of the existence of multiple waste sites within many of the operable units and the presence of mixed radioactive and hazardous chemical wastes. Consequently, Pacific Northwest Laboratory (PNL) is developing the Remedial Action Assessment System (RAAS), which is aimed at screening, linking, and evaluating established technology process options in support of conducting feasibility studies under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA). It is also intended to do the same in support of corrective measures studies required by the Resource Conservation and Recovery Act (RCRA).

One of the greatest attributes of the RAAS project is that the computer interface with the user is being designed to be friendly, intuitive, and interactive. Consequently, the user interface employs menus, windows, help features, and graphical information while RAAS is in operation. During operation, each technology process option is represented by an "object" module. For example, the concentration of a contaminant exiting a treatment process, such as an incinerator, will be determined in the object module as a function of the input concentration, the residence time in the unit process, and the operating temperature. Object-oriented programming is then used to link these unit processes into remedial alternatives. (An example of a remedial alternative is vacuum extraction of volatiles from contaminated soil, followed by excavation, chemical fixation, and redisposal of the contaminated soil.) In this way, various object modules representing technology process options can communicate so that a linked set of compatible processes form an appropriate remedial alternative. Once the remedial alternatives are formed, they can be evaluated in terms of effectiveness, implementability, and cost. RAAS will access a user-selected risk assessment code to determine the reduction of risk after remedial action by each recommended alternative. The methodology will also help determine implementability of the remedial alternatives at the site and access cost estimating tools to provide estimates of capital, operating, and maintenance costs.

This paper presents the characteristics of two RAAS prototypes currently being developed. These include the RAAS Technology Information System, which accesses information on technologies in a graphical and tabular manner, and the main RAAS methodology, which screens, links, and evaluates remedial technologies.

INTRODUCTION

The U.S. Department of Energy (DOE) is facing the major task of cleaning up hundreds of waste sites and completing remedial investigations and feasibility studies (RI/FSs) or facility investigations and corrective measures studies for each of these sites at its facilities across the nation. For example, DOE has 330 proposed operable units on the National Priorities List alone. The first 67 of these waste sites are tentatively scheduled for RI/FS completion in the 1992 to 1997 time frame with implementation of remediation technologies to commence subsequently (U.S. Department of Energy 1989 and U.S. Environmental Protection Agency 1989). The RI/FSs for the remaining 263 operable units will be done over the next 10 to 20 years. These waste sites can involve groundwater, deep and shallow soils with interstitial (pore) waters, surface waters, sediments, sludges, and buried wastes. The initial source of the contamination may have been ponds, drain fields, trenches, cribs, leaky tanks, or pipes. These fabricated structures are themselves part of the remediation puzzle at many sites.

DOE has established a program to expedite the cleanup process through the development of new technologies and integrated demonstrations of developed technologies. It is essential that these technologies be considered, along with established alternatives, for implementation during the RI/FS process. The intent of each RI/FS is to characterize the waste problems and environmental conditions at the operable unit(s), segment the waste remediation problems into manageable media-specific and contaminant-specific pieces, define the remediation objectives, and propose several general response actions to meet these objectives (U.S. Environmental Protection Agency 1988). This might involve various combinations of: a) no action; b) institutional controls; c) waste stabilization and containment; d) waste recovery and treatment; and e) in situ treatment. The RI/FS team must then identify and evaluate various combinations of technologies and associated processes that might be employed to meet the remediation objectives. Furthermore, it must provide

* Operated for the U.S. Department of Energy by Battelle Memorial Institute under Contract DE-AC06-76RLO 1830

defensible rationale why other combinations of technologies and processes are not as effective, implementable, cost competitive, or acceptable.

Although the steps in a feasibility study are relatively straight-forward, there are many twists and turns along the way, especially considering the rigorous quality control that is demanded. A feasibility study analysis should be conducted in at least three different stages of the RI/FS process. First, the feasibility study should be conducted early in the site characterization process so that it can "drive" site remedial investigation activities. This could prevent the syndrome of overcharacterizing the site or repeating sampling and analysis activities at a later date. However, such an initial feasibility study analysis must be conducted with very limited site-specific information. This calls for the availability of a resident database of "engineering-judgement" values (with appropriate electronic tagging) to enable the user to forge ahead in an exploratory, screening mode. The feasibility study should be repeated later in the process to help drive the design of the treatability studies and the second phase of site characterization. Finally, the feasibility study should be again repeated at a later date to conduct the detailed evaluation of the remaining alternatives upon which cleanup can be negotiated with the regulator. To streamline this entire process and make it more defensible, Pacific Northwest Laboratory (PNL) is developing the Remediation Action Assessment System (RAAS). RAAS is a computer-based methodology that provides a discrete, useful product at each of these stages of the RI/FS process. Figure 1 shows graphically how RAAS contributes to the various stages of the RI/FS process.

CHARACTERISTICS OF THE REMEDIAL ACTION ASSESSMENT SYSTEM

In terms of directly supporting the technology development program being conducted by DOE, RAAS 1) provides a vehicle for collecting and sharing detailed information on technologies and regulations, 2) helps implement newly developed technologies as they emerge from demonstration, testing, and evaluation, 3) compares newly developed technologies with more established alternatives, and 4) can be used to support the selection and evaluation process for integrated demonstrations of existing and newly developed technologies.

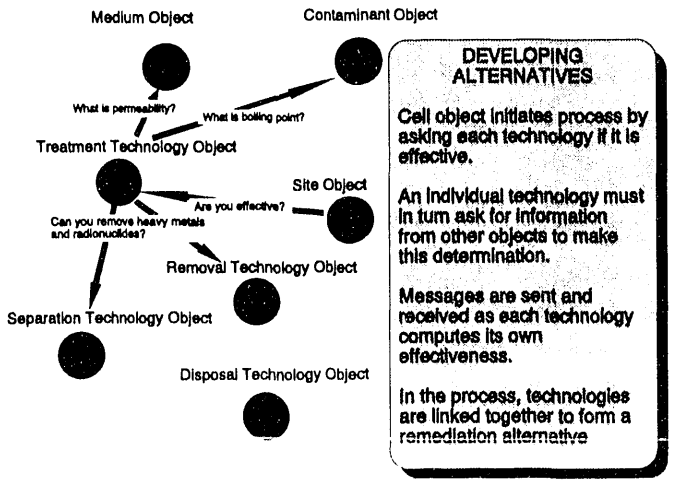


Fig. 1. RAAS contributions to the remedial investigation/ feasibility study process.

In terms of supporting the RI/FS process, RAAS is being designed to be a complementary member of an RI/FS team. As such, it provides 1) a comprehensive information source and broad-based expert advisor to the team; 2) a vehicle for documenting (archiving) the computer's and the RI/FS team's assumptions, data selections, and decisions; 3) a mechanism for identifying site and technology data collection requirements early in the RI/FS process; 4) a mechanism for recommending treatability study procedures; 5) a "cut-and-paste" tool for dumping text-type technology descriptions and tables of technologies that were excluded from further consideration and the rationale for their exclusion; and 6) a vehicle for capturing an RI/FS team's experiences and transmitting this information to other teams across DOE.

RAAS must also permit sensitivity (i.e., what if) studies and thus prompt an RI/FS team to consider innovative and potentially less costly solutions. Those experienced in RI/FS studies tell us that human experts often subliminally select technology combinations that they know the most about and with which they have grown comfortable. Since the overall costs of the DOE environmental restoration problem may be in the range of many tens of billions of dollars, prompting users to consider innovative, less costly technologies may ultimately prove to be one of RAAS's greatest contributions. RAAS is also expected to save millions of dollars by reducing the time and effort required to do (and redo) RI/FSs. RAAS could minimize challenges to the results of many feasibility studies by having the computer explore a much broader array of potential alternatives and document why these alternatives were or were not selected.

RAAS TECHNOLOGY INFORMATION SYSTEM

The RAAS Technology Information System provides the user a graphical display of the technologies that are being included in the main RAAS methodology. It is a stand-alone, computer-based system that identifies and sorts remedial technology information. To date, 88 technologies have been identified for inclusion in the RAAS Technology Information System. These are listed in Table I. Depending on the technology, various process options of each technology are described within the technology description. For example, the rotary kiln, controlled air, and fluidized bed incinerators are described as process options within the incineration technology entry. The information developed for each of these technologies includes:

- a graphical depiction or flow diagram of the process
- a brief narrative description of the process (one to three pages)
- engineering parameters such as power and space requirements
- applicability information as the technology relates to contaminant and media type (e.g., soil, groundwater, sludge)
- regulatory constraints such as compliance with air, water, and solid waste discharge regulations
- limiting technical constraints such as pH or particulate loading limits on feed materials to a unit process
- a graphics screen that accesses information on technologies that are generally combined with the

specific technology of interest (pretreatment processes or processes for treatment of residual waste streams)
- a list of sites where the technology has been considered or implemented in the past
- a list of key technical references.

Information on each of these categories is accessed through the active screen shown in Fig. 2. The cursor is simply clicked on the block of information desired for a particular technology that the user wants to access.

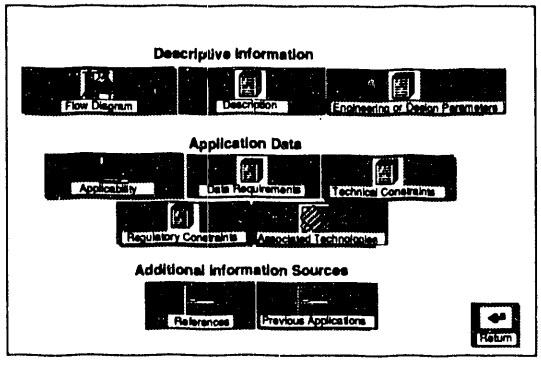


Fig. 2. Screen for accessing technology information in the RAAS Technology Information System.

The technology information has been derived primarily from existing databases (attained via subcontract with private industry), technology reports, and past feasibility studies. The contents of new technology databases are evaluated as they emerge and, to the extent practicable, technology information is adapted for the RAAS Technology Information System.

Development of the user-friendly personal computer program for accessing the technology information was conducted in parallel with the development of the technology information. The computer system selected was the MacIntosh IIc® series personal computer with 5 megabytes of memory and equipped with a 256 color monitor. The program uses Supercard® as its platform software for the user interface and ORACLE® for the database in which the technology information is stored and sorted. The user interface relies on a mouse with pull-down menus to eliminate the necessity of keyboard entries. The demonstration model has been shown to numerous potential user groups with great acceptance of the tool. The first operational version, after incorporation of comments from field testing, is expected to be completed in September, 1991.

Aside from providing an early, usable product, the RAAS Technology Information System will be linked with the main RAAS methodology as a user help feature. The curious user of RAAS can access explanations of technologies or specific information that was used to formulate object modules of technologies considered by the main RAAS methodology. This feature is critical in gaining acceptance of the RAAS methodology by the user community.

MAIN RAAS METHODOLOGY

Another key accomplishment for the RAAS project has been the completion of the demonstration prototype of the main RAAS methodology. This part of the RAAS project is developing the product that selects, screens, links, and evaluates remedial alternatives in support of the feasibility studies required for every DOE operable unit. Some of the methodology's features include:

- screening and linking of technology unit processes into remedial alternatives
- comparative evaluation of technologies and remedial alternatives in terms of established EPA criteria
- documentation of assumptions and decisions made by the user, crucial in defending the recommended alternative for each waste site
- recommendations for treatability tests and site characterization requirements for streamlining the remedial investigation portion of the RI/FS process
- upgrade mechanisms for keeping technology information current
- internal consistency checks to ensure data inputs by the user are consistent with previous data entries and results
- an internal risk assessment model for back calculating cleanup objectives from health-based risk criteria and a data gate for accessing user-selected technology risk assessment models.

The main RAAS methodology is based on object-oriented programming. For each technology unit process, an "object" module is developed for RAAS to describe the controlling characteristics, including the inputs, outputs, and the processing rules and constraints. For example, final concentrations of a contaminant exiting an ion exchange treatment process might be related to the input concentration specified by a pretreatment air-stripping process through direct communication among technology objects. Similarly, the application of in situ vitrification might be constrained by the percentage of organic litter in the soil as specified by internal rules in its object module. Each object-oriented module will have its input and output specifications and its own set of internal operating or process rules and local data. Let us illustrate further.

Numerous ways exist in which various unit processes could be combined into waste containment and/or treatment trains. Therefore, methodology is required to sort these potential combinations and suggest viable alternatives for further considerations. The purpose of this effort is to develop a linking scheme that will allow the RAAS user to identify the "most likely" trains of the particular site problem.

It is impractical to "hard-code" this complex problem. Therefore, a method must be employed that allows the computer program to interact with itself in a free-flowing manner and to interact with the RAAS user and a variety of external databases during operation. Object-oriented computer programming accomplishes this function. In this object-oriented approach, a unit process or technology is represented by an object, and the objects can send messages and ask questions of each other or request more information (Thomas 1989). For example, a certain treatment object may "know" that it is good at handling nonvolatile organics as long as the waste stream it receives does not also contain certain quantities of heavy metals and radionuclides. If such waste constituents are present, the object may send out a request message to all other waste separation and/or treatment objects asking if any of them can deal with the heavy metals and/or organics prior to the waste stream being delivered to the organic treatment

TABLE I

Technologies Included in the RAAS Technology Information System

INSTITUTIONAL ACTIONS

access controls
alternative water supply
groundwater use restrictions
land use restrictions
monitoring

CONTAINMENT

capping
constructed barriers
dust and vapor supression
erosion control
extraction/injection wells
liners
subsurface drainage
surface water control

RECOVERY OR REMOVAL

bulk material storage
dredging
drum and debris removal
excavation
extraction wells
pipelines
surface water control
transportation
underground storage tank removal

VOLUME REDUCTION
air stripping
bioaccumulation
coagulation/flocculation
crystallization
dewatering
distillation
electrokinetic separation
evaporation (forced)
open air evaporation
freeze crystallization
gas absorption and adsorption
gas particulate removal
gravity separation
ion exchange
liquid adsorption
liquid-liquid extraction
media filtration
membrane separation
oil/water separation
soil vapor extraction
soil flushing
in situ soil heating
soil washing
solids classification
solvent extraction
thermal desorption

TOXICITY REDUCTION
aerobic biological treatment
anaerobic biological treatment
calcining
catalytic destruction
catalytic oxidation
chlorinolysis
dehalogenation hydrolysis
in situ biodegradation
in situ vitrification
in situ chemical treatment
incineration
molten solids processing
neutralization
oxidation
photolysis
precipitation
pyrolysis
reduction
roasting
wet air oxidation

MOBILITY REDUCTION

bioaccumulation
encapsulation
in situ solidification
in situ sorption
in situ vitrification
molten solids processing
solidification and stabilization

DISPOSAL

deep well injection
discharge to POTW
discharge to surface water
gaseous discharge to atmosphere
geologic repository
in situ water disposal
in situ soil disposal
injection wells
land application
landfill
low level waste burial
materials reuse
mixed waste landfill
off-site disposal
open air evaporation
TRU disposal
waste to energy

process. This concept is illustrated in Fig. 3. Since all other unit processes (objects) presumably contain local information and rules about what they can and cannot do, return messages will only be received from viable candidate processes or possibly more information will be requested of the original sender.

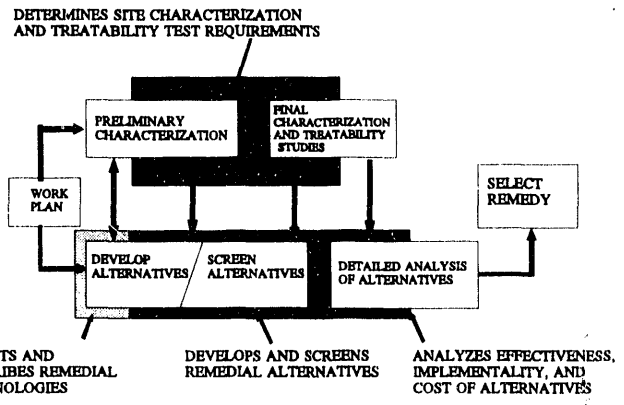


Fig. 3. Object-oriented programming allows technology objects to communicate with each other to form remedial alternatives (treatment trains).

It is important to understand that the human user can and should interact frequently with this process by sending his or her own messages and asking questions of the system. Inversely, the computer program must be able to solicit additional or clarifying information from the user and expect the user to make certain decisions along the way. RAAS is not a black box that the user just turns on and waits for the final answer. The user is an integral, interactive part of the computer methodology. This object-oriented computational approach facilitates this function and minimizes the number of hardwired (hard-coded) connections that are built into the computer model. Although object-oriented programming is very intuitive, powerful, and flexible, it has only recently been made available due to the much greater computing capacity (size, speed) of mini- and micro-computers and commercial software shells now on the market.

CONCLUSIONS

Development of the RAAS Technology Information System and the prototype of the main RAAS methodology has been successful in accomplishing three goals during the project's first year of development. These accomplishments have:

- provided a tool for users to comment on the functionalities and user interface features for development of the first operable versions of RAAS due in late 1991.
- provided a vehicle for gaining acceptance of the RAAS methodology from the regulatory and technical community.
- demonstrated to the development team that object-oriented programming can be used to determine whether technologies are applicable for specific waste site conditions and to effectively construct remediation trains.

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SELECTION OF A PREFERRED REMEDIAL WELL CONFIGURATION USING GROUNDWATER MODELING TECHNIQUES

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International Technology Corporation
Albuquerque and Richland Offices

ABSTRACT

The alternative screening process of a Remedial Investigation/Feasibility Study (RI/FS) at a California location was assisted through the use of numerical modeling techniques to evaluate several groundwater pumping and injection schemes. Computer modeling was used to winnow the alternatives down to a recommended well configuration. The final scheme was a further refinement based on operational considerations. The remedial pumping rate was 200 gallons per minute (gpm), and the initial concentration of trichloroethylene (TCE) was estimated to be less than 300 parts per billion (ppb). The pumped groundwater was projected to reach a TCE concentration of 5 ppb after approximately 8 years of operation.

When the 95 percent upper confidence limit on the arithmetic mean chemical TCE concentration of 15 monitoring wells is used to indicate compliance with the Applicable or Relevant and Appropriate Requirements (ARARs), the TCE plume may be cleaned-up after 6 years of operation. Aquifer tests at the site have reduced the uncertainty in aquifer hydraulic parameters. However, uncertainties in TCE plume definition, natural TCE degradation, and TCE retardation with groundwater movement dominate the concentration estimates and the projected clean-up times.

MODELING FOCUS

Numerical modeling was initiated to evaluate proposed groundwater pumping and injection schemes at a California location during the alternative screening process of an RI/FS. The groundwater pumping and injection schemes were intended to both control and recover the local TCE plume as well as to protect the drinking water supply of downgradient users. The objective of the numerical groundwater modeling was to help minimize the cost and/or duration of TCE clean-up efforts in accordance with regulations and clean-up standards imposed by the State of California and Region IX of the U.S. Environmental Protection Agency (USEPA). This objective was achieved by an iterative computer simulation process involving:

- Minimizing the number of wells installed to remove TCE.
- Limiting the pumping rate to 200 gallons per minute (gpm) pass-through for the groundwater treatment system.
- Maximizing the reduction in TCE mass contained in the shallow water bearing zone.
- Minimizing the aquifer remediation time.

The goal of the numerical modeling was to provide (1) a recommended configuration for the location of remedial pumping/injection wells at the California site, (2) a pumping/injection rate for each well, and (3) a predicted TCE concentration profile over time as delivered to the groundwater treatment system.

Key assumptions used in the numerical modeling include:

- Groundwater system characterized by two composite layers; a shallow water bearing zone (SWBZ) and a lower water bearing zone (LWBZ).
- Water table and potentiometric surface variations consistent with measured site conditions (March 1990).
- Variable aquifer thicknesses from geologic cross sections shown in the Draft Remedial Investigations Report.
- Heterogeneous aquifer materials (SWBZ and LWBZ) as determined from actual pumping and recovery tests.
- The dissolved TCE concentrations, interpreted from field data in the Draft Remedial Investigations Report, accurately describe the existing plume.
- A retardation coefficient for TCE of 1.8 (1).
- A half-life for TCE due to chemical degradation in water of 900 days (2).
- Longitudinal dispersivity of 300 feet.
- Transverse dispersivity of 18 feet.

GROUNDWATER FLOW AND CONTAMINANT TRANSPORT MODELS

The vadose zone is approximately 120 feet thick and extends from the ground surface to the water table (top of the SWBZ). This zone is primarily sands and gravels with some silts. The SWBZ ranges from 60 to 80 feet in thickness and is essentially unconfined. The top of the zone is delineated by the water table and the base is defined by the top of the LWBZ. The SWBZ is mostly composed of silts and minor thin sands. The LWBZ may locally exceed 50 feet of thickness and consists of silty to gravelly sands and a few thin, laterally discontinuous silt layers.

The groundwater flow model consists of two layers. The upper layer simulates the SWBZ, and the lower layer simulates the LWBZ. Groundwater flow was modeled with the **GWFL3D** code (3), an interactive version of the **PLASM** code (4). A finite difference approach is used to formulate the equations of groundwater flow. The groundwater flow and contaminant transport models use a model grid of 400 square elements with an element side dimension of 300 feet.

A numerical modeling approach to simulate groundwater flow was selected for the evaluation of remedial pumping and treatment alternatives for the following reasons:

- In-situ spatial site conditions can be modeled more accurately than that modeled with closed-form analytical solutions.
- Simulations of several different pumping/injection schemes can be obtained using the same spatial numerical model.
- The hydraulic properties and boundary conditions can be readily adjusted to obtain a calibration of the flow model with observed physical conditions.
- The reporting of modeling results can be spatially correlated with existing maps for useful graphic presentation.

The two-layer model was calibrated by adjusting the vertical and horizontal hydraulic conductivities to obtain a match with the water levels and interpreted potentiometric contours for March 1990. Vertical hydraulic conductivity in the SWBZ was adjusted by a factor of approximately 1/100 times the nominal value of horizontal hydraulic conductivity. Vertical hydraulic conductivity in the LWBZ was adjusted to a factor of approximately 1/10,000 times the nominal value of horizontal hydraulic conductivity. The flow calibration process demonstrated that the two layers were more isolated from one another, hydraulically, than originally anticipated. Parameter values for the calibrated computer model are listed in Table I.

The transport of TCE was simulated with the **GWTR3D** code (5), an interactive version of **RANDOM-WALK** (6). The solute transport model uses the steady state potentiometric surface generated by the groundwater flow model (**GWFL3D**) to provide velocity vectors for advective movement of constituent particles. Each of these particles is moved by groundwater flow and is assigned a mass which represents a fraction of the total mass of chemical constituent in the system.

The random-walk technique was selected to simulate contaminant transport for the following reasons:

- No dispersion equation to solve.
- Particles representing constituent mass are needed only where water quality is of interest.
- Eliminates finite differencing phenomena associated with overshoot and numerical dispersion.
- Concentration distribution calculated only when needed.

TABLE I

Parameter Values For Calibrated Model

Model Layer	Modeling Parameter	Nominal Value	Model Range
SWBZ	K (horizontal)	27 ft/day	10-67 ft/day
	K (vertical)	0.3 ft/day	
	Porosity	0.25	
	Dispersivity (long.)	300 ft	
	Dispersivity (trans.)	18 ft	
	TCE retardation	1.8	
	TCE half-life	900 days	
LWBZ	K (horizontal)	134 ft/day	26-268 ft/day
	K (vertical)	0.001 ft/day	
	Storage coefficient	0.0005	

The transport model possibly represents the highest degree of uncertainty in the clean-up predictions. The uncertainty exists in three areas:

- Definition of the TCE plume.
- Quantification of natural TCE decay constant.
- Quantification of TCE retardation with groundwater flow.

Evaluation of Remedial Pump and Treat Alternatives

Several well configurations were examined. However, the three configurations described below are representative of the simulation results and are compared in Table II. A baseline well configuration (#1) used two pumping wells, each removing groundwater at the rate of 25 gpm, and five injection wells, each returning treated water back to the hydrologic system at the rate of 10 gpm. Less than 50 percent of the original TCE mass was calculated to be removed from the system after 10 years of operation. An intermediate well configuration used four pumping wells and three injection wells operating at a total system pass-through rate of 200 gpm. The intermediate well configuration (#2) was projected to remove over 70 percent of the original TCE mass from the subsurface after 10 years of operation. The final pumping/injection well configuration that was modeled (#3) used three pumping wells and three injection wells. Other configurations and pumping/injection rates were also evaluated.

The recommended remedial configuration makes use of an existing well and specifies two additional production wells and three new injection wells. Fig. 1 shows the recommended configuration with respect to the TCE plume. The pass-

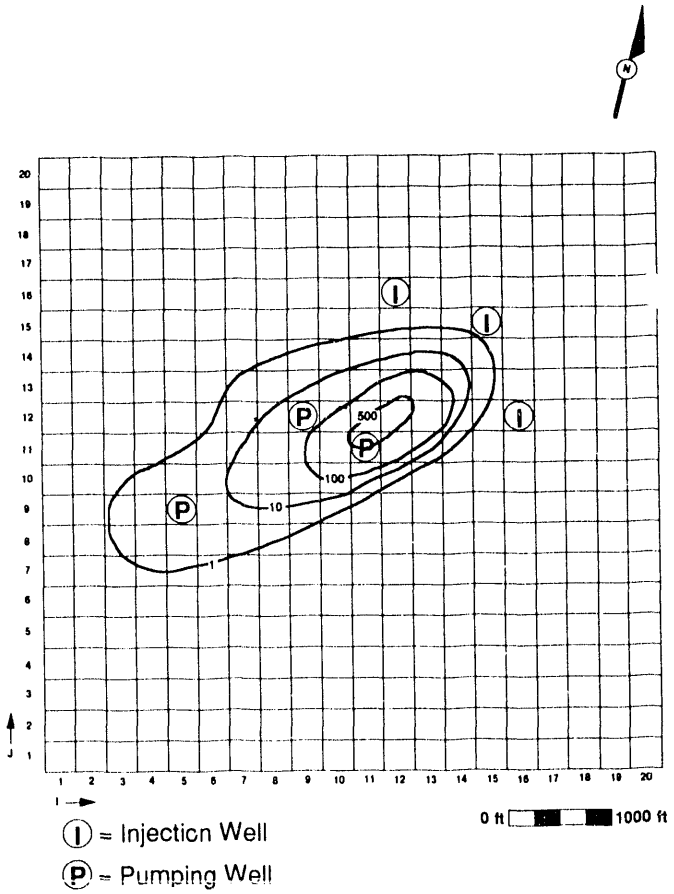


Fig. 1. Recommended remedial well configuration and TCE plume (interpreted).

TABLE II

Comparison of Well Configurations

Parameter		Duration of Pumping and Injection 1 yr C (ppb)	5 yr C (ppb)	10 yr C (ppb)	Duration of Pumping Only 1 yr C (ppb)	5 yr C (ppb)	10 yr C (ppb)
Average Value	#1	91	17	3	91	14	3
	#2	53	6	1	92	22	5
	#3	61	4	1	71	10	1
Standard	#1	132	24	4	134	19	3
Deviation	#2	73	7	1	191	60	12
for n-1	#3	86	4	1	103	15	2
95% Upper	#1	151	29	5	152	22	5
Confidence	#2	86	9	1	178	50	10
Level	#3	100	6	1	118	16	2
Percent of	#1	13	30	43	13	29	41
Original Mass	#2	24	58	72	18	36	46
Produced	#3	31	66	77	27	63	79

through rate for groundwater in the remedial pumping/injection system is 200 gpm. The injection wells, placed upgradient of the TCE plume, increase the hydraulic gradient and tend to sweep the contamination into the downgradient production wells, as shown in Fig. 2. The recommended configuration offers flexibility in the groundwater pumping and injection rates for individual wells and can be tailored as necessary to accommodate changes in the TCE concentration of pumped groundwater or well maintenance during system operation.

The initial concentration of TCE at system start-up is anticipated to be less than 300 parts per billion (ppb), and the pumped groundwater is projected to reach a TCE concentration of 5 ppb after approximately 8 years of operation (Fig. 3). If the 95 percent upper confidence limit on the arithmetic mean chemical TCE concentration of 15 monitoring wells is used to indicate compliance with the ARARs (8), the TCE plume may be cleaned-up after 6 years of operation. The recommended pumping/injection well configuration is projected to remove more than 25 percent of the TCE mass after one year of operation, more than 60 percent of the TCE mass after five years of operation, and more than 75 percent of the TCE mass after ten years of operation. These estimates include assumed values for natural decay processes and migration retardation of TCE during system operation.

Preferred Alternative

Based on an evaluation of the trade-offs between the injection and pumping only scenarios, the non-injection extraction configuration was selected as part of the preferred alternative. The rationale behind the selection was twofold:

- The pumping only scenario was judged to be more technically implementable (i.e., potential plugging/scaling problems were eliminated by avoiding discharge via injection wells).
- Discharge of the treated water to a nearby lake offered some advantage in that the water can be put to beneficial use by augmenting water levels. (The lake

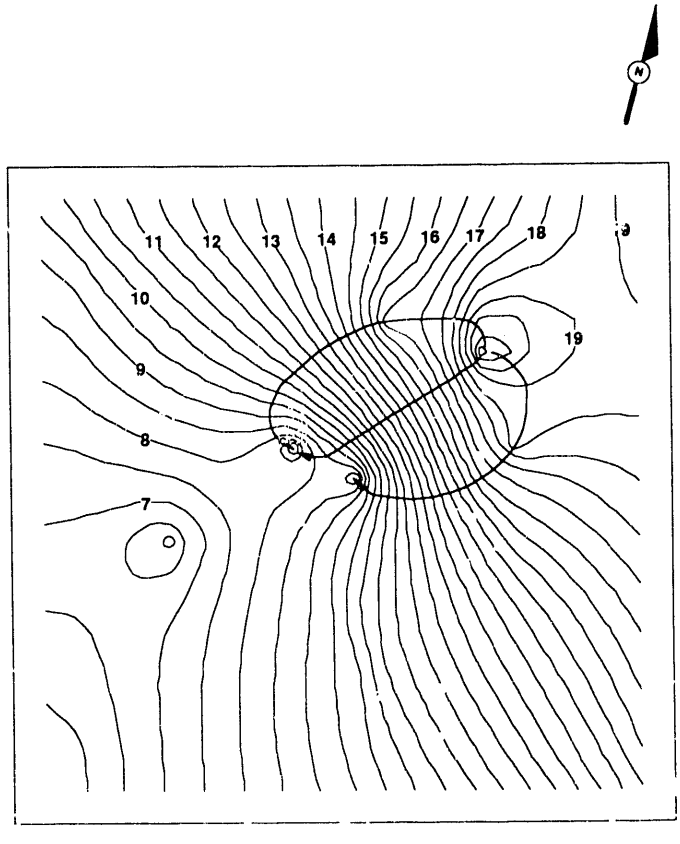


Fig. 2. Steady-state flow field for recommended well configuration (increased gradient between injection and pumping wells).

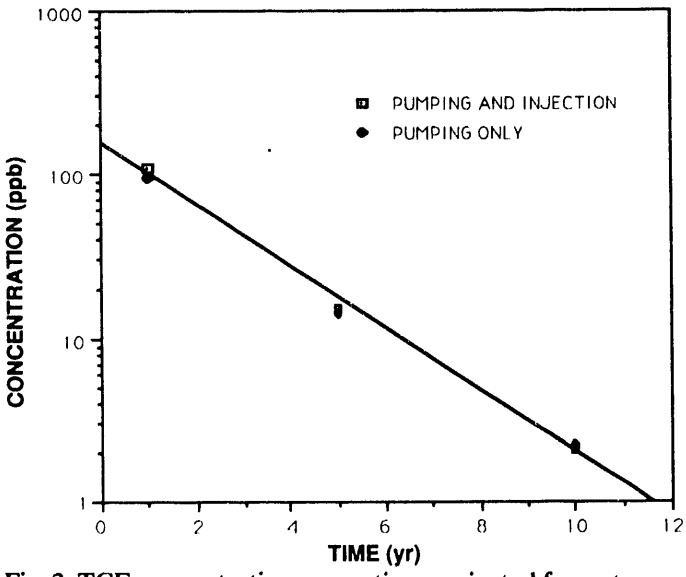


Fig. 3. TCE concentration versus time projected for water treatment design purposes.

is traditionally short of water through much of the year and reli s upon water from irrigation canals to maintain adequate water levels.)

Modeling Uncertainties

The aquifer pumping tests of the shallow water bearing zone and the lower water bearing zone at the California site have reduced the uncertainty in aquifer hydraulic parameters. However, uncertainties in TCE plume definition, natural TCE degradation, and TCE retardation with groundwater movement dominate the concentration estimates and the projected clean-up times. Additional field data can further define the vertical extent of the TCE plume. The low total organic content (TOC) of the soils suggests that retardation of TCE migration with respect to the groundwater may be insignificant. Perhaps the greatest reduction in the model uncertainties will be obtained when the value associated with the degradation of TCE can either be substantiated or refined.

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ISSUANCE OF THE CERCLA ROD FOR AN OPERABLE UNIT REMEDIAL ACTION AT THE WELDON SPRING SITE - LESSONS LEARNED*

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ABSTRACT

Finalizing a record of decision (ROD) for remedial action at a federal facility involves considerable interagency coordination and can be very time-consuming. The ROD incorporates input on a proposed remedial action that is received from the public and from state and federal agencies, and it represents the culmination of the decision-making process for that action. Because varying views on a number of issues must be brought together to finalize decisions, the sign-off process can be somewhat arduous. This paper discusses lessons learned in completing the record of decision for an operable unit remedial action at the Weldon Spring site.

SITE BACKGROUND

The U.S. Department of Energy (DOE) is responsible for conducting remedial actions at the Weldon Spring site under its Environmental Restoration and Waste Management Program. The site is located in St. Charles County, Missouri, about 48 km (30 mi) west of St. Louis. The Weldon Spring site became contaminated as a result of processing and disposal activities that took place from the 1940s through 1960s, and it is listed on the National Priorities List of the U.S. Environmental Protection Agency (EPA). The site consists of two noncontiguous areas: a chemical plant area and a limestone quarry. The chemical plant area consists of about 40 buildings and miscellaneous structures as well as four raffinate pits and two small ponds.

The chemical plant area was previously used as an ordnance works facility to produce conventional explosives; later, a feed materials plant (generally referred to as the "chemical plant") was constructed at the site to process uranium and thorium ore concentrates. The quarry is located about 6.4 km (4 mi) southwest of the chemical plant area and within 1.6 km (1 mi) of an alluvial well field that constitutes a major source of potable water for St. Charles County; the nearest supply well is located about 0.8 km (0.5 mi) southwest of the quarry. Various wastes were disposed of in the quarry from 1942 to 1969; wastes therein include approximately 75,000 m^3 (100,000 yd^3) of contaminated soil and sediment, rubble, metal debris, and equipment.

QUARRY OPERABLE UNIT DOCUMENTATION

The remediation strategy for the Weldon Spring site consists of several components, one of which is management of the bulk (solid) wastes currently located in the quarry. These wastes constitute the source of contaminants migrating into the air and the underlying groundwater at the quarry. A remedial investigation/feasibility study (RI/FS) process was conducted to address the quarry bulk wastes in accordance with the requirements of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), as amended, and the National Oil and Hazardous Substance Pollution Contingency Plan (NCP). Documents developed during this process included an RI report, a baseline risk evaluation, an FS report, and a proposed plan. Compliance with the National Environmental Policy Act (NEPA) was satisfied by integrating the requirements of an Environmental Assessment into the CERCLA documents. These documents were reviewed by EPA Region VII and the state of Missouri, and general concurrence was received prior to release for public review.

The RI/FS documents and an informational bulletin were issued to the general public on March 5, 1990. A public meeting was held on March 29; representatives from DOE, EPA Region VII, and the state of Missouri participated in this meeting. The preferred alternative for managing the quarry bulk wastes presented at the public meeting was to remove the wastes from the quarry and transport them along a private haul road to a temporary storage facility constructed at the chemical plant area. The public was generally supportive of this action.

PREPARATION AND APPROVAL OF THE RECORD OF DECISION

Following the public comment period, a CERCLA responsiveness summary (RS) report was prepared to address written and oral comments received on the RI/FS. The RS was issued in August 1990 following review and concurrence by

* Work supported by the U.S. Department of Energy, Office of Environmental Restoration and Waste Management, under contract W-31-109-Eng-38.

EPA Region VII and the state of Missouri. The CERCLA Record of Decision (ROD) was prepared concurrently with EPA Region VII and the state of Missouri. The CERCLA record of decisions (ROD) was prepared concurrently with the RS report and was transmitted for comment to EPA Region VII and the state of Missouri along with the RS report. In parallel, a Finding of No Significant Impact (FONSI) was prepared to document the NEPA decision for this action. DOE issued the FONSI on November 15, 1990.

EPA Region VII and the state of Missouri had only minor comments on the RS, but they provided significant comments on the ROD. Most of these comments concerned the evaluation of potentially applicable or relevant and appropriate requirements (ARARs).

The first draft of the ROD did not include a detailed discussion of ARARs but noted that additional discussion would take place between DOE, EPA Region VII, and Missouri state officials during the engineering design phase of the action. The EPA stated that a much more definitive evaluation was required. The draft ROD was revised in response to this comment.

A detailed evaluation of ARARs was incorporated into the revised draft ROD, including a determination that the quarry bulk waste was not a listed waste as defined by the Resource Conservation and Recovery Act (RCRA). The EPA signed the ROD on September 29, 1990, and sent a letter to the state of Missouri noting that it was their understanding that the state concurred with the action but disagreed with some of the ARAR determinations. The state subsequently sent a letter to EPA Region VII formally objecting to some of the ARAR determinations. Given that the state objected to portions of the ROD, the DOE deferred signing it.

During the next six months, several meetings were held between DOE, EPA Region VII, and the state of Missouri to resolve ROD issues. Concurrence was achieved on all topics except the RCRA determination. Because the selected alternative is an interim remedial action and does not involve waste disposal, all parties agreed that this RCRA issue should not delay the action. The DOE signed the ROD on March 7, 1991, after the state reaffirmed its desire to have the remedial action implemented.

LESSONS LEARNED

A great deal of experience was obtained and significant lessons were learned by carrying out the environmental compliance process for this operable unit remedial action. The ROD process took over the one year to complete following issuance of the RI/FS documents to the public for an action that had universal acceptance. This time frame needs to be shortened if DOE is to meet its commitments and develop a positive public image. Two important lessons learned that will help streamline this process include (1) finalizing the ARARs evaluation early in the ROD process and (2) assuring adequate agency input during ROD development.

Other lessons learned included (1) a greater appreciation of the difficulties in integrating NEPA and CERCLA and the amount of engineering required to support the environmental compliance process; (2) the recognition that the ARARs evaluation process provides an opportunity to make sense of conflicting (or impossible to meet) regulations (for example, land ban requirements) and time limits for storage under the Toxic Substance Control Act (which were waived); and (3) consistency, small group meetings, and compromise contribute much to public acceptance. The importance of obtaining early input from regulatory agencies such as the EPA and from directly impacted parties such as state, municipal, and county agencies, as well as the general public, cannot be overstated in the development of remedial action plans that are reasonable and that can be successfully implemented.

CHANGES IN "SELECTED REMEDY" AFTER RECORD OF DECISION

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ABSTRACT

The U.S. Environmental Protection Agency (EPA) chose the U.S. Department of Energy (DOE) and its prime contractor, Chem-Nuclear Geotech, Inc. (Geotech), to remediate several operable units in the Denver Radium Superfund Site. The Denver Radium Site consists of 41 properties grouped into 11 operable units containing low-level radioactive contamination that could endanger public health, welfare, and the environment. This environmental restoration was completed in compliance with applicable environmental laws and the Denver Radium Project was recognized by the EPA as the "Regional Superfund Team of the Year" in 1989 and the "National Superfund Team of the Year" in 1990.

This paper examines a case at Operable Unit (OU) III of the Denver Radium Site in which new information regarding the location of contamination was discovered after the Record of Decision (ROD) had been signed. This discovery required a significant change to the remedy described in the ROD and involved an analysis of a no action alternative. A history of the Denver Radium Site is presented, along with an overview of the methods and processes of risk assessment, remedy selection, cleanup standards, and remedial actions. Results indicate that flexibility in environmental laws does permit changes to the ROD, given reasonable interpretation and application of statutory provisions.

DENVER RADIUM SITE HISTORY

In 1898, radium was first discovered in pitchblende, a rare mineral found in Bohemia, Saxony, Cornwall, and Colorado. By the early 1900s, the ability of radiation to destroy or inhibit the growth of selected cells was known and radium was widely used for cancer treatment, creating a strong demand for radium in the United States (U.S.) and Europe. New sources of radium were sought, and another radium-bearing mineral, carnotite, was identified in Colorado. This material provided the ores from which radium was extracted in Denver through the early 1920s.

The outbreak of World War I prompted concern in the U.S. for the continued availability of radium processed in Europe. This concern led to the establishment of the National Radium Institute (NRI) in Denver in 1913 by the U.S. Bureau of Mines. The NRI successfully demonstrated that radium could be economically processed in the U.S. Other radium processors were also active in Denver from the period of the NRI through the 1920s, when extremely rich deposits of radium-bearing ore were discovered in Africa. The U.S. radium producers were unable to compete, and the Denver radium industry closed almost overnight as the refineries went bankrupt or were converted to other uses.

Although much of the radium and uranium was recovered, process residues, sandy tailings containing uranium, radium, and other radioactive materials were discarded. In spite of the leaching and erosion that have taken place over the last 70 years, this material and other debris have contributed to the radiation currently associated with the Denver Radium Site.

Until recently, the historic use of the NRI lands was ignored or forgotten. In 1979, EPA noted a reference to the NRI in a 1915 U.S. Bureau of Mines report. Subsequent research brought the radium extraction facilities to the attention of EPA and the State of Colorado. Following notice of the potential problem, the Colorado Department of Health (CDH), EPA, and the DOE began a series of studies to locate the contaminated areas and to identify the associated hazards (1).

In 1981, the Denver Radium Site was placed on the National Priorities List (NPL) (pursuant to Superfund), the list of contaminated sites across the United States with the highest priority for cleanup actions. The Denver Radium Site consists of 41 properties grouped into 11 operable units containing low-level radioactive contamination that could endanger public health, welfare, and the environment.

The U.S. Environmental Protection Agency (EPA) chose the U.S. Department of Energy (DOE) and its prime contractor, Chem-Nuclear Geotech, Inc. (Geotech), to remediate several operable units in the Denver Radium Superfund Site. This environmental restoration was completed in compliance with the National Contingency Plan (NCP) and the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA) as amended by the Superfund Amendments and Reauthorization Act of 1986 (SARA). The Denver Radium Project was recognized by the EPA as the "Regional Superfund Team of the Year" in 1989 and the "National Superfund Team of the Year" in 1990.

During Geotech's remedial action efforts, new information regarding the extent of contamination at one of the operable units, OU III, was obtained, requiring a change to the Record of Decision (ROD). The ROD documents the chosen remedy for a given site. This paper presents a case study of OU III and the process for making a change to the selected remedy in the ROD.

CLEANUP REMEDY SELECTION

Determining a cleanup remedy involves two stages: performance of a Remedial Investigation/Feasibility Study (RI/FS) following the preparation of a work plan for the RI/FS, and EPA's selection of the remedy with a Record of Decision. The "preferred remedy" in the RODs for the Denver Radium sites was "off-site permanent disposal" of all radiologically contaminated soils.

CHANGES AFTER THE ROD

In some cases, new information regarding a site's contamination may be identified after the ROD is signed. This information may affect the remedy selected in the ROD. The EPA must analyze this new information to determine if changes should be made to the selected remedy.

Once the EPA determines that a change to the remedy is warranted based on information submitted by the public, the support agency, or simply generated through the Remedial Design/Remedial Action (RD/RA) process, the change is evaluated and categorized as one of the following (2):

- A non-significant or minor change,
- A significant change to a component of the remedy, or
- A fundamental change to the overall remedy.

According to Ref. 2, changes are defined as follows.

Non-Significant Changes

Non-significant (i.e., minor) changes fall within the normal scope of changes occurring during the RD/RA engineering process. These minor changes typically are the result of value engineering conducted during remedial design and construction. Through the value engineering process, modifications are made to functional specifications of the remedy to optimize performance and minimize costs. This may result in minor or non-significant changes to the type and/or cost of materials, equipment, facilities, services, and supplies used to implement the remedy. When such changes do not significantly affect the scope, performance, or cost of a remedy, they are considered minor or non-significant.

Significant Changes to a Component of a Remedy

Significant changes to a component of a remedy generally are incremental changes to the hazardous waste approach selected for the site (i.e., a change in timing, cost, or implementability). These changes do not fundamentally alter the overall approach intended by a remedy. When significant changes are made to a component of a remedy, an Explanation of Significant Differences (ESD) is prepared.

During the period when the ESD is prepared and made available to the public, the EPA proceeds with the pre-design, design, construction, or operation activities associated with the remedy. The remedy can continue to be implemented during this time because the ESD is only a notice of change and is not a formal opportunity for public comment since the agency is not reconsidering the overall remedy.

Fundamental Changes to the ROD

In a few cases, the new information may cause the lead agency to reconsider the hazardous waste management approach selected in the ROD. For example, the lead agency may determine that an innovative technology originally selected in the ROD did not perform satisfactorily during the pilot-scale testing conducted during design. Based on this information, the lead agency could decide to switch to thermal destruction or to a biological treatment process rather than use the innovative technology -- both fundamental changes. When such fundamental changes are made to a remedy, the lead agency must repeat the ROD process in accordance with the requirements of CERCLA by issuing a revised Proposed Plan and an amended ROD.

Factors the EPA Uses To Categorize a Change

The EPA's categorization of a change is a site-specific determination. In making this determination, the EPA considers the effect the change has on the scope, performance, or cost of the remedy as described in the ROD in accordance with the following factors:

- Does the change significantly alter the scope of the remedy (i.e., the physical area of the response, remediation goals, type and volume of wastes)?
- Would the change alter the performance (e.g., treatment levels to be attained) and thus raise concerns about the protectiveness or long-term effectiveness of the remedy that could not have been anticipated based on information in the ROD?
- Are the changes in costs of such a nature that they could not have been anticipated based on the estimates in the ROD and the recognized uncertainties associated with the hazardous waste engineering process selected?

Based on an evaluation of these factors, the EPA determines whether the proposed change is non-significant, significant, or fundamental in nature.

ROD FOR OU III

When the ROD for OU III was signed in September 1987, a permanent disposal facility was not available. Therefore, EPA's selected remedy for OU III was off-site temporary land storage of contaminated material from one of the five properties; excavating, consolidating, and capping the remaining contaminated material on a vacant lot of the OU III site; and off-site permanent disposal of all contaminated material at a later time (3).

Since 1987, a permanent disposal site for the radiologically contaminated soils from this site was identified. Consequently, EPA's preferred remedial action alternative of offsite Permanent disposal was implemented in the Design of Remedial Action for OU III.

ADDITIONAL CONTAMINATION FOUND AT OU III

Before performing remediation activities, Geotech conducted a review to confirm the findings of the RI upon EPA's request. This review identified contamination extending under the public street and around major utility lines from properties located directly east and west of the street. This contamination was not identified in the RI; thus, the 1987 ROD had not included a "selected remedy" for such contamination.

Table I summarizes the estimated extent of radium-contaminated material associated with the utility lines located under the street at OU III.

Following this discovery of additional contamination, the EPA requested Geotech to study the possibility of a no-action alternative of leaving the contamination in place. The EPA determined that this no action alternative was a "significant change" to a component of a remedy and, therefore, preparation of an ESD was required.

ISSUES SURROUNDING CONSIDERATION OF THE NO ACTION ALTERNATIVE

One of the most chronically difficult and important CERCLA issues has been how to determine the appropriate

TABLE I

Summary of Utility Line Contamination

Utility	Total Length (ft)	Contaminated Length (ft)	Percent
Gas Line	900	150	17
Water Line	880	250	28
Sanitary Sewer	45	20	44
Storm Drain	225	80	35
Sanitary Sewer Interceptor	850	220	26

Average percent of utility lines in contaminated material 30%

extent of the remedy at a particular site; this is known as the "how clean is clean" issue. The statutory provisions provide a great amount of detail on this issue in Section 121 of CERCLA (4). Yet the reality is that despite all the detailed direction from Congress in Section 121, there is still a tremendous amount of discretion left with EPA decision-makers on a site-by-site basis to determine what remedy will ultimately be employed. Thus far, no matter how much additional guidance EPA headquarters supplies through memos or regulations, this great degree of site-by-site discretion has not been curtailed and does not seem likely to be in the future. Although this results in some uncertainty in the consistant application of a remedy, it also allows for the flexibility that is needed when dealing with cases such as OU III.

In order to evaluate the no action alternative allowing contaminated material to remain under streets adjacent to OU III, many documents were reviewed and issues were considered as described in the following subsections.

"Applicable" or "Relevant and Appropriate Requirements" (ARARs)

The "ARARs" under Section 121(d) of CERCLA deal with the "Degree of Cleanup" for a particular site. This section sets forth the basic requirement that site cleanups must attain standards (from other Federal/state environmental programs) that are "applicable" or "relevant and appropriate" under the circumstances (5).

A key feature in the development of the "appropriate extent of a remedy" is determining what level of cleanup of the hazardous substances, pollutants, and contaminants at the site will be required to ensure adequate protection of human health and the environment. In the 1986 Superfund Amendments, Congress directed that if hazardous substances (or pollutants or contaminants) remain at the site, the remedial action must result in a level or standard of control for the substance that at least attains the legally applicable standards, requirements, or criteria under Federal environmental laws (including the Resource Conservation and Recovery Act, the Clean Air Act, and the Clean Water Act) or state environmental or facility siting laws that are more stringent than federal standards. However, no Federal, state, or local permit is required for actions taken entirely on site, if the remedial action is taken in compliance with the statutory cleanup standards (5). EPA has issued guidance on these applicable or relevant and appropriate requirements that will be incorporated into the proposed revision of the NCP. EPA defines applicable requirements as

> "those cleanup standards, standards of control, and other substantive environmental protection requirements, criteria or limitations promulgated under Federal or State law that specifically address a hazardous substance, pollutant, contaminant, remedial action, location, or other circumstance at a CERCLA site."

Relevant and appropriate requirements are those standards that, while not "applicable" to the situation, "address problems or situations sufficiently similar" to those encountered at the CERCLA site that their use is well suited to the particular site. In deciding whether a requirement is relevant and appropriate, EPA considers factors such as the characteristics of the remedial action, hazardous substance involved, and the physical circumstances of the site. It is important to note that this "ARAR" requirement applies when "any" hazardous substance, pollutant, or contaminant will remain on site (5).

Cleanup Standards

Cleanup standards set by the EPA for "Remedial Actions at Inactive Uranium Processing Sites," 40 CFR 192, have been identified as ARARs, providing remedial action objectives for the Denver Radium Site. Because of the similarity between uranium mill tailings and the contaminated soils at the Denver Radium Site, this standard is a relevant and appropriate Federal requirement as defined by the NCP, 40 CFR Part 300. The standards in 40 CFR Part 192.10-.22 serve as both the initiator and the goal of the remedial actions at the Denver Radium Site. For properties contaminated with uranium or radium processing residues, these standards establish limits for the gamma radiation level and the annual average radon decay product concentration in any occupied or habitable building and for the concentration of radium in soil on open lands.

Because it was anticipated that there may be some cases in which application of these standards would be impractical, the EPA established certain conditions under which remedial action may be limited to non-removal or partial removal of uranium mill tailings from contaminated properties (Code of Federal Regulations Title 40: Protection of Environment; Subpart C 192.22: Supplemental Standards to Health and Environment Protection Standards for Uranium and Thorium Mill Tailings). The EPA criteria for deciding that conditions in a given instance warrant a variation from usual remedial action procedures are known as "Supplemental Standards for Remedial Action."

Supplemental Standards (40 CFR 192.21)

When one or more of the criteria (a) through (e) listed below applies, the implementing agencies shall select and perform remedial actions that come as close to meeting the otherwise applicable standard as is reasonable under the circumstances (6).

a. Remedial actions required to satisfy Subparts A or B [of 40 CFR Part 192] would pose a clear and present risk of injury to workers or to members of the public, notwithstanding reasonable measures to avoid or reduce risk.

b. Remedial action to satisfy the cleanup standards for land, §192.12(a), or the acquisition of minimum materials required for control to satisfy §192.02(b), would, notwithstanding reasonable measures to limit damage, directly produce environmental harm that is clearly excessive compared to the health benefits to persons living on or near the site, now or in the future. A clear excess of environmental harm is harm that is long-term, manifest, and grossly disproportionate to health benefits that may reasonably be anticipated.
c. The estimated cost of remedial action to satisfy §192.12(a) at a "vicinity" site (described under Sec. 101(6)(B) of the Act is unreasonably high relative to the long-term benefits, and the residual radioactive materials do not pose a clear present or future hazard. The likelihood that buildings will be erected or that people will spend long periods of time at such a vicinity site should be considered in evaluating this hazard. Remedial action will generally not be necessary where residual radioactive materials have been placed semipermanently in a location where site-specific factors limit their hazard and from which they are costly or difficult to remove, or where only minor quantities of residual radioactive materials are involved. Examples are residual radioactive materials under hard surface public roads and sidewalks, around public sewer lines, or in fence post foundations. Supplemental standards should not be applied at such sites, however, if individuals are likely to be exposed for long periods of time to radiation from such materials at levels above those that would prevail under §192.12(a).
d. The cost of a remedial action for cleanup of a building under § 192.12(b) is clearly unreasonably high relative to the benefits. Factors that should be included in this judgment are the anticipated period of occupancy, the incremental radiation level that would be affected by the remedial action, the residual useful lifetime of the building, the potential for future construction at the site, and the applicability of less costly remedial methods than removal of residual radioactive materials.
e. There is no known remedial action.
f. Radionuclides other than radium-226 and its decay products are present in sufficient quantity and concentration to constitute a significant radiation hazard from residual radioactive materials.

Previous Experience in Applying Supplemental Standards

The U.S. Department of Energy Grand Junction Projects Office (DOEGJPO) manages the Uranium Mill Tailings Remedial Action (UMTRA) Vicinity Property Program at Grand Junction, Colorado. This work is performed under the "Uranium Mill Tailings Radiation Control Act" (Public Law 95-604). Of the 4,150 properties to be remediated, approximately 3,500 properties have been remediated to date by the DOEGJPO.

Geotech, the remedial action contractor for the DOEGJPO, has applied supplemental standards to several properties in the Grand Junction UMTRA Vicinity Property Program. When utility lines were involved, the health risk for utility maintenance workers was evaluated for situations where workers were in trenches and possibly exposed to higher levels of radiation (a worst-case scenario). In order to address this concern, Geotech developed a "Utility Worker Health Risk Analysis" for a group of properties being submitted for supplemental standards.

The cleanup activities in the Grand Junction area are very similar to the cleanup activities at the Denver Radium Site and involve similar materials and hazards. Experience over several years has shown that the hazard to utility workers and the public from contaminated materials left under roads, sidewalks, or utility lines is quite small and easily managed. Supplemental standards have been applied in only a few cases and then only after careful consideration of the risks.

Supplemental Standards as Applied to Streets at OU III

In order to consider application of supplemental standards to the street, at least one of the six criteria in 40 CFR 192.21 must be met.

One of the primary concerns associated with remedial action activities is the safety of the people doing the cleanup work as well as those who will work on or near the site in the future. The EPA recognized this in establishing the criteria for the application of supplemental standards. This is evident as noted in criterion (a) of 40 CFR 192.21.

When performing remedial action on underground utilities (especially gas lines and high- pressure waterlines), the potential of physical injury to a worker still exists even when reasonable safety measures are taken. For example, during the first phase of this site's remedial action, a 2-inch gas line was ruptured by excavation activities, even though the exact location and depth of the line were identified and reasonable measures were taken. The area was immediately evacuated and Fire Department personnel were called to the site. Luckily, no injuries occurred. However, this incident shows that even when precautions are taken, the unexpected can happen when dealing with buried utility lines.

Geotech believed that criterion (a) of 40 CFR 192.21 was met because results of a "Health Risk Assessment" indicated that the removal of the contaminated soil posed a greater risk to the remediation workers from the underground utilities than the risk to the utility workers from working in the contaminated soil. While the physical hazards of excavation were not easily quantifiable, the radiologic hazards to utility workers were shown to be low, even under assumptions of maximum realistic exposure.

The "Health Risk Assessment" showed that (1) no unacceptable health risk will exist if the tailings are allowed to remain under the street, (2) precedent exists for allowing the radiologically contaminated soil to remain, and (3) costs associated with removing the soil are not justified. Item number 3 also supported application of criterion (c) of 40CFR 192.21, which addresses unreasonably high cost of remedial action relative to long-term benefit, and identifies examples where the criterion applies, such as hard-surface public roads or around public sewer lines. The street and utility lines at OU III fall within this category (6).

Geotech has submitted the "Health Risk Assessment" to the EPA, which supports the no action alternative. Presently, EPA is preparing an ESD giving notice of change to the remedy in the ROD.

CONCLUSION

This case study shows that changes can be made to the Record of Decision when such changes are warranted.

Because of the flexibility built into the environmental laws and the level of discretion exercised by the EPA in determining the appropriate extent of the remedy at a particular site, a case can be made for implementing remedies such as no action alternatives, given new information and effective supporting studies.

ACKNOWLEDGEMENT

Work supported by the U.S. Department of Energy Office of Environmental Restoration and Waste Management at the Grand Junction Projects Office under DOE Contract No. DE-AC07-86ID13584.

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COMPARATIVE OVERVIEW OF FEDERAL FACILITY COMPLIANCE AGREEMENTS AND CONSENT ORDERS

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ABSTRACT

This presentation provides a layman's guide through the labyrinth of regulatory, political, economic, and contractual issues associated with the development of Federal Facility Compliance Agreements (FFCAs). A comparative analysis was summarized from among eight of the major Department of Energy (DOE) Weapons Complex facilities throughout the country, including the Feed Materials Production Center ("Fernald"), Hanford, Idaho National Engineering Laboratory (INEL), Kansas City Plant (KCP), Lawrence Livermore National Laboratory (LLNL), Mound, the Oak Ridge Reservation (ORR), and the Rocky Flats Plant (RFP). Variations in FFCA provisions reflected site-specific characteristics, evolutionary refinements in terms and tactics of negotiation, heightened awareness among the parties as to policy implications, increased participation, and the application of "lessons learned" from implementing practices at other federal facilities subject to the similar tri-party deliberations.

INTRODUCTION

Only a moment ago, in the measure of human history, did man harness the power of water, fire, and the atom to assist in his comfort and enhance his well-being. The negative impacts generated by man's excessive reliance on these work tools and weaponry were evident before he adequately prepared satisfactory solutions to the problems created by his reliance on such valuable resources.

Fortunately, today, even with the vast flux of sociopolitical systems, there remain some constants within the human condition that define and direct attitudes, processes, and institutions, even the course of nations. Universally, man has come to recognize the fundamental need for the preservation and perpetuation of the human species and concurrently the preservation of delicate ecosystems that he inhabits. Global human survival has been overshadowed by the requirements of collective national security. Such prioritization has dominated international conduct and configured the economic, social, and political infrastructures of major world powers for decades.

As with any critical issue where the stakes are high, the debate is intensely political and, in this instance, technically volatile. Costs are not simply gauged in dollars but in long-term health risks. Some of the potential trade-offs to be considered are wholly unacceptable to differing interest groups. The urgency of intergovernmental cooperation and compliance dictates an expedient and effective method for complex conflict resolution. Given the mandate of selecting the most effective and affordable methods of environmental management, the issues are ripe for the civilized application of collective bargaining, binding arbitration, and alternative dispute resolution techniques. Thus the advent of variations of negotiated settlement agreements, including Federal Facility Agreements and correlational Consent Orders.

FFCAs and Consent Orders are exceedingly sophisticated negotiated settlements. The terms and conditions of the contract are debated, discussed, and decided up front. The parties conclude their discussions knowing what rights, roles, and responsibilities are required *ab initio* (from the beginning).(1) The consequences of nonperformance are equally clear and mutually accepted. Very difficult, sensitive, and intricately interwoven issues may be reduced to workable "game plans" for relevant entities. Today's complex systems of hazardous waste management demand well orchestrated solutions.

When multiple parties with competing interests intend to effect a mutually beneficial compact restraint, compromise, and credibility are essential. Restraint is required to curb excessive demands while compromise is necessary to avoid conceding too much. The parties must be able to reasonably rely on assurances that adversarial parties will carry out the letter and spirit of the accord. Absent credibility, the negotiation process would prove to be a futile and costly exercise.

PURPOSE

Several commentators in recent law review articles have referred to a new theory of administrative jurisprudence as the "unitary executive theory." This practice identifies the President of the U.S. as "the sole authority to resolve interagency disputes,"(2) yet by mutual agreement the federal agencies have not subordinated their powers to EPA as logical practical enforcement practices would dictate.

The boundaries between executive enforcement and congressional legislative mandates are not well defined. There continue debates among federal agencies and executive offices as to who is "on first" and at what level of authority.

* Managed by Martin Marietta Energy Systems, Inc., for the U.S. Department of Energy under contract DE-AC05-84OR21400.

FFCAs and Consent Orders are the strongest enforcement tool EPA has available to integrate and coordinate the responsibilities and substantive requirements among the spectrum of interested parties. The function of the FFCA negotiation is to facilitate environmental decontamination and restoration at federally controlled installations. EPA is restricted in appealing to the Office of Management and Budget (OMB) or the U.S. Attorney General in the event of failure to resolve disputes or non-compliance by sister agencies.

Obviously, environmental cleanup is subject to inherent bureaucratic constraints, including, but not limited to, budgetary concerns, availability of technically competent manpower, the applicability of remediation technologies, and the effects of information or misinformation disseminated by the media that may possibly further exacerbate budgetary, manpower, or resource applications within the program administration.

The FFCA negotiation process provides an appropriate and tested forum for airing divergent interests enabling the respective parties to carry out their roles to protect human life and the environment. Reducing the assignment of duties and responsibilities among the parties to writing at the outset serves to (1) minimize confusion as to authority, lead agency, or approval requirements, (2) avoid unnecessary duplications and costly misallocations of time, materials, and manpower, (3) promote and enhance cooperation and communication among the parties, and (4) generally provide an operational framework in which a realistic implementation of regulations becomes possible.

Although the agreements are site-specific, the nature, scope, purpose, and implementation terms of the accords directly impact the prioritization schemes, schedules, and execution of the remedial actions required. Defining the implications of federal environmental statutes reduces regulatory uncertainty and promotes the integration required for cleanup activities where applicable and appropriate.

FFCAs have evolved into workable, flexible, and enforceable tri-party contractual arrangements for expediting environmental restoration activities at federal sites. The use of the dispute resolution process has significantly reduced the volume and expense of prolonged litigation. Instead, where legal action or judicial review is required it may focus on very narrow issues, perhaps reducing the burden on the court's time and added expense to the taxpayer. Delaying cleanup activities only serves to prolong potential risks and exponentially increase costs; neither circumstance serves the public's best interest.

COMPETING INTERESTS OF THE PARTIES

A number of competing interests become readily apparent when reviewing documents related to the operations of federal facilities. Having been statutorily empowered with the responsibility to protect human health and the environment, the U.S. Environmental Protection Agency (EPA) bears the lion's share of administrative and regulatory enforcement activity related to the implementation of environmental laws. (3) As the agency accountable for monitoring compliance and enforcement activities related to the implementation of environmental laws in the United States and to maintain public trust and confidence, EPA has established a comprehensive, uniform, and aggressive national enforcement posture to achieve and sustain general regulatory compliance. Uniformity requires an evenhanded application of environmental laws to federal and nonfederal facilities alike. EPA has a wide array of enforcement mechanisms available to ensure the preservation and protection of human health and the environment. (4) Among the civil administrative remedies available to contractually resolve noncompliance issues at federal facilities is the use of FFCAs or Consent Orders. EPA Regional Offices represent the interests of the Administrator of EPA in negotiating most agreements and orders. EPA desires orderly, consistent, and uniform application and enforcement of environmental statutes nationwide.

All federal agencies are required to comply with pollution control legislation to the same extent as nonfederal entities (5); thus, DOE has a vested interest in the uniform application of EPA enforcement programs and practices. As a sister agency, DOE is not subject to standard civil judicial suits brought by other executive branch agencies. Most instances of interagency dissonance are based on political determinations and as such are nonjusticiable issues. (6) Alternative dispute resolution methodologies are not only highly encouraged but are essential for intergovernmental cooperation and operations.

In the 1950s, the DOE Weapons Complex was charged with the mission of research, development, testing, and production of nuclear weapons systems for the United States.(7) Environmental impacts were not of significant concern until the enactment of hazardous waste legislation in the 1970s. Although noncompliance with environmental requirements may not be excused *per se* because of inadequate levels of federal funding, the nonavailability of various funding levels may be considered in determining media-specific compliance schedules and enforceable time frames for performance of remediation milestones. The interests of federal facility operators and government-owned, contractor-operated facilities are also brought to the bargaining table by the DOE team of representatives.(8) Settling jurisdictional overlaps among the parties and delineating lead agencies serve to maximize implementation of interagency agreements.

States charged with facility permitting and oversight activities have a significant interest in the general health and welfare of their citizenry in addition to the long-term preservation and protection of the environment within their boundaries. Yet states have limited impacts over the operations of federal facilities within their jurisdiction. Effective compliance programs that do not unduly burden state treasuries are therefore exceedingly important. Tri-party agreements allow states to have direct influence on provisions concerning the application of the respective state cleanup requirements, public involvement and participation, citizen suit enforceability issues, setting priorities, maintaining an active voice in the dispute resolution process, and providing review and comment for the technical documents required. This a role allows states to effectively impact the compliance process to expedite remediation, avoid wasteful duplication, and the possibility of imposing "recleanup" requirements at some future date.

Finally, the public demands a vested interest in the process. Federal agency regulatory compliance accountability is of significant concern. The Resource Conservation and Recovery Act (RCRA) provides for citizen suit enforcement provisions. These provisions have subsequently been incorporated into the FFCAs. The general public is actively

represented by all parties to the agreement in differing capacities. EPA represents compliance and oversight issues, DOE addresses technological concerns, and state governments bargain for adequate participation by the public throughout the process. Each of the parties has specific notification and information access requirements so that the media and community have relevant information at appropriate times. Thus, individuals with significant interests in the monitoring, management, and ultimate performance of the FFCAs are provided adequate representation and receive a full and informed hearing within the negotiation process in promoting their individual concerns for the common good.

KEY PROVISIONS OF FEDERAL FACILITY COMPLIANCE AGREEMENTS

Among pivotal provisions incorporated into most FFCAs, boiler plate "model language" has been developed. The following are eleven of the primary issues subject to negotiation among the parties.

- Jurisdiction
- Purpose and Scope
- Regulatory Compliance or RCRA/CERCLA Integration
- Interagency Consultations
- Dispute Resolution Process
- Stipulated Penalties
- Enforceability
- Extensions and Terminations
- *Force Majeure* Events
- Funding
- Covenants Not to Sue/Reservation of Rights

Other issues routinely addressed by FFCAs include terms that are vital to contractual implementation, yet are of moderately less concern to negotiators, such as: accessibility to property, property transfers, quality assurance, permitting issues, public participation provisions, expense recovery, confidentiality, Applicable or Relevant and Appropriate Requirements, reporting requirements, actions plans, and issues regarding work stoppages. The following discussion shall briefly identify and reference some of the key provision variations among FFCAs for DOE operations located in Ohio, Washington, Idaho, Kansas, California, Tennessee, and Colorado. For this analysis, a comprehensive review was made of the key provisions listed among the FFCAs for the DOE Weapons Comple sites of Fernald, Hanford, INEL, KCP, LLNL, Mound, ORR, and RFP. Of the Weapons Complex site agreements, the Nevada Test Site (NTS) and the Savannah River Site (SRS) agreements have been intentionally omitted from this review. No evidence from the NTS suggests any significant compliance problems exist. As for the SRS, as of this writing, the FFCA has not been finalized. A comparison among secondary provisions shall remain for future analysis.

Jurisdiction

Essential to any FFCA will be the identification of applicable governing legislation authorizing and empowering the contractual arrangement between or among the parties. This is known as the jurisdictional provision. The standard jurisdictional references for FFCAs have been the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) as amended by the Superfund Amendments Reauthorization Act (SARA), RCRA as amended by the Hazardous Solid Waste Amendments, Executive Orders 12088 and 12580, the National Environmental Policy Act (NEPA), and the Atomic Energy Act. KCP is exclusively controlled by RCRA; therefore, CERCLA and NEPA references do not apply. NEPA references were absent from Hanford and RFP. Subsequent amendments to Hanford and RFP may be considered. State environmental legislation impacting federal facility operations was actively included within jurisdictional parameters for the states of California, Colorado, Idaho, Tennessee, and Washington.

Purpose and Scope

The general purpose and scope of the FFCAs were tailored to site-specific requirements, although the basic statements regarding the nature of the work, general objectives, and time schedule provisions mirrored FFCA model language. The general statements of purpose most often articulated were (1) ensuring thorough investigations of environmental response actions, (2) establishing procedural frameworks by which to monitor cleanup activities, and (3) facilitating interaction and cooperation among the parties. Specific objectives included (1) establishing a framework to ensure statutory compliance for both federal and state requirements, (2) establishing performance criteria for Remedial Investigations (RIs) and Feasibility Studies (FSs), and (3) performing the necessary cleanup. In two instances, Fernald and LLNL, DOE further agreed to more specific provisions, including (1) risk assessment activity, (2) Record of Decision procedures, (3) Work Plan reviews, and (4) public comment activities.

RCRA/CERCLA Integration and Interagency Consultation

In order to ensure concurrent statutory compliance for RCRA and CERCLA requirements, FFCA drafters analyzed and created an integrated approach to meeting the threshold requirements of federal regulations.(9) These provisions taken together provide DOE, EPA, and the states with specific assignments of responsibilities and obligations that subsequently avoid confusion and provide necessary leadership, thus reducing costly delays and duplication of effort. Although some provisions are not specifically referenced, most states have attempted to accommodate the integration of RCRA and CERCLA on-site cleanup issues. State roles are becoming more clearly defined as in the Hanford, INEL, LLNL, and RFP agreements. Lead agency status is usually outlined in the site action plan, often supplied in the FFCA attachments or appendixes.

Because the parties share duties for document review and approval, a separate section described as "Interagency Consultation" is included as a key provision in most agreements. The "Primary" document list includes, but is not limited to, RI/FS Work Plans, RI and FS Reports, Proposed Plans, and Remedial Design and Remedial Action Work Plans. Primary documents are generally subject to review and approval by the parties and may be thrust into the dispute resolution process by any of the parties. Documents designated of secondary importance may be subject to review and comment by the parties but not elevated to the formal dispute resolution process for reconsideration. Secondary docu-

ments include data quality objectives, sampling and data results, treatability study findings, technical memoranda, monthly progress reports, baseline risk assessments, initial screenings of alternatives, and health and safety plans. Project managers must become thoroughly familiar with the relevant document designations.

Dispute Resolution Process

Following attempts to resolve matters informally, the parties have available a procedural framework through which to settle issues of significant impact without going immediately to court. It is generally agreed that undisputed work will continue to be performed while the Dispute Resolution Committee (DRC) reviews the issues under consideration. Upon receipt of a written request, party representatives serving on the committee will review the issues and within twenty-one (21) days (30 days at KCP) respond with their determinations in writing. If the concerns remain unresolved, the dispute advances to the Senior Executive Committee (SEC) where parties are represented from higher levels of decision-making power and oversight authority. Twenty-one days are again permitted for the SEC to reach an equitable conclusion. Should the issue remain unresolved, the conflict is raised to review and final determination by the Administrator of EPA (or the state designee, where applicable), and the determination made will be final subject to implementation or adjudication as circumstances warrant.

The final key provisions of FFCAs to be discussed are clustered together and known in legal parlance as the "hammer" clauses, which create bargaining tools of leverage to ensure the enforcement of the negotiated terms, providing flexibility and fairness to all parties.

Stipulated Penalties

To avoid complex, prolonged, and expensive litigation among contracting parties, it is useful to know the penalties for nonperformance from the beginning. The amount of proscribed penalties and a determination of which parties will be liable may be established at the outset by mutual agreement. The standard stipulated penalty clauses that appear in all but one FFCA require that (1) the penalty shall not exceed $5000 for the first week or $10,000 for each additional week and that (2) the amount stipulated may not exceed the amount set forth in Sect. 109 of CERCLA. Stipulated penalties are conspicuously absent from the KCP agreement. A unique provision of the INEL agreement directly references any succeeding changes in the law that may impact stipulated penalties, providing for the opportunity to modify the agreement if subsequent changes in regulations occur.

Extensions and Terminations

All FFCAs reviewed allow for reasonable extensions for performance upon (1) timely written requests and (2) the existence of "good cause." (10) Slight variations in the definition of "good cause" appeared, but agreements generally include *Force Majeure* events, delays by third parties, invoking dispute resolution actions, or events mutually agreed upon as "good causes." Terminations were agreed to have occurred when all parties completed their work or satisfied the contract terms.

Force Majeure Events

Force Majeure events are circumstances that may justify the suspension of performance by one or all parties because such circumstances remove completion of tasks from control of the obligated parties and are unavoidable regardless of the amount of due care exercised by the parties. *Force Majeure* events are generally occurrences such as acts of God, fire, war, insurrection, adverse weather, plagues, or pestilence. For the modern settings of the federal facilities, plagues and pestilence are omitted; instead, concerns such as transportation delays, court orders, labor disputes, strikes, unavailability of necessary licensing, and inadequate funding constitute *Force Majeure* events. Additionally, the KCP agreement includes delays imposed by compliance with NEPA regulations. Expressly excluded as a *Force Majeure* event is the increased cost or expense of response actions.

Funding

Determining which parties bear the legal burden for expenses is one of the most volatile issues of negotiation. All parties anticipate the allocation of appropriate funding, but contingency planning needs to be prearranged to avoid delays or termination of cleanup activities. EPA generally reserves alternative enforcement options in the absence of full funding and the right to seek reimbursement as authorized by CERCLA. DOE has limited cost recoveries when possible and has declined to compel reimbursement by other parties.

Enforceability

Most agreements allow significant standards, requirements, orders, conditions, timetables, schedules, and deadlines relating to removal and remedial actions to be enforceable by any person under CERCLA. (11) Violations of CERCLA provisions subject the parties to civil penalties. It is evident from case law that federal employees are subject to criminal enforcement provisions as noted in the case of *United States v. Dee*, 912 F.2d 741 (4th Cir. 1990). Three civilian engineers working for the U.S. Army performing chemical warfare system research and development at the Aberdeen Proving Ground, Maryland, exhibited reckless disregard for the proper storage and disposal of hazardous materials and were convicted of criminal violations of RCRA. Federal employees working at federal facilities are clearly not protected by sovereign immunity when engaged in criminal conduct, however, limited civil immunity for official actions remain.

It is noteworthy to mention the exceedingly detailed description of enforceability provisions drafted by those executing the agreement at RFP. The parties delineated enforcement provisions applicable where the state holds supremacy as well specifying actions to be taken where EPA maintained the status as lead regulatory agency.

Covenants Not to Sue/Reservation of Rights

Generally, to be enforceable, a contract requires evidence of "consideration." Sometimes this requirement is referred to as legal detriment. It suggests the performance of an act or forbearance from some action as the basis for a bilateral exchange of promises. Without the exchange of promises, the contract may not be binding.

Certainly it is arguable that imposing a compliance regime on governmental operations to perform an existing

obligation does not suggest new consideration. Yet, the cleanup operation performed within a specific time frame does create a new obligation involving a considerable expenditure of funds, thus constituting a legal detriment to the facility and becomes sufficient consideration to enforce the promise. The parties may agree to do or refrain from doing something that they may have full legal rights and authority to engage in. The forbearance not to sue but instead apply alternative dispute resolution processes is another bargained-for term of the contract. EPA and the states have made only limited concessions "not to sue," and each of the parties has reserved some rights to judicial intervention where needed. The reservation of rights provisions are "escape clause" options once the administrative remedies agreed to by the parties have been exhausted.

Of the eight agreements reviewed, one had no Reservation of Rights terms (KCP), three had only Reservation of Rights provisions (Hanford, INEL, and RFP), and four held both Covenants Not to Sue and Reservation of Rights conditions (Fernald, LLNL, Mound, and ORR).

FUTURE ENFORCEMENT STRATEGIES

Interagency litigation over regulatory authority (i.e., jurisdiction) will continue, but hopefully the numbers and volume will be significantly reduced. (12) EPA, with burgeoning responsibilities and limited resources, has redesigned its previous enforcement tactics. EPA will begin to effect a comprehensive multimedia inspection and compliance approach. EPA has a variety of monitoring data bases and will integrate them more efficiently to target violators and track compliance activity. By issuing federal/state enforcement agreement policies and guidelines, state enforcement programs are buttressed and become wholly "consistent with EPA guidelines." EPA and the states will apply uniform performance criteria, procedures, and penalty enforcement for federal facilities out of compliance exactly as they do with private commercial enterprises.

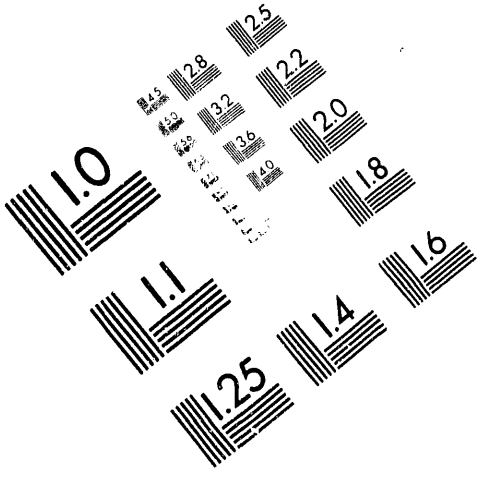
Federal facilities should be models for environmental compliance. The level of commitment to this achievement extends to (1) better prioritizing of enforcement activities based upon facility compliance histories; (2) creating a list of significantly impacted operations determined by EPA Region, thereby distinguishing "candidates for multimedia inspections"; (3) creating "a more intensive (multimedia) inspection scheme for federal facilities"; and (4) integrating the "target resources on the basis of greatest potential for risk reduction." (13) The new approaches to maximizing compliance at federal facilities in conjunction with heightening intergovernmental cooperation and improving relations with state enforcement divisions should serve to stockpile EPA's enforcement arsenal for the decades to come in managing these complex but critical concerns of modern man.

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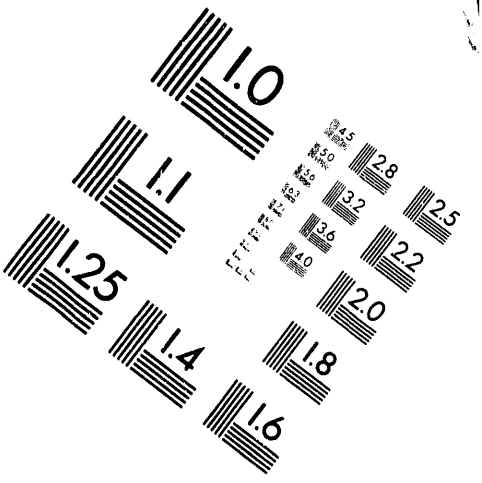
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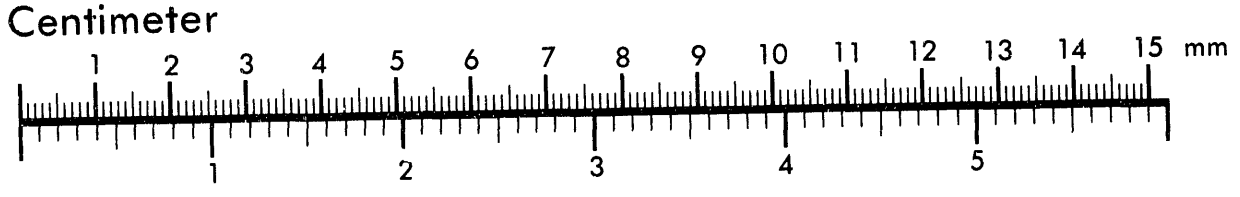
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
DOE	Department of Energy
DRC	Dispute Resolution Committee
EPA	U.S. Environmental Protection Agency
Fernald	Feed Materials Production Center
FFCA	Federal Facility Compliance Agreement
FS	Feasibility Study
INEL	Idaho National Engineering Laboratory
KCP	Kansas City Plant
LLNL	Lawrence Livermore National Laboratory
NEPA	National Environmental Policy Act
NTS	Nevada Test Site
ORR	Oak Ridge Reservation
RCRA	Resource Conservation and Recovery Act
RFP	Rocky Flats Plant
RI	Remedial Investigation
SARA	Superfund Amendments and Reauthorization Act
SEC	Senior Executive Committee
SRS	Savannah River Site

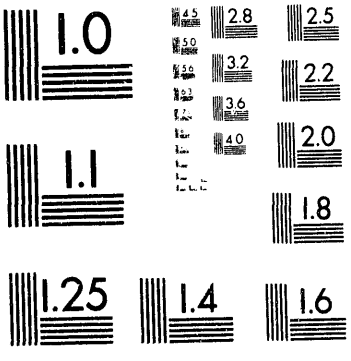


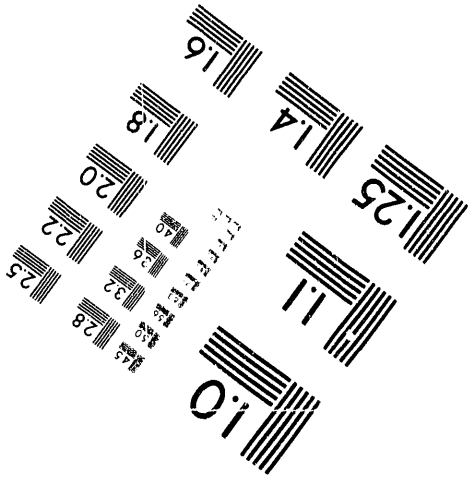


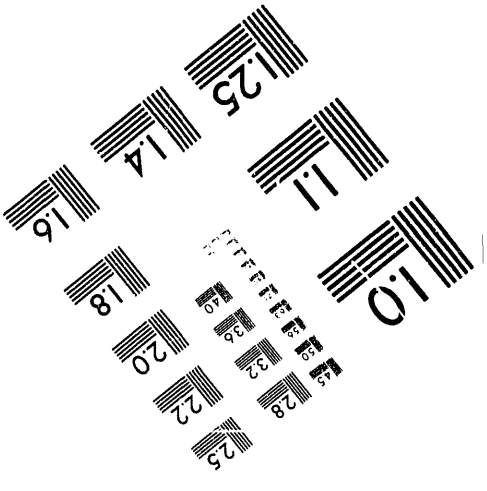
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TIGER TEAM FINDINGS RELATED TO DOE ENVIRONMENTAL RESTORATION ACTIVITIES

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ABSTRACT

Tiger Team Assessments were implemented in June 1989 as part of a strategy to ensure that DOE facilities fully comply with Federal, state, local and DOE environment, safety, and health (ES&H) requirements. The Tiger Teams provide the Secretary of Energy with information on current ES&H compliance status of each DOE facility and causes for noncompliance. To date, Tiger Team Assessments have been completed at 25 DOE facilities. With regard to assessments of environmental restoration activities, the performance of DOE facilities was evaluated against the requirements of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), as amended, the National Contingency Plan (NCP), and DOE Order 5400.4, CERCLA Requirements, among others. Five major categories of environmental restoration-related findings were identified: 1) environmental restoration program planning and management (found at 60 percent of the sites assessed); 2) community relations/administrative record (60 percent); 3) characterization of extent of contamination (56 percent); 4) identification and evaluation of inactive waste sites (56 percent); and 5) DOE and NCP requirements for response action studies (44 percent). Primary causal factors for these findings were inadequate procedures, resources, supervision, and policy implementation.

INTRODUCTION

On June 27, 1989, Secretary of Energy James D. Watkins announced a Ten-Point Initiative to strengthen safety, environmental protection, and waste management activities at U.S. Department of Energy (DOE) facilities. The Initiative is part of the Secretary's overall strategy to ensure full compliance with Federal, state, local, and DOE environment, safety, and health (ES&H) requirements. As part of the Ten-Point Initiative, the Secretary implemented independent internal Tiger Team Assessments to determine the degree to which DOE facilities are adhering to these requirements and to create a new culture of self-assessment and accountability. Specifically, the Tiger Teams are to provide the Secretary with concise information on: 1) current ES&H compliance status of each DOE facility and associated vulnerabilities, 2) root causes for noncompliance, 3) adequacy of DOE and site contractor management programs, 4) response actions to address identified problem areas, and 5) DOE-wide ES&H compliance trends and root causes. The goals of the Tiger Team program are to determine and implement actions to bring facilities into compliance and to develop systems to ensure continued compliance.

Tiger Team Assessments consist of three related subjects -- Environment, Safety and Health, and Management. Within the Environment portion generally are ten topics related to regulatory and environmental media issues -- for example waste management, air, and radiation. Each of these topics is evaluated for performance against specific objectives and criteria, mainly environmental regulatory requirements and generally recognized good management practices. Findings and contributing causal factors are then identified for situations in which the regulatory requirements or good management practices are not being met at DOE facilities.

Environmental restoration activities are evaluated within the Inactive Waste Sites topical area of the Environment portion of the Tiger Team Assessment, as well as within the Groundwater and National Environmental Policy Act (NEPA) areas. The focus of the Inactive Waste Sites section is an assessment of studies and restoration activities associated with releases of hazardous substances, including radionuclides. Related Groundwater issues include the manner in which groundwater monitoring is being implemented to support Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) response and Resource Conservation and Recovery Act (RCRA) corrective action activities. Related NEPA issues include the integration of the NEPA process into CERCLA response and RCRA corrective action activities.

The purpose of this paper is to present some of the major findings categories and causal factors related to DOE environmental restoration activities identified in the 25 Tiger Team Assessments completed to date. Table I lists the sites assessed in chronological order, the completion date, and the responsible program and field office. It should be noted that sites in all program and field offices have now been evaluated by Tiger Teams. The findings categories were developed through a review of all Inactive Waste Site, Groundwater, and NEPA findings for the 25 Tiger Teams conducted to date.

TIGER TEAM ASSESSMENT METHODOLOGY

The scope of the environmental restoration-associated portion of Tiger Team Assessments is an evaluation of: 1) compliance with Federal and state requirements dealing with inactive waste sites, such as CERCLA, as amended by the Superfund Amendments and Reauthorization Act (SARA); RCRA corrective action; and DOE Order 5400.4, CERCLA Requirements; as well as best management practice; 2) DOE and site contractors' management of environmental restoration programs; and 3) the management and conduct of studies and actions taken to respond to the cleanup of inactive waste sites.

The assessments are generally conducted through document reviews, interviews, and site tours. Documents reviewed include remedial investigation/feasibility study (RI/FS) work plans and reports, regulatory correspondence, standard operating procedures, and regulatory agency agreements and orders. Interviews are conducted with environmental restoration management and operations personnel as well as with Federal and state regulators. Visual inspections are made of

TABLE I

DOE Facilities Assessed by Tiger Teams

Facility	Date Completed	Program Office	Field Office
Rocky Flats Plant	7/89	DP	AL/HQ
West Valley Demonstration Project	7/89	NE	ID
Feed Materials Production Center	8/89	DP/EM	OR
Y-12 Plant	10/89	DP	OR
Pantex Plant	10/89	DP	AL
Mound Plant	11/89	DP	AL
Portsmouth Uranium Enrichment Complex	11/89	NE	OR
Nevada Test Site	12/89	DP	NV
Kansas City Plant	12/89	DP	AL
Pinellas Plant	2/90	DP	AL
Savannah River Site	3/90	DP	SR
Lawrence Livermore National Lab	3/90	DP	SAN
Brookhaven National Laboratory	4/90	ER	CH
Sandia National Laboratories, Livermore	5/90	DP	AL
Hanford Site	7/90	DP/EM	RL
Paducah Gaseous Diffusion Plant	7/90	NE	OR
Argonne National Laboratory	10/90	ER	CH
Oak Ridge National Laboratory	11/90	ER	OR
Lawrence Berkeley Laboratory	2/91	ER	SAN
Princeton Plasma Physics Laboratory	2/91	ER	CH
Energy Technology Engineering Center	4/91	NE	SAN
Sandia National Laboratories, Albuquerque	5/91	DP	AL
Morgantown Energy Technology Center	6/91	FE	-
Idaho National Engineering Laboratory	8/91	NE	ID
Solar Energy Research Institute	8/91	CE	CH

the inactive waste units and any ongoing investigative or cleanup activities.

Observations made during the assessment are evaluated against Federal, state, and local regulations; DOE Orders; and best management practices as described in guidance documents and current industry standards. The major requirements used in evaluating environmental restoration activities and programs are depicted in Table II. DOE Order 5400.4, CERCLA Requirements, requires that CERCLA, as amended by SARA, and the National Contingency Plan (NCP) be followed regardless of whether or not a DOE facility is on the National Priorities List (NPL). In cases where other regulatory authorities apply, such as RCRA corrective action, the Order states that activities should not be inconsistent with CERCLA, as amended by SARA, and the NCP.

CERCLA, the NCP, RCRA corrective action, and associated guidance, as well as interagency agreements and consent orders, provide the framework, process, and procedures by which environmental restoration activities are effected. DOE Order 5480.19 on conduct of operations requires formality in the conduct of such activities as inactive waste site response actions, including the development of procedures and training. DOE Order 5700.6B establishes the standards by which quality of operations and data can be ensured.

Observations which do not conform to these requirements and practices are then developed into findings. The findings, which describe not only the nonconformances but also the factors that may have caused them, are presented in Tiger Team Assessment reports. The sites and their respective program offices then develop action plans that describe the manner in which the deficiencies and their causes will be corrected and the associated estimated budgets and schedules.

MAJOR ENVIRONMENTAL RESTORATION FINDINGS CATEGORIES

An analysis of the Inactive Waste Sites, Groundwater, and NEPA findings from the 25 Tiger Team Assessments conducted to date identified five major findings categories:

- Identification and Evaluation of Inactive Waste Sites;
- DOE and NCP Requirements for Response Action Studies;
- Characterization of Extent of Contamination;
- Community Relations/Administrative Record; and
- Environmental Restoration Program Planning and Management.

Two minor categories of findings were also noted: NEPA/CERCLA/RCRA Integration and Natural Resource Damage Assessment. The following paragraphs describe the issues associated with these categories; in addition, Table III depicts the DOE facilities at which the major findings categories were identified.

Findings related to inadequate identification and evaluation of inactive waste sites were noted at 56 percent of the sites assessed. In general, these findings resulted from observations that facilities had not performed adequate historical investigations or other types of information searches to discover past

TABLE II

Environmental Restoration Performance Objecti

DOE Order 5400.4, CERCLA Requirements

Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (Superfund)

Superfund Amendments and Reauthorization Act of 1986

National Oil and Hazardous Substances Contingency Plan [National Contingency Plan - 40 Code of Federal Regulations (CFR) 300]

Executive Order 12580, Superfund Implementation

Releases from Solid Waste Management Units (40 CFR 264, Subpart F, promulgated under the Resource Conservation and Recovery Act)

Corrective Action for Solid Waste Management Units at Hazardous Waste Management Facilities (Proposed 40 CFR 264, Subpart S, promulgated under the Resource Conservation and Recovery Act)

DOE Order 5480.19, Conduct of Operations Requirements for DOE Facilities

DOE Order 5700.6B, Quality Assurance

Interagency Agreements and Consent Orders

Guidance Documents

waste sites. In cases where past sites had been identified, evaluation of those sites through information searches was not sufficient to describe the wastes they received or the manner in which they were operated, to determine the risk, or to assess further response actions. Other issues associated with these findings included nonexistent or incomplete notifications to regulatory agencies, such as preliminary assessments, and inadequate formalized programs to identify past waste sites.

Site discovery and evaluation is one of the first steps required in the NCP for inactive waste site response. In addition, the DOE CERCLA Order requires that the NCP be followed regardless of whether or not the site is on the NPL. As a result, where these findings were made, they were generally based as a nonconformance with the NCP and the DOE CERCLA Order.

Forty-four percent of DOE facilities assessed did not adhere to the requirements of the DOE CERCLA Order, the NCP, or site-specific interagency agreements for performing removal evaluations and RI/FSs. Findings that contributed to this category included: 1) RI/FS work plans and reports that were inadequate either for technical reasons or for failure to follow the requirements of the NCP or RI/FS guidance; 2) RIs that did not follow associated work plans; 3) implementation of response actions without conducting removal site evaluations or RI/FSs; 4) inadequate quality assurance and data quality objectives; and 5) inadequate assessment of remedial alternatives in an FS. It should be noted for this category of findings that not all sites had progressed to the stage of conducting removal site evaluations or RI/FSs.

Associated with the previous findings category, 56 percent of the DOE sites assessed by Tiger Teams had not adequately characterized the extent of contamination during response studies such as removal evaluations or RIs. This included a lack of delineation of the horizontal and vertical extent of contamination in the soil column and groundwater and an incomplete definition of the hydrogeologic regime. The findings supporting this category were generally identified in the Groundwater sections of the Tiger Team Assessment reports and were based on the requirements of the NCP and U.S. Environmental Protection Agency RI/FS guidance.

Facilities listed on the NPL performing inactive waste site response studies and planning restoration activities are required by the NCP to involve the public through the preparation and implementation of a community relations plan and the maintenance of an administrative record. The DOE CERCLA Order requires all DOE facilities to follow the NCP regardless of whether or not the site is on the NPL. Sixty percent of the sites assessed had not adequately fulfilled the public involvement requirements. They either had not prepared or implemented a community relations plan or had not established or had an incomplete administrative record.

Sixty percent of the DOE facilities assessed were not adequately managing their CERCLA or RCRA corrective action activities. Findings contributing to this category were based on best management practices and the concept of formal conduct of operations, as delineated in DOE Order 5480.19, rather than on specific regulatory requirements. Areas where weaknesses were noted included: 1) inadequate or reactive program planning and funding; 2) lack of procedures and definition of roles and responsibilities; 3) inadequate program oversight and tracking; 4) lack of timeliness of document reviews internally by DOE and externally by regulatory agencies; and 5) proceeding without formal regulatory agency approval.

Two other categories of lesser prominence were also noted in the review of environmental restoration-related findings -- NEPA/CERCLA/RCRA integration and natural resource damage assessment. With regard to the former, 20 percent of the sites either had not adequately integrated or planned for the integration of NEPA requirements with those of CERCLA response or RCRA corrective actions. The DOE CERCLA Order specifies that NEPA requirements be integrated into CERCLA activities, although formal guidance is presently lacking. As to the latter category, 16 percent of the sites had not identified or notified natural resource trustees of potential threats to natural resources under their charge, as is required in the NCP and the DOE CERCLA Order.

CAUSAL FACTORS

Causal factors for Tiger Team environmental findings were assessed based on the EG&G Idaho, Inc. Management Oversight and Risk Tree (MORT) analysis process. The MORT system has 27 root cause categories from which Tiger Team causal factors were selected, adapted, and defined. For the most part, there were four causes of environmental restoration-related findings -- procedures, resources, supervision, and policy implementation. All four factors were generally cited as causes in all categories of findings, rather than any one specific factor causing a particular type of finding.

TABLE III

Environmental Restoration Findings Categories and Associated Facilities

	Identification and Evaluation of Inactive Waste Sites	DOE and NCP Requirements for Response Action Studies	Characterization of Extent of Contamination	Community Relations/ Administrative Record	Environmental Restoration Program Planning and Management
Argonne National Laboratory	X			X	
Brookhaven National Laboratory	X	X	X	X	
Energy Technology Engineering Center		X	X	X	
Feed Materials Production Center		X		X	X
Hanford Site	X	X			X
Idaho National Engineering Laboratory	X		X	X	X
Kansas City Plant	X		X	X	X
Lawrence Berkeley Laboratory	X		X		X
Lawrence Livermore National Laboratory			X	X	
Morgantown Energy Technology Center	X	X	X	X	X
Mound Plant	X	X		X	
Nevada Test Site	X	X	X		X
Oak Ridge National Laboratory	X		X		X
Paducah Gaseous Diffusion Plant		X		X	X
Pantex Plant				X	X
Pinellas Plant		X	X	X	X
Portsmouth Uranium Enrichment Complex			X		
Princeton Plasma Physics Laboratory	X		X		X
Rocky Flats Plant	X	X	X	X	X
Sandia National Laboratories, Albuquerque				X	X
Sandia National Laboratories, Livermore		X	X	X	
Savannah River Site	X				X
Solar Energy Research Institute	X				
West Valley Demonstration Project					
Y-12 Plant					

Procedures were lacking, inadequate, or not fully implemented or disseminated for a variety of functions, including conduct of environmental restoration operations, routine training, and assignment of roles and responsibilities; also, lack of or inadequate guidance from DOE Headquarters was cited. Resources, in terms of personnel, funding (prioritization and efficient use), and equipment, were often found to be insufficient. In addition, lack of program supervision, oversight, and management coordination by DOE and site contractors contributed to the environmental restoration findings.

Other less frequently cited causal factors included lack of or inadequate training, quality assurance, policy, risk prioritization, and product and program reviews. As a result of these major and minor causal factors, policy in the form of environmental restoration-related regulations, DOE Orders, guidelines, or site procedures was not fully implemented.

SUMMARY

Tiger Team Assessments of environmental restoration activities have identified nonconformances in the major phases of the NCP that have been conducted at DOE facilities. These phases include inactive waste site identification and evaluation, removal and remedial studies, and associated delineation of extent of contamination, implementation of community relations activities, and maintenance of administrative records. In addition, environmental restoration program planning and management have been found to be inadequate. The major causes of these findings appear to be insufficient procedures, resources, and supervision, resulting in inadequate implementation of the DOE policy of adhering to CERCLA and the NCP for environmental restoration activities.

The findings categories and causal factors are widespread among DOE facilities and do not appear to be correlated to specific DOE field offices or program offices.

INTEGRATION OF REMOVAL ACTIONS INTO THE OPERATIONS AT A DOE FACILITY

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ABSTRACT

The implementation of Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) removal actions at a DOE facility can be a complex and complicated process. This paper examines the application of CERCLA removal actions at the Fernald Environmental Management Project (FEMP). Specific discussion is presented on: the regulatory background, the framework utilized to conduct removal actions, and examples of successful implementation. The flowchart presented has been derived from the approach currently employed at the FEMP. Case histories for two specific time-critical removal actions which were successfully completed following the system employed at the FEMP are provided to assist other sites in noting potential problem areas encountered during the planning, preparation, and implementation phases of removal actions.

INTRODUCTION

On November 21, 1989, the Fernald Environmental Management Project (FEMP), formerly the Feed Materials Production Center, was placed on the National Priorities List in response to significant concerns regarding existing and potential environmental impacts associated with facility operations. In response to this listing, the Department of Energy (DOE) jointly signed a Consent Agreement with the United States Environmental Protection Agency (U.S. EPA) in April, 1990 establishing a framework for the application of CERCLA statutory requirements to the DOE facility. One significant provision of the Agreement was the establishment of a consensus approach and specific milestone schedules for the evaluation and implementation of removal actions at the facility.

This paper reviews the regulatory and DOE requirements regarding the conduct of removal actions, some site specific methodology being employed and some experience and lesson learned over the last two years at the FEMP implementing these actions.

REVIEW OF THE REMOVAL ACTIONS PROCESS

A removal action under CERCLA is broadly defined as the implementation of the necessary actions to prevent, minimize or mitigate damage to public health or welfare or the environment as a result of a release or a threat of a release of a hazardous substance. Removal actions are implemented pursuant to either Section 104 (a) or Section 106 (a) of CERCLA. Section 104 (a) provides for the implementation of such actions as may be necessary to address a release or a significant threat of a release of a hazardous substance to the environment. Section 106 (a) provides statutory authority to implement actions as may be necessary to address the imminent and substantial endangerment to human health and the environment due to a release or a significant threat of a release. Executive Order 12580 empowers the Secretary of the Department of Energy with the statutory authority to conduct removal actions consistent with Section 104(a) at DOE facilities.

On March 8, 1990, a final rulemaking was published in the Federal Register providing a revision to the National Oil and Hazardous Substance Contingency Plan (NCP)(1) fully incorporating the 1986 Superfund Amendments. The NCP and relevant guidance(2) establish the minimum requirements and basic framework for the conduct of removal actions. Removal actions are typically classified into three basic types; emergency, time-critical and non-time critical actions. Figure 1 summarizes the key activities required by regulation or recommended by U.S. EPA guidance to initiate each of the types of removal actions.

Emergency removal actions are typically initiated in response to active release situations which involve known or significant threats of endangerment to human health or the environment. Emergency removal actions have not been employed to date at the FEMP and are not a subject of this paper.

As identified in Fig. 1, consideration for the implementation of a removal action is initiated with a discovery or notification of a release of a hazardous substance. Typically, these discoveries take place as a consequence of the preliminary assessment phase of a remedial site evaluation or due to the progressive evaluation of data collected during a Remedial Investigation/Feasibility Study. On the basis of the discovery, available information is compiled and a Removal Site Evaluation (RSE) is conducted. As part of the process of preparing the RSE, the responsible party evaluates existing data in context of the current and potential threats to human health and the environment. RSEs at the FEMP typically have entailed a risk assessment of the existing situation surrounding the release or threatened release and the potential for exposure to on-site workers or the general public. On the basis of the data compilation and evaluation in the RSE and in consideration of eight specific factors identified in Section 300.415 of the NCP, the lead agency (i.e. the DOE at FEMP) is required to make a determination if the existing situation warrants a removal action. This determination, which is documented in an Action Memorandum, must also include an assessment of the time period which exists before which the removal action must be implemented. Consistent with the provisions of the NCP, if the lead agency deems that less than a six month planning period exists before abatement actions must be implemented, then the Action Memorandum will typically classify the removal as a time-critical action. In the event that the lead agency deems that greater than a six month planning period exists, then the action is categorized as a

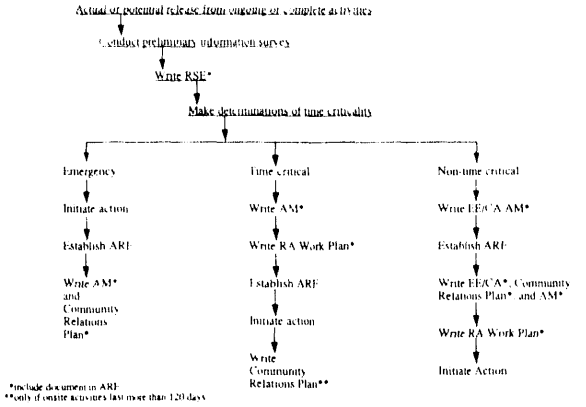


Fig. 1. CERCLA removal action.

non-time-critical removal action. Upon issuance of the Action Memorandum establishing the need for a removal action, the DOE project manager is typically confronted with the formitable task of integrating the environmental and project requirements of DOE with the U.S. EPA, state and local regulatory requirements.

For time-critical removal actions, the first primary requirement is the issuance of a Work Plan establishing the scope, schedule and anticipated cost of the required action. This Work Plan is recommended pursuant to U.S. EPA guidance and provides a vehicle for identifying and properly integrating DOE requirements. At the FEMP, the development of the Time-critical Removal Action Work Plan typically involves the completion of an engineering alternatives evaluation and the development of a resource loaded schedule in accordance with the project requirements defined in DOE Order 4700.1, (Project Management System). An important consideration in the development of the Work Plan is the establishment of definitive removal action objectives and performance criteria. The objectives of the removal action are typically based upon a risk management decision fully addressing the concerns identified through the RSE. As identified in CERCLA, one important objective of any removal action is the need to ensure that any proposed removal action contributes to the successful performance of the anticipated final remedial action. Performance criteria for the removal system are typically identified through a determination of the Applicable and Relevant Requirements (ARARs) and To Be Considered Requirements (TBCs) appropriate for the action. The ARARs/TBC identification process involves the examination of the universe of existing regulations and guidance to determine what, if any, requirements must be applied to the removal action to ensure protection of human health and the environment. Consistent with the NCP, a removal action must comply to the maximum extent practical with the technical requirements of identified ARARs and TBCs.

The Removal Action Work Plan must also consider the schedule and resource requirements to address DOE requirements such as: Compliance with the National Environmental Policy Act (NEPA) as specified in DOE Order 5440.1D (NEPA Compliance Program), Safety Analysis consistent with DOE Order 5481.1 (Safety Analysis and Review System), and Operational Readiness Reviews also consistent with DOE Order 5481.1.

Consistent with DOE Order 5440.1D, the environmental consequences of proposed actions, including removal actions at DOE facilities, must be evaluated and documented. On September 7, 1990, supplemental guidance was provided in the Federal Register(3) on the integration of the NEPA process with proposed removal activities. This supplemental guidance amended DOE's NEPA guidelines by adding a categorical exclusion for certain removal actions conducted pursuant to CERCLA. This categorical exclusion is specifically limited to those actions which would not have any significant impact on the human environment. The NEPA determination process must be fully integrated with the removal action decision process to ensure full compliance with this DOE Order and with the statutory requirements of NEPA.

DOE Order 5481.1 establishes the requirements for the preparation and review of safety analyses for DOE operations, including the identification and control of hazards and the assessment of safety system related risk. The DOE Order also establishes a formal management authorization process which must be completed prior to the initiation of operation. DOE Order 5481.1 requires the preparation of safety analyses for each proposed DOE operation to ensure that an independent review of the associated safety systems is completed and appropriately documented. Pursuant to the Order, identified hazards are classified as either low, medium, or high. Environmental cleanup actions, such as removal actions, will typically include only low classes of hazards and can be approved by the operating organization. If, however, a moderate or high hazard class is identified, then the review and approval levels become significantly elevated.

Also, as provided by DOE Order 5481.1 and DOE 4700.1, DOE facilities are responsible for the performance of Operational Readiness Reviews to ensure that any planned operation or activity, including removal actions, are systemmatically reviewed to assure and demonstrate that a proper state of readiness has been achieved. On the basis of the complexity of the proposed action, a graded approach is employed to establish the proper level of review and approval prior to initiation of activites. Considerable up-front planning is required to ensure that the appropriate review process is appropriately factored into the project schedule.

For non-time critical removal actions, the Action Memorandum will typically specify that greater than a six month planning period exists before required implementation and a more thorough evaluation of the required action is warranted. This detailed evaluation is completed through preparation of an Engineering Evaluation/Cost Analysis (EE/CA) or equivalent study. The EE/CA typically entails an engineering and risk assessment of the viable removal action alternatives considering the cost, implementability and effectiveness of each alternative. Following lead and support agency and public reviews, an Approval Memorandum is issued selecting the proposed action. As previously identified, following issuance of the Approval Memorandum, a Removal Action Work Plan is compiled establishing the schedule and project specific requirements.

The planning and implementation of removal actions must also provide for the involvement of the public and the completion of a proper documentation trail. Consistent with the NCP, the planning and implementation of each of the types of removal action processes must provide for the involvement of the public. This involvement should include the issuance of Action Memorandum for public review and the preparation of project specific community relations plans.

Documentation requirements are satisfied through the proper establishment and maintenance of an Administrative Record file for each removal action. The Administrative Record file must contain all documentation supporting the removal action selection process. Project specific final reports are also recommended by guidance to provide for a complete project file and ensure consistency with the final remedial actions.

FRAMEWORK FOR THE CONDUCT OF REMOVAL ACTIONS

A time-scaled flow diagram depicting the integrated requirements of U.S. EPA and DOE for both time-critical and non-time-critical removal actions is provided as Fig. 2. It is important to note that different sites will have site-specific requirements which must be met prior to the initiation of a removal action. These site-specific requirements must also be factored into the timeline.

Emergency removal actions are not depicted in this flow diagram but follow similar logic. A major difference with emergency removals is that the action is initiated prior to the development of justification documentation. When an emergency removal action is identified, both HQ-DOE and EPA counsel should be obtained and documented. It is extremely likely that if an emergency removal action is warranted, approval will be readily attainable.

The flow diagram (Fig. 2) is generic in nature and identifies major activities required for preparation and planning of removal actions. Review and approval requirements and cycles may vary from site to site as well as from removal action to removal action. The logic flow diagram depicts a typical chronology of events to be initiated to meet removal action schedule requirements and to support the successful management of removal actions.

As indicated on the flowchart (Fig. 2), completion of numerous activities must be accomplished prior to actual field implementation of construction for a removal action. Issues such as NEPA determination and approval, safety assessment completion, and the assessment of potential ARARs can significantly affect the planned start date of the action.

NEPA Determination and Approval

The National Environmental Policy Act, as addressed earlier, requires all Federal Agencies to assess their activities as they relate to the protection of the environment. Time-critical removal actions are typically excluded from the stringent evaluation criteria imposed and are considered "Categorically Excluded". Documentation must be produced and approved by HQ-DOE prior to the initiation of the activity. Non-time-critical removal actions, which require an EE/CA, are more complicated. These actions generally require an Environmental Assessment (EA), and require State regulatory agency input. The EE/CA can suffice as the EA if prepared correctly, however, there will be a longer review/approval cycle.

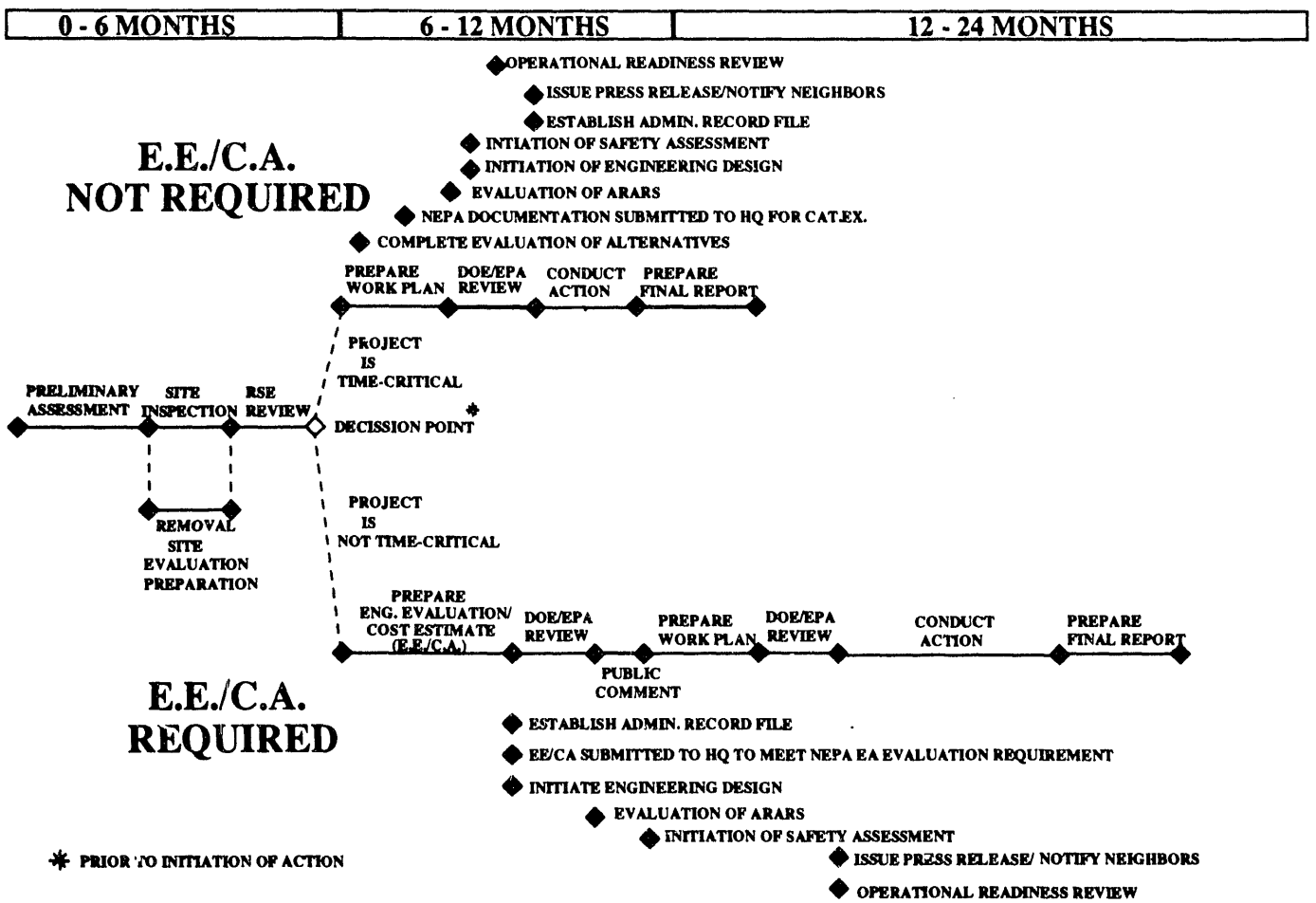


Fig. 2. DOE removal action flowchart.

Safety Assessment Determination

Prior to initiating field activities for a removal action, DOE Orders require that the safety assessment be completed and reviewed. For time-critical removal actions, this review can be conducted at the site and easily coordinated into the planning process. However, non-time-critical removal actions can become complicated, possibly requiring the construction and/or start-up of facilities to support the removal, therefore, these actions may require higher levels of safety assessment review which can cause significant program schedular impacts. Typically, safety assessments should be initiated as soon as possible in the removal action process.

ARAR Evaluation

Probably the most difficult activity to plan for and to implement is the assessment of the requirements of ARARs. Close dealings with the regulators and compliance staff can greatly facilitate this action. Issues dealing with RCRA requirements, asbestos notification requirements, wetland assessment requirements, and Army Corp of Engineer Permit requirements may be applicable and require significant actions to be completed prior to the initiation of the action.

REMOVAL ACTION IMPLEMENTATION

Implementing Removal Actions at the FEMP following the flow chart outline (Fig. 2) has led to several successful examples of start-to-finish interim measures that have mitigated personnel/environmental risk.

For example, a Removal Action which significantly reduced the potential for fugitive airborne radioactive emissions from the FEMP's waste pit area, was accomplished when a mound of dried radioactive waste in Waste Pit 6 was submerged under the water which covers the waste pit.

Waste Pit 6 has a surface area of approximately 3010 square meters and is 7.3 meters in depth. The pit contains uranium tetrafluoride, process filter cakes, slag, process residues, and asbestos. The pit contains an estimated 8.5×10^5 kg. Approximately 446 square meters of the surface of the waste pit were not covered with water which exposed waste materials to the atmosphere. This exposed pit waste was subject to wind erosion and contributed to fugitive airborne releases. These factors made a response action appropriate due to potential off-site exposure as a result of wind erosion.

The objectives of the Removal Action established by a Removal Site Evaluation and Action Memorandum were:

1. Evaluate alternatives to eliminate the inhalation hazards,
2. Implement the preferred control measures to prevent the release and spread of contamination,
3. Initiate an air sampling program to quantify the extent of airborne emissions from the Waste Pit area.

An evaluation of the various alternatives to accomplish the objectives established in the Removal Action Memorandum for this Removal Action considered six alternatives:

1. No Action
2. Cover
3. Removal and Containerization of Exposed Material
4. Distribute Material Below Water Level
5. Spray-on Sealant
6. Maintain Higher Water Level

These alternatives were evaluated based upon effectiveness, implementability, and cost. The evaluation determined that distribution of the exposed material below the existing water level of the waste pit was the preferred method for accomplishing the goals of this Removal Action.

Contamination control was an issue of specific concern for the Removal Action. To prevent the spread of contamination during the Removal Action, the following precautions were taken: material movements were accomplished remotely with the use of a crane and clamshell; low-volume water spray during material movements was utilized; and a three-zone contamination barrier system was established using a contamination zone, an exclusion area, and a decontamination zone. These zones were established, and required various levels of personal protective equipment and radiological monitoring at transition areas.

A project specific Health and Safety Plan was prepared for this Removal Action to identify, evaluate, and provide strategies to control all anticipated health and safety hazards. The Health and Safety Plan was consistent with 29 CFR 1910.120 and site Health and Safety Standards.

The Removal Action to relocate the exposed waste pit contents below the water level of the pit was executed December 17-20, 1990. The following events transpired to support the Removal Action consistent with the flow chart outline:

Complete Removal Site Evaluation	September 26, 1990
Issue Removal Action Memorandum	October 4, 1990
Complete Control Measures Evaluation Study	October 8, 1990
Submit Work Plan and Health and Safety Plan to U.S. EPA for Approval	November 20, 1990
Personnel Training Completed	December 7, 1990
NEPA Approved HQ-DOE	December 14, 1990
Complete Safety Assessment	December 14, 1990
Work Plan Approved by U.S. EPA	December 14, 1990
Perform Operational Readiness Review	December 17, 1990
Press Release/Establish Administrative	December 17, 1990
Start Removal Action	December 17, 1990
Complete Removal Action	December 20, 1990
Work Area Restored	December 28, 1990
Complete Installation of Air Monitors and Preparation of Final Report	Pending

The Waste Pit 6 Removal Action successfully eliminated the migration potential of contamination through airborne particulates due to wind erosion. Removal Action Objectives were achieved and completed in a cost effective and timely manner consistent with future remedial actions.

Another example of a recently undertaken Removal Action involved the removal of liquid collected in a decant sump tank located underground between two above-ground storage silos. The tank was used to store liquid that was drained from the silos after solid material had settled out. After 35 years in service, the integrity of the underground sump tank was questionable and undeterminable. Removal of the liquid from the underground sump tank would reduce the potential for a release to the environment.

A Removal Site Evaluation and Action Memorandum were issued on August 20, 1990. This triggered preparation of

the National Environmental Policy Act documentation (for this action a Categorical Exclusion was applicable), placement of appropriate documents in the Administrative Record, and issuance of a Notice of Availability.

The Sump Tank Removal Action Work Plan was submitted to the U.S. EPA for approval on December 10, 1990. The U.S. EPA conditionally approved the Sump Tank Removal Action Work Plan on January 10, 1991. Response to the conditional approval along with a revised implementation schedule were submitted to the U.S. EPA on February 8, 1991.

Removal of the liquid from the decant sump tank was initiated on March 26, 1991, and completed on April 16, 1991. The liquid was transferred to holding tanks pending availability of analytical results to support a RCRA determination and to assist in defining treatment requirements for the removed sump liquid.

These Removal Actions were expedited through a system that generally would take much longer. The mentioned successes, along with current ongoing Removal Actions at the FEMP, rely on support from HQ-DOE as well as from state and federal regulators. Good job planning and commitment from all involved groups ensured an interim response with a sense of urgency and personal ownership.

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MANAGEMENT OF PETROLEUM UNDERGROUND STORAGE TANKS AT THE HANFORD SITE

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ABSTRACT

This report represents the timetables, responsible organizations, and methods required to comply with the newly promulgated Washington Administrative Code (WAC) 173-360 Underground Storage Tank (UST) Regulations which became effective December 29, 1990. This report only addresses UST systems that contain nonradioactive material.

A total of 84 tanks at the Hanford Site are currently regulated under WAC 173-360. In addition, 32 regulated tanks have been removed as a result of the federally mandated program and the newly implemented state regulations.

The majority of the USTs at the Hanford Site are operated by Westinghouse Hanford; however, one is operated by Kaiser Engineers Hanford (KEH) and one by Pacific Northwest Laboratory (PNL).

TANK CATEGORY DEVELOPMENT

Introduction

Before the state underground storage tank (UST) regulations became effective, UST systems were regulated beginning in 1988 under Title 40 Code of Federal Regulations (CFR) 280 and 281. The Washington State Department of Ecology (Ecology) was directed by Revised Code of Washington (RCW) 90.76 to establish a UST program designed, operated, and enforced in a manner that, at a minimum, meets the requirements for delegation of the federal regulations. Their purpose is to protect the groundwater supplies of the State of Washington by closing old tanks, detecting and remediating tank leaks and spills, establishing stringent standards for new tanks, and upgrading existing tanks to new-tank standards.

The active USTs on the Hanford Site have been divided into eight categories, based on the age and service status of the tanks, each having a succeeding annual compliance date for installed leak detection capability beginning December 22, 1989 (except for the deferred tanks which do not require leak detection). All fully regulated Hanford Site tanks and associated piping must meet new-tank standards by December 1998 or undergo permanent closure. Westinghouse Hanford Company (Westinghouse Hanford) has responsibility for implementing the tank removal program and managing the release detection program on the Hanford Site.

The Hanford Site originally had 356 storage tanks placed wholly or partially underground. Petroleum USTs comprise the majority of active and out-of-service tanks, and most of the regulations are geared towards them. Of the USTs on the Hanford Site, 65 were initially regulated by Title 40 CFR 280 and 281 [U.S. Environmental Protection Agency (EPA) (1988a)]. Once the regulated tanks were identified in mid-1988 and the final rules (EPA 1988a) published, an implementation plan was prepared by Westinghouse Hanford detailing how those rules would be implemented. In December 1990, the State of Washington implemented its new WAC regulation for USTs (WAC-173-360). Of the 65 USTs originally identified as regulated in 1988, 22 were permanently closed (removed) in 1989, five were removed in 1990, and five were removed to date in 1991. There are currently 84 tanks which are regulated to varying degrees by the WAC regulations of which 21 are abandoned (orphan tanks) and will be removed.

CONTRACTOR ROLES AND RESPONSIBILITIES

Project Management

Westinghouse Hanford is assigned project management responsibility at the Hanford Site by the U.S. Department of Energy (DOE) Field Office, Richland, for the implementation of Chapter 173-360 WAC UST Regulations. Implementation of this program is governed by an internal Westinghouse Hanford implementation plan.

OTHER CONTRACTORS RESPONSIBILITIES/INTERFACES

Kaiser Engineers Hanford (KEH) and Pacific Northwest Laboratory (PNL) have contractual responsibilities to DOE Field Office, Richland, as operators of UST systems under WAC 173-360. To assure that these responsibilities are met and liabilities minimized, a close, well-understood interface exists between Westinghouse Hanford, as Project Manager, and KEH and PNL, as operators; and DOE Field Office, Richland, as the owner.

Interface Requirements

Table I lists the methodology, from start of project to site remediation (if necessary), for a typical UST closure. The interface points and the approval/notifications that the Project Manager will provide for the operators (KEH or PNL) are included in the tables. Westinghouse Hanford also provides KEH and PNL designated representatives with appropriate project status.

COMPLIANCE REQUIREMENTS

Table II provides an overview of compliance schedules listed in WAC 173-360-330.

RELEASE DETECTION PROGRAM REQUIREMENTS

Tightness Testing

Tank tightness testing is performed by a Westinghouse Hanford subcontractor and is made available to Westinghouse Hanford Operating Divisions, KEH, and PNL as a

TABLE I

Contractor Interface Actions

Westinghouse Hanford Environmental Division Action	Pacific Northwest Laboratory* or Kaiser Engineers Hanford* Approval of Action	Pacific Northwest Laboratory* or Kaiser Engineers Hanford* Notification of Action Completion
1. Prepare Liquid Sample Plan.	X	
2. Subcontractor laboratory analysis.**		X (Copy of Results)
3. Designate waste.	X	
4. Pump contents/rinse tank.		X
5. Prepare waste manifests and ship wastes.		X (Copy of Documents)
6. Subcontractor disposes of waste and provides certification.		X (Copy of Certification)
7. Prepare Implementation Plan.	X	
8. Prepare detailed work plan including soil sampling	X	
9. Obtain excavation permit.	X	
10. Obtain cultural resource review.		X
11. Prepare Job Control documentation.		X
12. Inert, excavate, and remove UST.		X
13. Transport UST to storage area to await final disposition.		X
14. Obtain soil samples of UST impression in excavation.		X
15. Provide immediate notification if a leak is evident.		X
16. Subcontractor laboratory analysis.**		X (Copy of Results)
17. Backfill excavation.		X
18. Subcontractor removes and certifies UST is clean and properly disposes of.		X (Copy of Certification)
19. Provide follow-up reports if UST was found to have leaked.		X
20. Site remediation (if necessary).		X

* Approvals, notifications, etc., required only if KEH or PNL UST systems are affected.
** Duplicate samples for independent analysis may be obtained if desired for the contractor who has operator responsibilities for a particular UST.

service provided by Westinghouse Hanford Restoration Operations, or by separate certified testing subcontract administered by each tank operator.

Necessary tank preparations are specified by the subcontractor, and each tank is prepared for testing by the operating unit. Schedules for the Hanford Restoration Operations administered tank testing are developed with normally two week notification before testing. This lead time is necessary because of the tank conditions for the tests, i.e., completely filled and out of service for 8 to 12 h before the test and out of service until after the test completion.

Each UST operator, and Westinghouse Hanford Restoration Operations, are informed in writing of the test results by the subcontractor as soon as available. In the event that a tank fails to meet tightness requirements as discussed in WAC-173-360-345, Westinghouse Hanford Restoration Operations initiates the notification process.

Monitoring Program

The Monitoring Program provides for routine data collection and monthly evaluations to ensure that tank leaks that may develop between annual tightness testing are identified and stopped as early as possible. Westinghouse Hanford Restoration Operations provides an administrative control procedure to specify data requirements for each participating UST operator. Although each UST operator may opt to use individually developed procedures and methods, all Hanford Site UST Release Detection data must meet the requirements of WAC 173-360-345.

All data, regardless of operator or method of monitoring, is submitted to Westinghouse Hanford Restoration Operations for monthly evaluation, trend analysis, and release reporting as outlined.

LEAKS AND SPILLS

The EPA estimates that nationwide as many as 25% of the 5 M USTs currently operating in the country are leaking (API 1987). A lower failure rate has been experienced at the Hanford Site because of low soil moisture and corrosivity. Removal and testing of USTs revealed tank failure by corrosion problems at two of the closure sites to date. Three

TABLE II

Closure or Upgrade Schedules for Underground Storage Tanks

Schedule For Required Temporary/Permanent Closure

Type of Tank & Piping	Required Action	Deadline Date
Category A - Permanently Closed	Empty and Clean Remove From Ground or Fill With Inert Solid Material Perform Site Assessment and Corrective Action as Necessary Provide Notification Prior and Following Action as Required	December 22, 1989 Or 12 mo After Temporary Closure or as Negotiated With WDOE
Category B - Temporarily Closed	Operate and Maintain Corrosion Protection Operate and Maintain Release Detection if Not Empty	Immediately
	Cap and Secure All Lines, Pumps, Manway & Ancillary Equipment Leave Vent Lines Open & Functional	March 22, 1989 Or 3 mo After Temporary Closure
	Permanently Closed	December 22, 1989 Or 12 mo After Temporary Closure

Schedule For Implementation of Required Upgrades

Type of Tank & Piping	Leak Detection	Corrosion Protection	Spill/overfill Prevention
New Tanks and Pipings*	At Installation	At Installation	At Installation
Existing Tanks** Installed	No Later Than:		
Category C Tanks	December 1989		
Category D Tanks	December 1990		
Category E Tanks	December 1991	December 1998	December 1998
Category F Tanks	December 1992		
Category G Tanks	December 1993		
Category H Tanks	December 1994		
Category I Tanks	December 1995		
Existing Piping**	December 1990 Same as	December 1998	Does Not Apply
Pressurized Suction	Existing Tanks	December 1998	Does Not Apply

* New tanks and piping are those installed after December 1988.
** Existing tanks and piping are those installed before December 1988. Tanks that cannot meet this schedule for upgrade must be closed permanently by the scheduled upgrade deadline date.

additional sites have identified releases from overfilling the tanks or leaking piping systems.

TANK CLOSURE

Notifications and Tank Preparations

The following are the initial steps for permanent tank closure once the decision has been made to permanently close a particular UST:

- Westinghouse Hanford Environmental Division notifies Ecology through DOE Field Office, Richland, identifying tanks to be pulled at least 30 d before tank removal as required by WAC 173-360-385
- Tank liquid samples are obtained for analysis and waste designation per approved procedures if inventory history is unavailable
- Removal and disposal of tank contents per state and federal regulations

- Rinse and flush tank, vacuum rinsate, and dispose of rinsate per state and federal regulations
- Perform Ground Penetrating Radar survey to obtain exact location of tank and piping system.

Actual Tank Removal

Actual tank removal is performed by a Westinghouse Hanford approved procedure to ensure a safe and technically correct approach. The basic process for tank removal is as follows:

- Inert potentially explosive atmospheres in the UST by adding CO_2 or dry ice before excavation. Excavation will not proceed until UST oxygen level is below 10%
- Excavate and remove UST piping. Piping is placed in tank for offsite cleaning and disposal
- Excavate, remove UST, perform radiation surveys, and transport to a central location for storage until final cleaning and disposal
- Perform a visual inspection of the tank and excavation, inspect again using an organic vapor monitoring instrument, and then obtain soil samples per an approved sample plan
- Westinghouse Hanford will provide immediate (24 h) notification and follow-up reports for any tank/piping determined to have leaked.

Follow-up Actions

Following soil sample collection and analysis, the excavation is normally backfilled, compacted, and sloped to match the pre-excavation site appearance. If a significant leak was determined to have occurred, additional excavation and sampling is done to confirm the size of the release. If it is determined that the release is significant and goes beyond the lowest point of sampling, then the requirements of WAC 173-340 are followed.

All USTs removed and stored at a central location as part of a project are cleaned and certified free of any hazardous material by an approved subcontractor. This work is performed by experienced personnel working to industry standards. Copies of the certification are kept in the project files as part of the UST records.

Site remediation/cleanup that is required because of UST leakage is planned, scheduled and performed in accordance with the *Guidance for Remediation of Releases from Underground Storage Tanks* issued by the Ecology. This document, while not a regulation, is used in conjunction with Chapter 173-340 WAC, "The Model Toxics Control Act Cleanup Regulation" requirements on an individual case basis. Remediation plans are reviewed by and coordinated with the tank operator before submission to the regulatory agency.

All USTs removed and stored at a central location as part of the project are to be taken offsite to be cleaned and certified free of any hazardous products by an approved subcontractor. The tanks are scrapped after they have been certified clean. Copies of the certification are kept in the project files as part of the UST records which are maintained by Decommissioning Engineering, Hanford Restoration Operations.

Twenty-one tank sites (some sites contained multiple tanks) have been permanently closed since 1989. Five of these were identified as release sites, two by tank penetration and three by overfills and/or pipe leakage during tank operation. Remediation plans for two of these sites have been forwarded to Ecology for concurrence before the start of field work. One plan calls for soil removal and cleanup of the soil by means of controlled solid-phase soil remediation. The other tank site soil is expected to be a hazardous waste and will be disposed of in a landfill in accordance with state and federal regulations based on characterization sampling during the soil removal work. The remaining two sites were characterized following tank removal; however, cleanup has been deferred. Cleanup of the petroleum contamination will be planned, following characterization of other wastes in the vicinity.

ORPHAN TANKS

It is possible that additional undiscovered USTs may exist at the Hanford Site. These are most likely in areas of old town sites, 1940s central construction areas, or abandoned farmsteads. As tanks are discovered, investigated, and confirmed to fall under the UST regulations, they are reported by Westinghouse Hanford Environmental Division to Ecology through DOE Field Office, Richland. A detailed historical research effort has been conducted in these areas. Orphan tanks identified for removal are treated the same as other USTs, i.e., sampled to confirm their contents, pumped out, cleaned, etc.

COMPLIANCE COST

Pre-Upgrade or Replacement Cost

Although cost estimates have been prepared for each UST covered by current regulations, the most detailed information is available from the work completed to date. These costs included site wide program development, engineering, tank content characterization, liquid waste disposal, radiological clearance, tank removal, cleaning, and disposal. Also included in this information is the cost of site assessment that exceeded regulatory requirements to support later remedial investigations that may be necessary in the area of the closed tank site.

Cost estimates for planning purposes, for active tanks requiring tightness testing, are approximately $700 annually per tank. While the necessity of forced tank removal will not be known until after each annual test, an estimate to remove 25% of the tanks tested (at an average of $30,000 per tank) is expected. The 25% value is based on industry averages for 15-yr-old UST systems (API 1987) and that experienced to date atthe Hanford Site. The actual removal costs can vary greatly between different tank sites depending on the number of sample analyses needed, amount of hand digging required, shoring required, etc..

LONG-RANGE PLANNING

In 1989, a conceptual design report was prepared to address the proposed compliance actions for Westinghouse Hanford USTs at the Hanford Site. Most of the existing tanks included in the proposed compliance project are single-wall steel tanks that were installed over 10 yr ago, some up to 45 yr ago. This compliance project covers work that is currently expected to be funded in fiscal year 1994 and bring all but six of the Hanford Site tanks regulated by WAC 173-360 to "new tank standards" by 1996. Five of the remaining six tanks will

be permanently closed before 1994, and the final tank is expected to be replaced by 1996.

Most of the Hanford Site infrastructure tanks will be removed and replaced. Consolidation of fueling operations at a new facility will eliminate the need to replace some of the removed tanks. The only tanks which will not be removed were installed in 1987 in accordance with the interim Federal regulations. These two tanks will be upgraded to meet the current regulations. Two other tanks used to store waste oil will be removed and not replaced, but rather a replacement for another tank in the area will be sized to accept all waste oil generated in the facility. The vehicle wash pad drains that are currently directed to two individual tanks will be routed to a new oil/water separator. This action will eliminate these two tanks and allow the clean, processed water to be discharged to a nearby sanitary sewer.

Site assessment is currently planned to be accomplished by the tank removal sub-contractor with Westinghouse Hanford oversight. It is anticipated that any necessary site remediation (soil removal and subsequent solid phase remediation) will be done by Westinghouse Hanford immediately to meet Ecology pre-established site cleanup levels and to prevent significant impact to the compliance project.

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OVERVIEW OF THE CLOSURE APPROACH FOR THE HANFORD SITE SINGLE-SHELL TANK FARM

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ABSTRACT

The disposal of chemical and radioactive waste stored within the single-shell tanks (SST) represents one of the most significant waste management problems at the Hanford Site. A comprehensive program has been established to obtain analytical data regarding the chemical and radiological constituents within these tanks. This information will be used to support the development of a supplemental environmental impact statement (SEIS) and ultimately to aid in the selection of a final disposal option.

This paper discusses some of the technical options and major regulatory issues associated with SST waste retrieval and in situ waste treatment and disposal. Certain closure options and treatment technologies will require further development before they can be implemented or accepted as being useful. In addition, continued negotiations with the regulatory authorities will be required to determine the preferred closure option and the regulatory pathway to accommodate such closure.

SINGLE-SHELL TANK SYSTEM BACKGROUND

Between 1943 and 1964, 149 SSTs were built at the Hanford Site for the storage of high-level radioactive waste. The SSTs are located in 12 tank farms consisting of 4 to 18 tanks each. These tank farms are located in the 200 West and 200 East Areas of the Hanford Site. The volumes of the SSTs vary from 208,197 L to 3,785,400 L as follows: 208,197 L (16 tanks), 1,892,700 L (60 tanks), 2,893,050 L (48 tanks), and 3,785,400 L (25 tanks).

The SSTs are constructed of carbon steel, American Society for Testing and Materials (ASTM) A283 Grade C or ASTM A201 Grade C (241-AX Tank Farm), that lines the bottom and sides of a reinforced concrete shell. The bottoms of most of the tanks are slightly concave. The tanks are below grade with at least 1.8 m of soil cover, which minimizes radiation exposure to operating personnel. Inlet and overflow lines are located near the top of the liner. Most of the 1,892,700-L and 2,839,050-L tanks were built in "cascades" of three or four tanks. Waste was transferred to the first tank of the cascade and allowed to overflow into successive tanks through piping in the side walls. Access to the tanks is provided by risers that penetrate the dome of the tanks.

The carbon-steel liners in the SSTs were not stress-relieved after fabrication. As a result, hot alkaline radioactive-waste mixtures of liquid and sludge have induced stress-corrosion cracking of the steel and over the years leakage to the environment has been suspected or confirmed in 67 SSTs.

Over the years, waste has been retrieved from the SSTs to recover specific radionuclides and later to reduce the volume of free liquids within the tanks. During the 1950's, SST waste was retrieved from certain tanks for extraction of uranium; during the 1960's and 1970's, SST waste was retrieved for extraction of cesium and strontium fission products. During the 1970's, the volume of liquid wastes stored in the SSTs was reduced by evaporating the liquids, leaving moist sludge and salt cake. The evaporation efforts also served to reduce the environmental impact of potential releases from the tanks by minimizing the volume of drainable liquids available to contaminate surrounding soils. The SSTs now contain approximately 37 Mgal of salt cake, sludge, interstitial, and non-pumpable supernatant liquids, based upon the "Tank Farm Waste Surveillance Report for March 1989" (1).

Interim management activities for the SSTs will continue until a decision is made on final closure and corrective action. These interim activities include the following:

1. Stabilization, via saltwell pumping of interstitial liquids
2. Surveillance for tank integrity (to detect leaks, liquid intrusion, and changes in the radiological status of the contaminated soil)
3. Heat management to prevent excessive tank temperatures
4. Tank isolation (i.e., sealing the tank piping and openings) to deter liquid intrusion
5. Groundwater monitoring.

HANFORD FEDERAL FACILITY AGREEMENT AND CONSENT ORDER

The "Hanford Federal Facility Agreement and Consent Order" (Tri-Party Agreement) was signed into effect in 1989 (2). This agreement establishes a mechanism for bringing existing treatment, storage, and disposal (TSD) facilities into compliance with the provisions of the Resource Conservation and Recovery Act of 1976 (RCRA) and the Washington (State) Administrative Code (WAC) 173-303 or conducting closure in accordance with these regulations (3,4).

The Tri-Party Agreement divides the Hanford Site into operable units and identifies subunits within each operable unit. The SST system has been divided into six operable units:

1. 200-BP-7
   241-B Farm (16 tanks)
   241-BX Farm (12 tanks)
   241-BY Farm (12 tanks)
2. 200-PO-3
   241-A Farm (6 tanks)
   241-AX Farm (4 tanks)
   241-C Farm (16 tanks)

3. 200-RO-4
   241-S Farm (12 tanks)
   241-SX Farm (15 tanks)
4. 200-TP-5
   241-TX Farm (18 tanks)
   241-TY Farm (6 tanks)
5. 200-TP-6
   241-T Farm (16 tanks)
6. 200-UP-3
   241-U Farm (16 tanks).

These six operable units include the SSTs, diversion boxes, catch tanks, contaminated soil from spills and discharges, cribs, valve pits, vaults, and septic tanks.

The current approach for closure of the SSTs is to close all ancillary equipment (i.e. diversion boxes, catch tanks, piping and contaminated soil) under the provisions of Section 3004(u) of the RCRA, which addresses remediation of past practice units. The SSTs, themselves, will be closed as RCRA TSD units in accordance with the RCRA and the WAC 173-303-610, "Closure and Post-Closure" (4). In addition, the Tri-Party Agreement establishes a schedule for closure of the SSTs. Some of the major milestones associated with this task include the following:

1. Complete SST interim stabilization by September 1995; interim stabilization removes pumpable interstitial liquids from SSTs
2. Complete preparation of the SEIS and issue a draft for public review by June 2002
3. Submit closure plan to the Washington State Department of Ecology (Ecology) for approval by December 2003
4. Complete closure of all 149 SSTs by June 2018
5. Complete closure of all six SST operable units by September 2018.

WASTE RETRIEVAL TECHNOLOGIES

Waste retrieval is intended to include the recovery of salt cake, sludge, slurries, and liquid wastes from the SSTs and the associated transfer of these wastes to an onsite pretreatment facility. Methods for removal of SST waste require special attention because the integrity of some of the tanks is questionable. In fact, 67 of the 149 SSTs are presumed to have released a portion of their contents to the environment. Because adding liquids to remove solids could potentially increase the risk of releasing waste to the environment, a mechanical waste retrieval method has been recommended.

At this time, three waste retrieval techniques have been examined. All three methods are scheduled to be reviewed by independent review panels, such as the National Academy of Sciences. The three techniques, discussed in the following paragraphs, are dry mechanical, hydraulic, and pneumatic retrieval.

Dry Mechanical Retrieval

Dry mechanical retrieval reduces the potential for additional releases from the SSTs due to hydraulic retrieval operations. Preliminary design studies for mechanical retrieval have been completed. Waste tank contents would be excavated with the aid of an articulated mechanical arm, placed in an elevator clamshell bucket, and brought to a platform. The platform would be carried by independently powered tracked transporters spaced beyond the diameter of the tanks. Straddling the tanks in this manner would minimize the loads applied through the ground to the tank structure. The retrieved waste would be unloaded from the elevator bucket to a shielded shipping container. This retrieval system would require only minimal alterations to tank farm structures and would be designed to avoid direct loads on the dome.

Hydraulic Retrieval

A hydraulic retrieval system would use a liquid-slurry transfer system to retrieve the waste. The equipment used would include a high-pressure, high-volume water jet with associated pumping and supply systems as well as accumulation tanks and recirculation systems. The waste would be dislodged by water jet impact, dissolved or broken down, and washed into the vicinity of a slurry pump where it would be pumped to the surface.

Leakage barriers, if required, would be provided to control leakage from the tanks during hydraulic retrieval operations. The leakage barrier would be a freeze barrier, grout barrier, or other water-impervious type of installation under and around the SSTs. The barriers would provide external containment during the hydraulic retrieval operation and would have a release detection and recovery system to recover waste if a major tank release occurred.

Pneumatic Retrieval

Pneumatic retrieval is a system that uses air conveyance to perform waste retrieval operations. Pneumatic retrieval uses a maneuvering and control system similar to the one for dry mechanical retrieval. The air conveyance system uses a positive displacement blower to produce high-velocity air for entraining the waste.

The key elements of the air conveyance system are the cyclone separator and positive displacement blower. The cyclone separator is used to remove particulate materials from the airstream. A positive displacement blower would create a high-air velocity in a suction hose. The system operating velocity would suspend material in the airstream to allow transfer of the material. The material can be transported any distance that the velocity can be maintained. All equipment in this system except the suction hose is outside the tank. This would reduce maneuvering system loads and improve reliability. The system would be able to move anything that can be suspended in the airstream. Air or water jets, or mechanical means may be used at the end effectors of the arm to break up the waste for transfer.

IN SITU TREATMENT TECHNOLOGIES UNDER DEVELOPMENT

If it is not practical to remove SST waste, several in situ treatment technologies are currently under consideration. The decision to leave or retrieve waste will be based, in part, upon the results of a performance assessment that evaluates the total risk associated with each closure option. At this time, three in situ treatment technologies (in situ drying, in situ chemical stabilization, in situ vitrification) are being evaluated for use in conjunction with the SST's closure. These options are discussed in the following paragraphs.

In Situ Drying

In situ drying uses radio-frequency drying to remove free liquids from the SST. The heating would drive the liquid into the vapor phase where it would diffuse through the salt cake and be removed in the off-gas system. After liquid removal has been completed, the remaining void space within the tank would be filled with basalt gravel. Then, a final engineered intrusion and infiltration barrier would be installed that meets all regulatory requirements.

Microwave or radio-frequency heating is the most effective way to introduce energy into the waste. Early developments using microwave frequencies indicate that dry salt cake attenuated 50 percent of the microwave energy within a few centimeters. Preliminary data indicate that in the radio-frequency ban dried salt cake would be transparent to radio-frequency energy. This would allow the radio-frequency energy to be transmitted throughout the dried upper layer of waste with low attenuation down to the lower wet layers.

In situ drying would not change the dangerous waste designation of SST waste. However, the final waste form would be free of liquids, thus eliminating the driving force for contaminant migration. This waste treatment and closure option would have the greatest dependence on engineered barriers and monitoring programs to ensure that dangerous waste does not migrate from the disposal zone after closure.

In Situ Chemical Stabilization

In situ chemical stabilization combines SST waste with a grout mixture to provide a stable, leach-resistant matrix. This in situ option uses augers to mechanically combine the SST waste with the grout mixture. It is expected that the grout would reduce the mobility of the waste and combine with nitrates and nitrites to reduce the reactivity of the waste. All mixing equipment would be located within a given SST, and the grout and chemical additives would be mixed in surface facilities. The off-gas generated from exhaust mixing operations would pass through prefilters before being discharged to high-efficiency particulate air filters and subsequently to an emissions stack.

In Situ Vitrification

In situ vitrification uses joule heating to melt the waste and associated tank in situ. The resulting vitrified mass provides a stable matrix for the long-term disposal of SST waste. The high temperatures from vitrification are expected to cause the decomposition of a majority of the wastes (nitrates, nitrites, and organic wastes) leaving oxides of nonvolatile constituents in the matrix. While certain wastes would be destroyed with this technology, the waste may continue to be subject to regulation under Washington State "Dangerous Waste Regulations" imposed by Ecology and/or due to the presence of listed waste constituents.

For this technology to be applicable to the SSTs, a melt depth of 20 m would be required. The current full-scale design with fixed electrodes has reached depths of 6 m. Technologists have proposed two new design concepts (moving and hot-tipped electrodes) to obtain the necessary depth. Moving electrodes eliminates expensive stationery electrodes that would require placement to a specified depth before melting begins. Hot-tipped electrodes concentrate power at the bottom of the melt, which improves melt efficiency.

REGULATORY STATUS OF SST WASTE

Federal and State regulations have been developed since the SST waste was generated and placed in storage within the SSTs that establish specific requirements for the management of hazardous waste. The overall intent of these regulations is to protect human health and the environment from hazards associated with hazardous waste. The number of regulations applicable to SST waste and the fact that the SSTs are regulated under the RCRA yet located within a Comprehensive Environmental Response, Compensation, and Liability Act of 1980 unit may lead to complicated and potentially conflicting regulations (5).

The SST waste is a complex mixture of chemical and radioactive constituents. On May 1, 1987, the U.S. Department of Energy (DOE) published its final byproduct rule (6), which stipulates "that only the actual radionuclides in DOE waste steams will be considered byproduct material." The effect of this interpretative rule is that the chemical waste constituents contained within DOE waste streams are subject to regulation under the RCRA and by authorized states. The radionuclides, however, remain subject to regulation in accordance with the Atomic Energy Act of 1954 (AEA) (7). Thus, radioactive mixed waste (i.e. waste containing both radioactive constituents regulated under the AEA and chemical constituents regulated under the RCRA) is subject to dual regulation by the DOE and the U.S. Environmental Protection Agency (EPA).

Section 70.105.050 of the State of Washington Hazardous Waste Management Act of 1976, in the Revised Code of Washington, was revised on July 26, 1987, to give Ecology the authority to regulate hazardous waste that also contains radioactive constituents (8). On November 23, 1987, Ecology received final authorization from the EPA to implement the amendment and to regulate the hazardous constituents of mixed wastes. Washington State implements the federal RCRA program through the WAC 173-303. Wastes regulated under WAC 173-303 are identified as dangerous wastes, rather than hazardous wastes as identified under the RCRA.

In response to this State action, the DOE Field Office, Richland, submitted a Part A permit application for the SSTs to Ecology on March 1, 1988. Thus, the SSTs have been identified as interim status RCRA treatment and storage tanks. The DOE does not intend to pursue final operating status for the SSTs. Therefore, the SSTs will undergo closure during interim status and a Part B permit application will not be submitted.

REGULATIONS APPLICABLE TO CLOSURE OF THE SSTs

Closure as a Treatment and Storage Tank

As discussed previously, the SSTs are regulated under the provisions of the RCRA and WAC 173-303 as treatment and storage tanks (3,4). The closure requirements for dangerous waste tanks are identified in WAC 173-303-640(8). This section of the WAC 173-303 regulations indicates that upon closure the owner or operator shall "Remove or decontaminate all waste residues, contaminated containment system components (liners, etc.), contaminated soils, and structures and equipment contaminated with waste, and manage them as dangerous waste" (4).

This section of the WAC 173-303 regulations further states that if the owner or operator can demonstrate that all contaminated soils cannot be practicably removed or decontaminated, then the owner or operator must close the tank system and perform postclosure monitoring in accordance with the requirements for landfills. Note, the landfill closure option assumes that a dangerous waste tank can be removed or decontaminated and that only contaminated soils will remain in place, if a landfill closure is pursued.

If the DOE determines that the preferred alternative includes leaving some SST waste in place, the remove-or-decontaminate standard would be applicable to the tanks and tank waste. According to the State dangerous waste regulations, the remove-or-decontaminate standard will be met only when listed and characteristic waste constituents or residues do not exceed background environmental limits. In addition, waste constituents or residuesmust be removed or decontaminated to at least designation limits for State- only dangerous wastes (i.e., those wastes regulated due to toxicity, persistence, or carcinogenicity).

Closure as a Landfill (Disposal Tank)

Although Washington State dangerous waste regulations do not allow closure of a treatment and storage tank as a landfill, the EPA has determined that under limited circumstances, a treatment and storage tank may require closure as a landfill. The EPA provided a clarification to the definition of a landfill in the December 10, 1987, "Federal Register" (9). This "Federal Register" states:

> 'Landfill' will cover tanks or vaults used for disposal of hazardous waste. Subpart J of Part 264 only regulated storage and treatment in tanks and the Agency to date has not developed specific standards for disposal of hazardous waste in tanks. However, under limited circumstances, the Subpart J standards do allow treatment or storage tanks that cannot remove all contamination at closure to close and to perform post-closure requirements for landfills. Disposal in tanks will be regulated under the Subpart N standards for landfills because 'landfills' and the disposal of hazardous waste in tanks raises similar human health and environmental concerns and because tanks are similarly placed on or in the land."

As discussed previously, the EPA interpretation establishes a mechanism that allows closure of the SSTs with waste and tank structures remaining in place. To demonstrate the need to pursue this closure option, a performance assessment that evaluates the risk to human health and the environment associated with SST closure options is being developed. In addition, closure options may be limited based upon available technology. To address this issue, waste retrieval and treatment technologies are being evaluated for technical feasibility and cost, among other things. If it is not feasible to meet the removal-or-decontamination standard of WAC 173-303-610, the DOE may be forced to pursue a landfill closure, which will involve revisions to the existing Part A permit and submittal of a closure plan that addresses closure of the SSTs as a landfill. In addition, a postclosure permit application will require development and approval by Ecology.

Atomic Energy Act of 1954

The AEA establishes the authority of the Government via the Atomic Energy Commission (later the U.S. Nuclear Regulatory Commission and the DOE) to regulate the production and use of source, special nuclear, and byproduct material. The DOE implements the requirements of the AEA through DOE orders, which establish the requirements for management of radioactive waste. One of the major provisions of the AEA is to maintain personnel exposure to radiation sources as low as reasonably achievable. The SSTs must undergo closure in accordance with the provisions of the AEA.

National Environmental Policy Act (NEPA)

Any closure and/or remedial action associated with the SSTs must satisfy NEPA requirements (10). The DOE has committed to provide NEPA documentation in the form of a SEIS to address SST waste disposal. In summary, the NEPA process analyzes reasonable alternatives, including a no-action alternative, in comparative form associated with a proposed Federal action. Information on environmental consequences and a description of the affected environment for each alternative is presented. Site characterization information is needed (1) to understand the nature to appropriately discuss in the SEIS the extent of contamination associated with the SSTs and (2) to appropriately discuss in the SEIS the levels of required actions. Finally, a record of decision (ROD) is issued that will select a preferred alternative for SST waste disposal. In the case of the SSTs, the ROD for the SEIS will establish DOE's position on SST waste retrieval, in-place disposal, or some combination of the retrieve and in-place alternative.

Final disposal options for the SSTs and associated ancillary equipment were initially addressed in the DOE's "Final Environmental Impact Statement for the Disposal of Hanford Defense High-Level, Transuranic and Tank Wastes, Hanford Site, Richland, Washington" (HDW-EIS) (11). The ROD for the HDW-EIS indicates that the DOE decided to undertake additional development and evaluation activities before a final decision on the SSTs would be made (12). As contained in the HDW-EIS ROD, these additional development and evaluation activities include the following:

- Characterize radioactive and hazardous waste constituents
- Demonstrate barrier performance by instrumented field tests, natural analog studies, and modeling
- Determine the need and methods for improving the stability of the waste form
- Determine the need and methods for destruction and stabilization of hazardous waste constituents
- Develop and evaluate a method for retrieving, processing, and disposing of the wastes.

The HDW-EIS final ROD commits to the preparation of a SEIS for SST waste. A major milestone has been added to the Tri-Party Agreement, milestone M-09-01, which indicates that a draft SEIS will be prepared and issued for public review by the year 2002. A review of the closure schedule established in the Tri-Party Agreement indicates that acceleration of the SEIS may be necessary to accomplish closure by the year 2018.

One of the problems with accelerating the SEIS is that significant waste characterization information from all of the

SSTs may not be available to support the ROD. To resolve this issue, the SSTs have been categorized into groups of tanks or tank farms that have received similar types of waste from specific chemical separation facilities. Based on existing process knowledge, the analysis from a given tank within a specified grouping is expected to be representative of the other tanks in that group. A statistical analysis will be performed to verify this assumption. If this is a correct assumption, analytical data regarding the chemical and radiological constituents contained within the SST waste will be available to support acceleration of the SEIS. The other development and evaluation activities will be ongoing throughout the development of the SEIS.

U.S. Nuclear Regulatory Commission Requirements for Disposal of High-Level Waste (HLW)

The U.S. Nuclear Regulatory Commission has established specific requirements in Title 10 "Code of Federal Regulations" Part 60 for the disposal of HLW in geologic repositories (13). The U.S. Nuclear Regulatory Commission also has licensing authority for the shallow land burial of HLW. If SST waste is determined by the U.S. Nuclear Regulatory Commission to be HLW and such waste is treated and disposed in situ, a license from the U.S. Nuclear Regulatory Commission will be required. At this time, the U.S. Nuclear Regulatory Commission has not issued licenses for the shallow land burial of HLW so the licensing requirements are not clear.

CONCLUSION

As discussed previously, SST closure options under evaluation include those that would require waste retrieval and in situ treatment and disposal. The risks associated with these closure options are being evaluated through development of a performance assessment. The performance assessment uses modeling techniques to evaluate the risk and performance associated with each closure option. The final disposal method must prevent significant impacts to human health and the environment, as envisioned by the EPA, while also keeping radiation exposure to workers in a manner consistent with the as low as reasonably achievable principle. The results of this analysis along with the conclusions reached in the SEIS will identify a preferred method of closure for the SSTs.

At this time, investigations and development of prototype retrieval equipment and technologies required for certain in situ closure options are in the initial phases of development. Milestones have been added to the Tri-Party Agreement to ensure (1) that these development activities are done and (2) that the 149 SSTs will be closed by the year 2018.

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UMTRA PROJECT MANAGEMENT OF RESIDUAL RADIOACTIVE MATERIAL COMMINGLED WITH HAZARDOUS WASTE AT VICINITY PROPERTIES

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ABSTRACT

The U.S. Department of Energy (DOE) has established a program of assessment and remedial action at properties in the vicinity of designated uranium processing sites to stabilize and control residual radioactive material (RRM). However, in addition to being contaminated with RRM, some vicinity properties are also contaminated with hazardous waste not derived from processing site activities. As a result, the RRM at these vicinity properties may have been commingled with the hazardous waste. The DOE has determined that it has limited authority to spend public funds to manage the hazardous waste component of commingled waste. Therefore, the property owner must assume responsibility for managing the hazardous waste component. To ensure that commingled waste is managed in a manner that protects public health and safety and the environment, the DOE has developed guidelines that define the management responsibilities for the RRM and hazardous waste components of commingled waste. The DOE will develop agreements for managing commingled waste with the affected states/tribes and the property owners with the concurrence of the appropriate regulatory agencies. The agreements will reflect the resolution of regulatory and liability issues concerning commingled waste management.

INTRODUCTION

The Uranium Mill Tailings Radiation Control Act (UMTRCA) requires the DOE to establish a program of assessment and remedial action at properties in the vicinity of designated processing sites to stabilize and control RRM derived from these sites. The DOE's remedial action program must ensure that RRM contamination at these vicinity properties is managed in a safe and environmentally sound manner and that associated health hazards to the public are minimized or eliminated.

The U.S. Environmental Protection Agency has promulgated remedial action standards for the cleanup and disposal of RRM (1,2). The UMTRCA requires the DOE to conduct remedial actions at vicinity properties that will result in compliance with these standards. These remedial actions are to be selected and performed with the participation of the affected states/tribes and the concurrence of the U.S. Nuclear Regulatory Commission (NRC).

In addition to having RRM contamination, some vicinity properties are also contaminated with waste that did not result from designated processing site activities and is regulated under the Resource Conservation and Recovery Act (RCRA) or other federal, state, and local environmental laws and regulations because of its hazardous or toxic nature. As a result, the RRM at these vicinity properties may have been commingled with hazardous waste. The RRM component of this commingled waste is clearly regulated under the UMTRCA and its implementing regulations (1,2) and is the DOE's responsibility to clean up. However, the DOE has determined that it has limited authority under the UMTRCA to spend public funds to manage the hazardous waste component of commingled waste since it was not generated by activities related to uranium processing.

This paper identifies the nature of the commingled waste found at vicinity properties and outlines the DOE Uranium Mill Tailings Remedial Action (UMTRA) Project Office's plans for managing this waste. The general responsibilities of the parties involved in remedial actions at vicinity properties are identified as well as procedural guidelines for dealing with hazardous waste found commingled with RRM or that interfere with cleaning up the RRM.

PROBLEM DEFINITION

The UMTRCA directed the DOE to conduct remedial action at 24 designated processing sites in 10 states. Over 5000 properties in the vicinity of these sites have been identified through radiological surveys as candidates for remedial action. Approximately 500 properties remain to be surveyed. Remedial action has been completed at over 4000 vicinity properties to date. Most of these cleanups have involved only RRM. However, remedial action at some sites has been complicated by the presence of hazardous wastes, particularly in Grand Junction, Colorado, which has over 4000 vicinity properties including many commercial properties. The DOE Grand Junction Projects Office (GJPO) has confirmed approximately 22.7 Gg (19.1 km^3) of commingled waste at 18 vicinity properties awaiting remedial action. A budget risk assessment by the GJPO estimates that treatment of this commingled waste could cost $2.1 million to $5.3 million. The GJPO suspects another 13.6 Gg (11.5 km^3) may be found at properties that have not been surveyed.

The DOE has identified four main categories of hazardous waste commingled with RRM at vicinity properties:

- petroleum products - releases covered under underground storage tank regulations (3) which may also

exhibit RCRA ignitability or toxicity characteristics (4),

- heavy metals - waste may exhibit RCRA toxicity characteristic (4),
- polychlorinated biphenyls (PCBs) - waste may be subject to PCB disposal requirements (5), and
- organic chemicals: hazardous organic constituents may be RCRA listed or characteristic wastes (6).

In the past, remedial action of commingled waste was handled on an ad hoc basis. This practice led to inconsistent application of waste management solutions and project delays. Inflated clean.up costs resulted that concerned not only the DOE but also the states, which pay 10 percent of the remedial action costs. On Indian lands, the DOE funds 100 percent of the remedial action.

The need for a commingled waste management policy became apparent when the DOE assumed responsibility for the management of the hazardous waste component of commingled waste that had been inadvertently transferred to the state repository in Grand Junction, Colorado. The DOE, in cooperation with the Colorado Department of Health, began studying options for managing commingled waste. As a result of these studies, the UMTRA Project Office has developed a Statement of Principles that identifies the DOE's commingled waste management responsibilities. This Statement of Principles declares that the DOE shall:

- manage the RRM component of commingled waste under the UMTRCA,
- ensure that the hazardous waste component has been managed in compliance with applicable regulations before initiating remedial action of the RRM component,
- obtain the concurrences of the appropriate regulatory authorities before accepting any waste for disposal, and
- assist the affected states/tribes and the property owners in identifying options for managing the commingled waste in a manner that protects public health and safety and the environment.

The UMTRA Project Office has developed commingled waste management guidelines that are consistent with the Statement of Principles. In developing these guidelines, the UMTRA Project Office recognized that each vicinity property's commingled waste is unique and proper management will require solutions tailored to the nature of the waste and the applicable environmental regulations. The DOE will negotiate with the affected states/tribes to develop general procedures for managing commingled wastes found at vicinity properties. Site-specific plans for managing commingled wastes will be developed jointly by the DOE, the affected states/tribes, and the property owners with the concurrence of the appropriate regulatory agencies.

COMMINGLED WASTE MANAGEMENT GUIDELINES

The following guidelines are intended to provide a framework for developing general agreements for managing commingled wastes with each affected state/tribe and site-specific agreements for each affected vicinity property.

State/Tribe Agreements

The DOE will negotiate with each affected state/tribe to develop general procedures based on these guidelines for managing commingled wastes. At a minimum, these procedures should address the four main categories of hazardous waste expected to be found at vicinity properties. Topics to be covered in the procedures should include the state's or tribe's requirements for notifications, characterization, treatment, and disposal of the hazardous waste component. For each hazardous waste category, the state/tribe should identify the appropriate regulatory authorities and applicable regulations. These procedures will form the basis for negotiating the site-specific agreements with the vicinity property owners.

Since the DOE has limited authority for managing the hazardous waste component of commingled waste, the state/tribe agreements will also establish the limits on activities that the DOE can perform during remedial action to ensure that the DOE or its remedial action contractor does not become inadvertently responsible for managing the hazardous waste component. These agreements will identify what actions can be taken without triggering hazardous waste management requirements such as the RCRA storage limits and permitting requirements.

Site-Specific Agreements

Plans for managing both the RRM and hazardous waste components of a commingled waste will be included in site-specific agreements negotiated between the DOE, the affected state/tribe, and the property owner. These agreements will be in place prior to any action being taken by the DOE or its contractors at the vicinity property. The agreements may be stand-alone documents or be incorporated into routine agreements such as access agreements to allow site inspections and the radiological and engineering assessments or the remedial action agreements. These agreements will state that the DOE cannot be responsible for managing the hazardous waste component of any commingled waste found on the property and that the DOE cannot clean up the RRM component until the hazardous waste component has been properly managed by the property owner, unless other arrangements have been made with the DOE and the affected state/tribe. The radiological and engineering assessments will include site history and characterization data, cost estimates, a recommended course of action, and, if appropriate, should identify treatment and disposal options. The remedial action agreements will include the selected remedial action, responsibilities, and cost-sharing arrangements.

The site-specific agreements will reflect resolution of regulatory and liability issues with the affected state/tribe, property owner, and appropriate regulatory agencies. The limits on characterization, handling, and treatment activities that can be taken without triggering hazardous waste management requirements shall be clearly identified in the these agreements. The DOE will not perform any waste sampling, characterization or other actions, such as moving, packaging, treating and storing, that could be construed as the DOE or its contractors assuming responsibility for managing the hazardous waste component, unless specifically agreed to in the site-specific agreements. The DOE's remedial action contractor will develop procedures to implement the site-specific

agreements, which will help ensure that all work will proceed in compliance with applicable laws and regulations.

The UMTRA Project Office has developed guidelines in the following areas that will be addressed in the site-specific agreements.

Notification

The DOE and the affected state/tribe will establish procedures to notify the appropriate regulatory authorities to be followed if hazardous waste is found at a vicinity property that could interfere with remedial action. When the presence of commingled waste has been determined, the DOE will notify the property owner of the approximate nature of the hazardous waste component, the extent of contamination, and the need to manage the hazardous waste component. The property owner, or other parties identified in the site-specific agreements, shall follow the established notification procedures. The DOE will not proceed with the preparation of the detailed site assessment and remedial action plan until notifications have been made in accordance with the site-specific agreements.

Characterization

Characterization of commingled waste should be in sufficient detail to determine: the nature, location, and estimated quantity of the RRM; the proper health and safety precautions to be taken and which regulations apply; whether the hazardous waste component can be treated until it is in a nonhazardous condition on the site; and whether supplemental standards or regulatory exemptions can be applied due to low concentrations, lack of significant hazard, lack of treatment or disposal means, or other considerations.

Prior to the start of remedial action, the DOE will perform an initial property assessment based on owner interviews, site history, reasonable scientific judgement, and sampling. The DOE will also perform a preliminary site assessment of the extent of the radiological contamination. If the RRM is suspected of being commingled with a hazardous waste, the DOE will assess the nature of the nonradiological hazard to determine if there is an imminent health and safety threat to the public and remedial action workers. The DOE will notify the property owner when the site assessment has identified the presence of hazardous waste.

The DOE will not perform further radiological and engineering assessments until the property owner has characterized the hazardous waste and removed or treated such waste, unless other arrangements have been approved by the DOE, the affected state/tribe, and appropriate regulatory authorities. If the property owner chooses to complete site characterization and treat or remove the hazardous waste prior to remedial action, the DOE will require a report which includes a demonstration that the remaining RRM is no longer regulated as a hazardous waste.

Packaging and Storage

All commingled waste stored to facilitate remedial action at a vicinity property will be managed in compliance with applicable regulations until appropriate treatment or disposal can occur. The responsibilities for packaging and storing of commingled waste shall be negotiated as part of the site-specific agreements. The DOE will not be responsible for any packaging and storage requirements related to the hazardous waste component.

Treatment

As few commercial hazardous waste treatment facilities will accept radioactive hazardous wastes and off-site treatment options are likely to be very costly, on-site treatment is likely to be the preferred, if not the only, option for commingled wastes. The property owner is responsible for identifying the appropriate treatment for the hazardous waste component of commingled waste, obtaining the necessary permits, and having the treatment performed, unless other arrangements have been negotiated with the DOE and the affected state/tribe and included in the site-specific agreements.

The DOE will review the treatment options proposed for commingled waste for effectiveness to ensure that the treated waste can be disposed of by the DOE in an UMTRA Project disposal cell. To the extent practical, commingled waste exhibiting a RCRA hazardous characteristic should be treated on the site to remove the characteristic. The property owner must certify to the DOE that the treatment removed the hazardous characteristic and that the waste is no longer regulated under the RCRA before the DOE will assume responsibility for the treated waste.

Disposal

Commingled waste disposal options will be selected on a case-by-case basis due to site- and waste-specific characteristics or circumstances. Whenever possible, the DOE will place commingled waste in UMTRA Project disposal cells, provided that the affected state/tribe, and the appropriate regulatory authorities concur. Placement of a commingled waste in an UMTRA Project disposal cell must not jeopardize the performance of the cell. The DOE will not accept any commingled waste containing a RCRA-regulated hazardous waste component for placement in an UMTRA Project disposal cell.

Supplemental Standards and Refusals

The EPA regulations allow supplemental standards to be applied at vicinity properties when the costs are unreasonably high relative to the benefits to be achieved, when such remedial action would impose a clear risk to the public health or safety or would cause excessive environmental harm, or when there is no known remedial action (1). The use of supplemental standards would allow the DOE to leave commingled waste in place if one of the above conditions can be met. The DOE will include an evaluation of the risks associated with both the hazardous waste component and the RRM component in any application of supplemental standards at a vicinity property. The DOE will consult with the property owner and the affected state/tribe before making any decision on the use of supplemental standards. The DOE will also obtain the concurrence of the NRC before applying supplemental standards to a vicinity property.

If the property owner refuses to treat the hazardous waste component of the commingled waste, the DOE may decide, after consultation with the affected state/tribe, to handle the vicinity property as a refusal to participate in the UMTRA Project.

Cost Sharing

Payment of any costs incurred by DOE contractors associated with complying with these guidelines will be negotiated between the DOE, the affected state, and the property owner. Cost-sharing arrangements will be made on a case-by-case basis and will become part of the site-specific agreements. The DOE will not share costs associated with off-site treatment or disposal of the hazardous waste component of commingled waste. If the hazardous waste component can be treated by the property owner, and the DOE and the affected state/tribe agree to place the treated waste in an UMTRA Project disposal cell, the DOE will pay its normal share of the site remedial action costs as stipulated in the UMTRCA.

ACKNOWLEDGEMENTS

The authors would like to thank the DOE GJPO and the Colorado Department of Health for their efforts in developing these guidelines.

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EFFECT OF RADON DOSE ON CLEANUP CRITERIA AND USING RESRAD FOR CHEMICAL RISK ASSESSMENT*

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ABSTRACT

The U.S. Department of Energy has used RESRAD, a pathway analysis program developed at Argonne National Laboratory, in conjunction with the as low as reasonably achievable (ALARA) principle to develop site-specific residual radioactive material guidelines (cleanup criteria) for many sites. This study examines the effects of the radon pathway, recently added to the RESRAD program, on the calculation of uranium, radium, and thorium cleanup criteria. The results show that the derived uranium guidelines will not be affected by radon ingrowth considerations. The effect of radon on radium and thorium generic guidelines are more significant, but the model does indicate that at the generic soil limits used for radium and thorium the indoor radon decay product concentrations would be below the 0.02 working level standard.

This study also examines the feasibility of applying RESRAD to chemical risk assessment. The results show that RESRAD can perform risk assessment of toxic chemicals after simple modifications. Expansion of the RESRAD database to include chemical compounds will increase its capability to handle chemical risk assessments.

INTRODUCTION

Argonne National Laboratory has developed a pathway analysis computer program, RESRAD, for the U.S. Department of Energy (DOE) (1). Since its release in June 1989, RESRAD has been used to derive soil cleanup criteria for uranium and other radionuclides and to estimate dose due to residual radioactive material in soil. Recently, a radon pathway was added to RESRAD. Radon-222 is a decay product in the uranium-238 and uranium-234 chain and therefore including ingrowth of radon-222 in the calculations could affect the derivation of uranium criteria.

The RESRAD code was designed for the analysis of sites contaminated with radioactive materials, but many of these sites also are contaminated with hazardous chemicals. Currently, there is no other computer code equivalent to RESRAD that can analyze risks to DOE-related environmental restoration activities resulting from disposal of hazardous chemicals. Therefore, it is desirable that a similar approach applicable to nonradioactive hazardous chemicals be developed.

The purpose of this paper is (1) to assess the possible effects of radon on the development of cleanup criteria for uranium, radium, and thorium; (2) to study and demonstrate the applicability of RESRAD to chemical risk assessment; and (3) to identify additional pathways and databases that are needed for chemical risk assessment.

RADON EFFECTS ON CLEANUP CRITERIA

DOE has developed site-specific residual radioactive material guidelines (cleanup criteria) for sites identified by the Formerly Utilized Sites Remedial Action Program (FUSRAP) and the Surplus Facilities Management Program (SFMP). In the derivation of uranium guidelines, seven pathways in RESRAD were considered: (1) external radiation from contaminated soil; (2) internal radiation from inhalation of contaminated dust particles; (3) internal radiation from ingestion of plant foods grown on site and irrigated with water drawn from an on site well or pond; (4) internal radiation from ingestion of meat from livestock fed with fodder grown on site and water drawn from an on-site well or pond; (5) internal radiation from ingestion of milk from livestock fed with fodder grown on site and water drawn from an on-site well or pond; (6) internal radiation from ingestion of fish from a nearby pond; and (7) internal radiation from drinking water from an on-site well or pond.

Adding radon-222, a decay product in the uranium-238 and uranium-234 chain, as a pathway could affect the derivation of uranium cleanup criteria. Under current guidelines, indoor radon is regulated independently of other exposure pathways. Therefore, it is not considered a direct component of the dose assessment that is conducted to derive radionuclide soil cleanup guidelines. Rather, specific concentration limits are provided for protection from exposure through this pathway (5 pCi/g surface and 15 pCi/g subsurface for radium and thorium in soil, and 0.02 working level [WL] for radon-222 decay products in indoor air) (2). The DOE guidelines require that properties be decontaminated to levels that are as low as reasonably achievable and that are lower than these concentration limits. In this study, the possible effects of radon on the development of cleanup criteria for uranium, radium, and thorium were assessed.

Approach

RESRAD has been used to derive uranium guidelines for many FUSRAP sites (3,4,5,6). Several site-specific RESRAD data files that were used to derive such guidelines were rerun

* Work supported by U.S. Department of Energy, Office of Environmental Restoration and Waste Management, and Office of Environmental Safety and Health, under Contract W-31-109-Eng-38.

** Wallo is associated with U.S. Department of Energy.

with the addition of the radon pathway. A dose limit of 100 mrem/yr was used in the derivation (7), and both indoor and outdoor radon dose contributions were considered. The time that the affected individual spent indoors or outdoors depended on the exposure scenario (industrial or residential) and was the same as previously assumed for the external radiation and inhalation pathways. A time frame of 1,000 years was considered. The lowest allowable concentration that will give a dose of 100 mrem/yr within 1,000 years was considered the reference cleanup criterion (100 mrem in a year represents the greatest allowable dose from the non-radon radionuclides). The reference cleanup criteria derived with and without the radon pathway then were compared. It should be noted that the actual cleanup guidelines set by DOE usually are much lower than the reference cleanup criteria because potential exposure scenarios, land use, and the as low as reasonably achievable (ALARA) principle are considered in the decision process. RESRAD also was run for radium-226 and thorium-230 to examine the effect of radon on generic criteria (5 pCi/g surface and 15 pCi/g subsurface).

Results

The RESRAD rerun results with the radon pathway included were compared to results that were obtained without the radon pathway. Table I contains the results of the analysis for a FUSRAP site. The range of derived radionuclide guidelines, with and without radon dose, for different exposure scenarios (industrial or residential) are reported in Table I. The percent reduction of the guidelines derived with radon dose also are listed in the table. Within the 1,000-year time frame, the guidelines for uranium were reduced 0-2.8% when the radon pathway was considered in the dose limiting assessment. The reduction depended on the exposure scenario and varied from one site to another. Adding the dose contributions of radon-222 to the other contributing pathways and radionuclides used to derive uranium-238 guidelines would produce negligible effects because the quantity of radon-222 ingrowth from uranium-238 is small.

Similar procedures were used for the radium and thorium isotopes. The results also are listed in Table I. The radon dose produced more significant effects in the derived guidelines for radium and thorium for the site studied. The reduction of guidelines for radium and thorium ranged from 2.5% to 18% over the 1,000-year period, depending on the exposure scenario. It should be noted that, although the derived guideline for radium-226 can be 60% lower than the generic limits, the model indicates that the generic limits still should ensure that the site meets the limit, adopted from Environmental Protection Agency (EPA) standards, of 0.02 WL indoor radon decay product (2). It is noted that the radon pathway is not directly applicable to the dose limits derived under current DOE directives. It is necessary to assess the impacts of cleanup levels lower than the generic soil limits under ALARA. The addition of this pathway to the code provides a tool to aid that analysis.

TABLE I

Range of Derived Guidelines for Different Exposure Scenarios

	Without Radon	With Radon	% Reduction
U-234	550-2,400	540-2.400	0-2.8%
U-238	410-1,600	410-1,600	0%
Ra-226	2.2-32	1.9-27	13-18%
Ra-228	13-38	12-37	2.6-5.5%
Th-230	6.6-95	5.7-79	7.2-16%
Th-232	6.4-21	6.1-20	2.5-4.9%

CHEMICAL RISK ASSESSMENT USING RESRAD

The RESRAD computer code is designed to perform risk analysis of a radioactively contaminated site. On many contaminated sites, survey results show the coexistence of toxic chemicals in the soil. To perform a parallel risk analysis for the coexistent toxic chemicals, software that adopts the consistent methodology used in RESRAD is desired. Therefore, the feasibility of applying RESRAD to the risk analysis of toxic chemicals was studied.

In RESRAD, the calculated results for radioactive materials are in terms of total dose (mrem/yr) and dose/source ratio [(mrem/yr)/(pCi/g)] -- the ratio between total dose and the original soil concentration -- during different years after decontamination for each radionuclide. The intermediate results during the calculations also are printed in the output data files. For chemical risk assessment, following EPA instructions (8), the average daily intake rate (mg/kg/day) during the exposure period and the lifetime average daily intake rate (mg/kg/day) should be predicted to facilitate the calculation of the hazard index and the excessive cancer risk for chronic toxic chemicals or carcinogens. Intake routes through inhalation or ingestion are considered separately. Therefore, when using RESRAD for chemical risk prediction, it is necessary to convert the results from total dose and dose/source ratio to average daily intake during exposure and lifetime average daily intake rate.

Pathways Consideration

There are eight environmental transport pathways considered in the RESRAD code: external exposure, inhalation of dust, ingestion of plants, ingestion of meat, ingestion of milk, ingestion of aquatic foods, ingestion of water, and inhalation of radon gas. Of these pathways, inhalation of contaminated dust particles and ingestion of plant, meat, milk, fish, and water also are applicable to chemical risk assessment. Therefore, intake rates for inhalation or ingestion can be derived from RESRAD output for these pathways. External ground radiation and inhalation of radon gas are unique to radionuclides; results from these pathways are irrelevant to chemical risk assessment.

Besides the inhalation and ingestion pathways mentioned above, there are other pathways characteristic of toxic chemicals that are not considered in RESRAD. These pathways include absorption through dermal contact while taking showers or swimming and inhalation of volatile vapors from chemicals in the soil or in water drawn from a nearby pond or well. These two pathways may be important for some toxic chemicals and should be included in chemical risk assessment. Using existent methodology, intake rate predictions for these

two pathways can be developed and incorporated into RESRAD's calculational structure.

Selection of Chemicals

RESRAD's current database consists of 50 radionuclides in their elemental forms. In order to perform risk assessment for chemical compounds as well as for radionuclides, the database needed to be expanded. To demonstrate the applicability of RESRAD to chemical risk assessment, elements that the EPA, after laboratory experiments and observation, has declared to cause adverse health effects or cancers in the human body were selected. These materials were manganese, nickel, lead, and antimony.

Manganese was found to cause respiratory symptoms and psychomotor disturbances in occupational workers when ingested in daily diet. The reference dose for manganese set by the EPA for inhalation is 1.1×10^{-4} mg/kg/day; for oral ingestion, it is 1.0×10^{-1} mg/kg/day (9). The reference dose is the limiting amount above which some sort of adverse health effect might develop and is a conservative number set by the EPA with consideration of uncertainty factors. Nickel was found to cause cancer and to reduce body and organ weights in experimental rats fed nickel sulfate constantly for two years. The EPA oral reference dose for nickel is 2×10^{-2} mg/kg/day; the inhalation slope factor is 0.84 $(mg/kg/day)^{-1}$ (9). The slope factor can be interpreted as the possibility of cancer development per unit intake rate -- 1 mg/kg/day. Lead is known to cause liver and neuronal damage from laboratory experiments with rats. The reference doses for lead set by the EPA for oral ingestion and inhalation are 1.4×10^{-3} mg/kg/day (10) and 4.3×10^{-3} mg/kg/day (9), respectively. From experiments in putting antimony potassium tartrate in rats' drinking water, antimony was found to cause cancer development, life span decrease, and altered blood chemistry. The reference dose for oral ingestion of antimony is 4.0×10^{-4} mg/kg/day (10). However, no slope factor was recommended by the EPA for antimony.

Calculation of Intake Rates

RESRAD calculates the effective dose of a radionuclide with the following equation:

$$(Dose)_{i,p}(t) = DCF_{i,p} \times ETF_{i,p}(t) \times SF_i(t) \times S_i(0) \quad \text{(Eq. 1)}$$

where $DCF_{i,p}$ (mrem/pCi) is the dose conversion factor; $ETF_{i,p}(t)$ (g/yr) is the environmental transport factor, defined as the ratio between the annual intake rate (pCi/yr) and the soil concentration (pCi/g) of radionuclide i at time t (yr); $SF_i(t)$ is the source factor, defined as the ratio of the soil concentration of radionuclide i at time t to the concentration at time 0; and $S_i(0)$ is the soil concentration at time 0. There are two factors affecting the soil concentrations of radionuclides. One is the ingrowth and decay process unique to radioactive materials, and the other is the leaching process caused by infiltration of rain and irrigation water. Therefore, the source factor $SF_i(t)$ is written in Eq. (2) as the multiplication of two factors -- the ingrowth and decay factor, $ID_i(t)$, and the leaching factor, $LF_i(t)$:

$$SF_i(t) = ID_i(t) \times LF_i(t) \quad \text{(Eq. 2)}$$

When considering the toxicity of hazardous materials instead of the radiation intensity of radioisotopes, the ingrowth and decay process is not applicable. Instead, chemical and biological degradation may take place. Because information is absent about the degradation half-lives in soil phase for manganese, nickel, lead, and antimony, the influence of degradation on soil concentration is neglected in the analysis. The average daily intake rate of chemical species i in terms of mg/kg/day can be calculated from RESRAD output results as:

$$Intake_i(t) = \sum_p ETF_{i,p}(t) \times [SF_i(t)/ID_i(t)] \times S_i(0)/(70\times365) \quad \text{(Eq. 3)}$$

The division of source factor $SF_i(t)$ by ingrowth and decay factor $ID_i(t)$ results in leaching factor $LF_i(t)$, which when multiplied by $S_i(0)$ (the initial soil concentration) gives the value of the soil concentration at time t. The number 70 is used based on the assumption that the average body weight is 70 kg, and 365 is used to convert the annual intake rate to the daily intake rate. If the soil concentration $S_i(0)$ is expressed in mg/g for chemicals, then the unit of the intake rate will be mg/kg/day in Eq.(3). For carcinogens, the lifetime average daily intake rate can be derived by multiplying the intake rate in Eq.(3) by 9/70; nine years is the average time for a person to live on site, i.e. the exposure period, and 70 years is the average life span, according to EPA publication (11). The oral intake rate of chemical species i should take into consideration the intake rate through ingestion of plant, meat, milk, water, and fish. These multiple considerations explain the summation sign in Eq.(3). For inhalation intake rate, with the current version of RESRAD code, only the pathway for inhalation of contaminated dust particles should be considered.

The hazard index and excessive cancer risk can be calculated with the use of reference dose (RfD) and slope factor:

$$(Hazard\ Index)_{i,p} = (Intake)_{i,p}/(RfD)_{i,p} \quad \text{(Eq. 4)}$$

$$(Cancer\ Risk)_{i,p} = (Intake)_{i,p}/(slope\ factor)_{i,p} \quad \text{(Eq. 5)}$$

where i stands for chemical species i, and p is the contamination pathway of oral ingestion or inhalation.

Example and Results

A hypothetical site with an area of 10,000 m^2 is considered contaminated by the disposal of manganese, nickel, lead, and antimony. The thickness of the contaminated zone is 2 m with a homogeneous concentration of 1 mg/g for each chemical. No cover material exists above the contaminated zone, and the groundwater table is 5 m below the ground surface. A pond is located at the edge of the contaminated site, and the pump intake depth below the groundwater table is 10 m for a well located at the down gradient edge of the site.

It is assumed that a farm family lives on the contaminated site; they raise vegetables and livestock for their needs and consume fish caught from a nearby pond. Of the plant food consumed by the farm family, 50% is grown on site. The adjacent pond provides 50% of their aquatic food, and an on-site well provides 100% of their drinking water and irrigation water. The farmer spends 50% of his or her time indoors on site, 25% outdoors on site, and 25% off site. The indoor dust level is assumed to be 40% of the outdoor dust level.

Based on these assumptions, RESRAD calculated the environmental transport factors (ETF(t)) for each pathway at different times. The source factors SF(t) and ingrowth and decay factors ID(t) at different times also were provided in the RESRAD output file. The average daily intake rate through oral ingestion or inhalation then was calculated using Eq.(3). According to RESRAD calculation results, the

breakthrough times of groundwater contamination were 1,601, 800, 801, and 1,097 years for manganese, nickel, lead, and antimony, respectively. Both the oral and inhalation intake rates had maximum values at time 0 for these chemicals. Intake rate from the plant ingestion pathway contributed most to the total oral intake rate throughout the 1,000-year time frame. Details of the calculated intake rates are listed in Tables II and III.

The maximum hazard indexes as calculated with the use of Eq.(4) are: 1.4 (inhalation and oral ingestion) for manganese, 3.6 (oral ingestion) for nickel, 170 (inhalation and oral ingestion) for lead, and 100 (oral ingestion) for antimony. When the soil concentrations are 1 mg/g for each chemical at the hypothetical site, the exposed resident farmer might develop adverse health effects in this scenario. The maximum excessive cancer risk caused by inhalation of dust contaminated with nickel, as calculated with the use of Eq.(5), is 3.1×10^{-6}.

TABLE II

Average Oral Daily Intake Rate (mg/kg/d)[a] for Soil Concentration of 1 mg/g

Time (yr)	Manganese	Nickel	Antimony
RfD	1.0×10^{-1}[b]	2.0×10^{-2}[b]	1.4×10^{-3}[c]	4.0×10^{-4}[c]
0	1.2×10^{-1}	7.3×10^{-2}	2.4×10^{-1}	4.1×10^{-2}
1	1.2×10^{-1}	7.3×10^{-2}	2.4×10^{-1}	4.1×10^{-2}
10	1.1×10^{-1}	7.3×10^{-2}	2.3×10^{-1}	4.1×10^{-2}
100	1.1×10^{-1}	7.2×10^{-2}	2.1×10^{-1}	3.8×10^{-2}
250	9.9×10^{-2}	7.1×10^{-2}	1.7×10^{-1}	3.3×10^{-2}
500	8.4×10^{-2}	6.8×10^{-2}	1.3×10^{-1}	2.6×10^{-2}
750	7.2×10^{-2}	6.6×10^{-2}	9.3×10^{-2}	2.1×10^{-2}
1,000	6.2×10^{-2}	6.4×10^{-2}	6.8×10^{-2}	1.7×10^{-2}

[a] All values are reported to two significant figures.
[b] Data from Integrated Risk Information System (IRIS).
[c] Data from Public Health Risk Evaluation Database (PHRED).

TABLE III

Average Inhalation Daily Intake Rate (mg/kg/d)[a] for Soil Concentration of 1 mg/g

Time (yr)	Manganese	Nickel	Lead	Antimony
RfD	1.1×10^{-4}[b,c]	ND[d]	4.3×10^{-4}[e]	ND[d]
0	2.9×10^{-5}	2.9×10^{-5}	2.9×10^{-5}	2.9×10^{-5}
1	2.9×10^{-5}	2.9×10^{-5}	2.9×10^{-5}	2.9×10^{-5}
10	2.9×10^{-5}	2.9×10^{-5}	2.8×10^{-5}	2.9×10^{-5}
100	2.7×10^{-5}	2.8×10^{-5}	2.5×10^{-5}	2.6×10^{-5}
250	2.5×10^{-5}	2.8×10^{-5}	2.1×10^{-5}	2.3×10^{-5}
500	2.1×10^{-5}	2.7×10^{-5}	1.5×10^{-5}	1.8×10^{-5}
750	1.8×10^{-5}	2.6×10^{-5}	1.1×10^{-5}	1.5×10^{-5}
1,000	1.5×10^{-5}	2.5×10^{-5}	8.3×10^{-6}	1.2×10^{-5}

[a] All values are reported to two significant figures.
[b] Values were obtained by multiplying the reference concentration (mg/m^3) listed in IRIS by an inhalation rate of 20 m^3/d and dividing the product by a body weight of 70 kg.
[c] Data from IRIS.
[d] ND = no data available for inhalation RfD.
[e] Data from PHRED.

CONCLUSIONS

The effects of including indoor radon with other pathways in deriving guidelines for uranium-238 and uranium-234 would be minimal within the 1,000-year time period studied for the FUSRAP and SFMP sites. DOE, using RESRAD and ALARA principles, has established uranium limits for cleanup that are much lower than those calculated on the basis of a 100 mrem/year limit. Therefore, sites for which uranium guidelines already have been established will not be affected by radon ingrowth considerations.

The effects of radon dose on radium and thorium, however, are more significant. Radon ingrowth, applied to the dose limit, could result in guidelines that are 60% lower than the generic limits. However, as noted, the model also indicates that the generic guidelines still should ensure that sites meet the 0.02 WL indoor radon decay product limit adopted from EPA standards (2). The new pathway is a useful tool to aid ALARA analyses for selection of radium and thorium limits.

This study shows that RESRAD can be used in risk analysis of hazardous chemicals. RESRAD's current calculational structure makes it easy and feasible to modify the program to produce the desired results for chemical risk assessment. Expansion of the RESRAD database to include chemical compounds will expand its capability to handle risk assessments of toxic chemicals. The addition of pathways applicable to chemical wastes, such as absorption of chemicals through dermal contact while taking showers or swimming and inhalation of volatile chemical vapors from contaminated soil or water, will provide users with the option of performing a complete chemical risk analysis. Including chemical or biological degradation models specific to hazardous chemicals would improve prediction accuracy.

The modified RESRAD code provides a consistent methodology for risk analysis of toxic chemicals comparable to that for analysis of radioactive materials in a site contaminated with mixed waste. The results thus obtained also will provide a clearer picture of the total cost/risk of cleaning up a chemical-radiological comingled site.

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LONG-TERM PUBLIC HEALTH IMPACTS OF DECOMMISSIONING THE HANFORD SURPLUS PRODUCTION REACTORS: IMPLICATIONS FOR CERCLA REMEDIAL ACTIONS AT HANFORD

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ABSTRACT

The public health impacts of decommissioning the eight Hanford surplus production reactors are not significant. The risk to the downstream population of in situ decommissioning cannot be distinguished from the risk of moving the reactors to the 200 Area. With similar recharge conditions and inventories, CERCLA risk assessments may reach similar conclusions. Thus, some CERCLA remedial action decisions may be driven by land use decisions rather than by risks to the public.

INTRODUCTION

The long-term public health impacts of decommissioning the eight surplus production reactors at Hanford have been evaluated in a draft environmental impact statement (EIS) published by the U.S. Department of Energy (DOE) in 1989 (1). These impacts have been evaluated for two major alternatives: in situ decommissioning and one-piece removal to the 200-West Area at Hanford. For each alternative, the reactors were assumed to be covered with dirt and with the Hanford permanent isolation barrier system (PIBS). The PIBS (also called the Hanford defense waste barrier) (2) is an engineered barrier consisting primarily of a fine-textured soil capable of acting as a capillary medium. Precipitation entering the barrier from above is held in the capillary medium until it is either evaporated to the atmosphere or is taken up in plant roots and transpired to the atmosphere. The design of the barrier is intended to limit recharge through the barrier to the waste form to 0.1 centimeter of moisture per year. Long-term public health impacts were calculated for reactor decommissioning based on this recharge rate.

The eight surplus production reactors contain an inventory of both radionuclides in the graphite reactor blocks and elemental lead in the thermal shields (Table I). The lead was in the neutron flux and now contains radioactive impurities. As wastes, the radionuclides are regarded to be low-level radioactive wastes, and the lead is likely classified as RCRA regulated radioactive-hazardous mixed waste. Major components of the inventory (in all eight reactors in 1985) are listed in Table I.

Public health impacts (birth defects and cancer deaths) to the public downstream of Hanford were calculated over a 10,000-year period using a conservative one-dimensional stream-tube model, laboratory-developed dissolution rates for radionuclides and lead, and a value of 0.1 cm/yr for the amount of moisture reaching the waste form through the PIBS (Table II). The dissolved radionuclides and lead were assumed to move down through the vadose zone driven by the 0.1 cm/yr of moisture, to reach the ground water, and then finally to reach the Columbia River.

TABLE I

Inventories of Major Radionuclides and Lead in the Eight Surplus Production Reactors at Hanford

H-3	98,100 Ci
C-14	37,400 Ci
Cl-36	270 Ci
Co-60	74,400 Ci
Cs-137	267 Ci
U-238	0.013 Ci
Irradiated Pb	653 MT

The estimated health effects to the same downstream population from a no-action alternative, assuming that DOE conducted surveillance and maintenance for 100-years and then lost institutional control of the site, 5 to 50.

The public health impacts of either decommissioning alternative are clearly not significant. The risk of leaving the reactors in place (in situ decommissioning) cannot be distinguished from the risk of moving the reactors to the 200-West Area, relative to the risk from background radiation or from the drinking water standard for lead. The estimated health effects resulting from background radiation over 10,000 years are from 900 thousand to 9 million cancer deaths. The EPA maximum concentration level for lead in public drinking water is 0.05 mg/L.

Similar risk assessments using more sophisticated three dimensional transport analysis models (validated to the Hanford Site) will be performed during the RI/FS phase of the CERCLA remedial action process being carried out for all of the operable units at Hanford under the Tri-Party Agreement.* The CERCLA hazardous substances include radionuclides and hazardous wastes similar to the hazardous substances in the reactors and other major facilities. Based on the risk assessments prepared for the eight surplus production reactors, and based on similar recharge conditions and inventories, the CERCLA risk assessments will likely show that the public health impacts are not significant for either leaving

* CERCLA means Comprehensive Environmenal Response, and Liability Act; RI/FS means remedial investigation/feasibility study; and Tri-Party Agreement means the Hanford Federal Facility Agreement and Consent Order among the U.S. Department of Energy, the U.S. Environmental Protection Agency, and the Washington Department of Ecology, signed May 15, 1989.

TABLE II
Estimated Health Effects to the Downstream Population and Maximum Columbia River Lead Concentration from Decommissioning the Eight Surplus Production Reactors at Hanford

	Radionuclide Health Effects	River Lead Concentration, (mg/L)
In situ	0.5 - 5	2E-10
Removal	0.2 - 2	2E-10

CERCLA wastes where they are (i.e., in situ remediation) or removing and disposing of them at other sites at Hanford.

A recent paper by Routson and Johnson (3) also has a bearing on the CERCLA risk assessments. Their paper reported a recharge rate for the Hanford 200 Area of 0 +/- 0.2 cm/yr. If this value is confirmed by other investigators, it is conceivable that the Hanford PIBS would only be needed in order to accommodate climate variations for any dry waste form at Hanford for disposal periods exceeding the required 30-year performance period for RCRA clay cap barriers.

It is likely that future CERCLA remedial action records of decision at Hanford will be driven by future land use decisions, rather than by risk assessments.

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EVALUATION OF A CONTAMINANT PATHWAY AND MOBILITY AT A U.S. DOE SITE USING GROUNDWATER CHEMICAL DATA

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ABSTRACT

An evaluation of groundwater chemistry data confirms the presence of a groundwater recharge zone beneath Paddys Run, a small stream that flows along the western edge of the U.S. DOE Fernald Environmental Management Project (FEMP) in Fernald, Ohio. The hydrologic connection between Paddys Run and underlying aquifer represents a pathway for potential groundwater contamination. Because uranium is a major constituent of waste presently stored at the FEMP, geochemical modeling was employed to assess the behavior of dissolved uranium in groundwater. Results indicate that uranium will be present as neutral- and negative-charged uranyl complexes. Some adsorption of uranium may occur; however, dissolved uranium will be relatively mobile in the aquifer. This study indicates the need to protect the Paddys Run channel from potential contamination during FEMP remedial activities.

INTRODUCTION

An understanding of the relationship between contaminant source, pathway, and receptor is critical to the evaluation of existing contamination and the prevention of future contamination. An analysis of groundwater chemistry from the U.S. Department of Energy (DOE) Fernald Environmental Management Project (FEMP), formerly known as the Feed Materials Production Center (FMPC), confirms the presence of a pathway for contaminant migration into the underlying aquifer.

Uranium is a naturally-radioactive actinide element that can exist in several different valence states in the environment, with the +4 and +6 valence states being dominant. To generalize the behavior of uranium in groundwater, under reducing conditions uranium is extremely insoluble, forming U^{+4}-minerals, and in oxidizing conditions uranium is relatively mobile, forming very stable aqueous $UO_2 + 2$-complexes. Langmuir (1) provides an overview of uranium speciation and solubility in the groundwater environment.

Uranium is a major constituent of waste that is presently stored at the FEMP. Thus, the behavior of uranium in the groundwater system beneath the FEMP is of concern to the DOE, regulators, and the public. In addition to confirming the presence of a potential pathway for uranium migration into groundwater, this study indicates that geochemical conditions may favor the transport of uranium into and through the aquifer via this pathway.

STUDY AREA

The FEMP is a U.S. government-owned, contractor-operated facility that, as the FMPC, produced metallic uranium from natural ore concentrates and recycled residues from the early 1950s to 1989. The FEMP is a 4.2-square-kilometer (km^2) reservation located in a rural area approximately 29 km northwest of downtown Cincinnati, Ohio. The facility is located on a three- to five-km-wide buried valley, formed during Pleistocene glaciation and subsequently filled with glaciofluvial outwash and till. Over most of the FEMP, fine-grained glacial overburden (i.e., till, loess, and lacustrine material) is the surficial geologic deposit. However, post-glacial erosion of the overburden by an intermittent stream system (Paddys Run and associated tributaries) has exposed the underlying glaciofluvial outwash sand and gravel on the west and southwest sections of the site.

Paddys Run is an ungaged, intermittent tributary of the Great Miami River that flows southward through the FEMP (Fig. 1). Paddys Run has a 26 km^2 drainage basin and an estimated average discharge of 10^{-3} to 10^{-1} cubic meters per second ($m^3\ s^{-1}$) (2). Sustained flow in Paddys Run generally occurs during the winter and spring and immediately following periods of heavy precipitation. Surface water from much of the FEMP drains into Paddys Run via several man-made and natural ditches and tributaries.

Large groundwater supplies occur in the glaciofluvial outwash deposits beneath the FEMP, in what is known as the Great Miami Aquifer. The unconfined aquifer is a source of groundwater for industrial, domestic, and agricultural users in the vicinity of the FEMP. Estimates of the Great Miami Aquifer hydraulic conductivity range from 7.1×10^{-5} to 1.8×10^{-3} m s^{-1} (3). Figures 1 and 2 show groundwater elevation contours for the aquifer during February 1989 and February 1990, respectively. Fig. 1 represents typical conditions, groundwater generally flows from west to east across the FEMP. Figure 2 shows evidence of groundwater mounding beneath Paddys Run along the west edge of the FEMP property. The groundwater mound is due increased recharge along Paddys Run during a period of above-normal precipitation in late 1989 and early 1990. Within the FEMP, the groundwater table elevation of the Great Miami Aquifer is below the elevation of the Paddys Run channel.

METHODS

Sampling of groundwater from the Great Miami Aquifer was conducted from January to March, 1989, as part of the on-going FEMP Remedial Investigation and Feasibility Study (RI/FS). In general, monitoring wells were installed in clusters, with two or three wells at each location. Each cluster location was given a unique three-digit number, and each well in the cluster was placed in a "well series" based on its depth. Monitoring wells in the 2000-Series were screened at the top of the Great Miami Aquifer water table. Likewise, 3000-Series wells were screened in the approximate middle of the aquifer, and 4000-Series wells were screened near the base of the aquifer, immediately above bedrock.

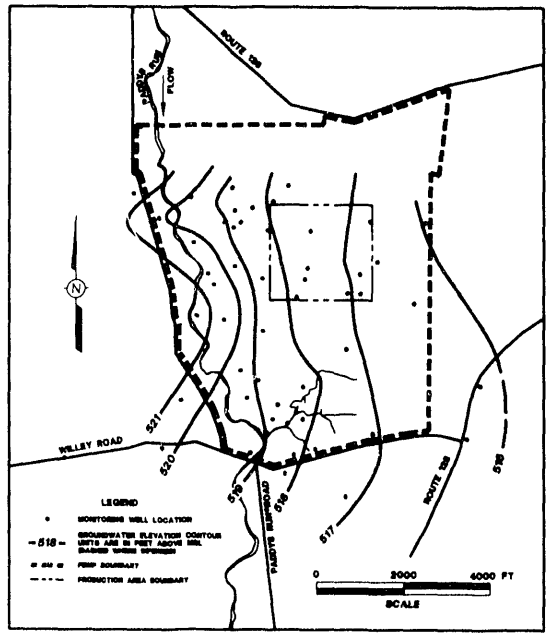


Fig. 1. Groundwater elevation contours 2000 series wells, February 1989.

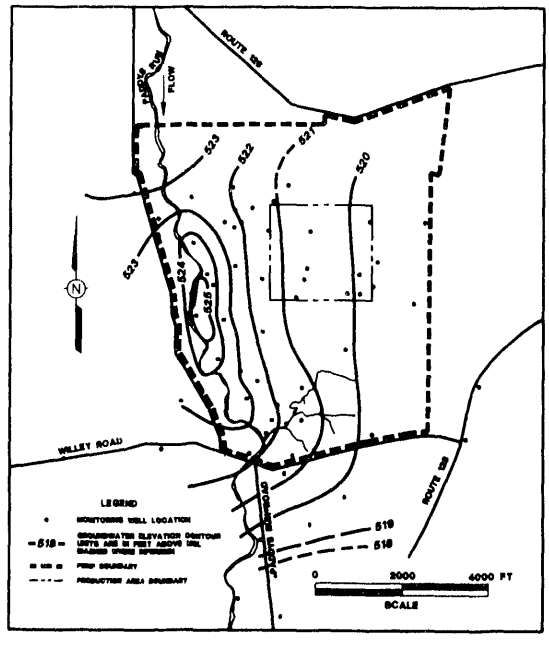


Fig. 2. Groundwater elevation contours 2000 series wells, February 1990.

Monitoring wells were purged prior to sampling using a submersible pump. The pH and dissolved oxygen (DO) concentration of groundwater were monitored during purging. Generally, three volumes of standing water in the well (casing plus sandpack) were evacuated before sampling began, and pH and DO readings stabilized during purging. Temperature, DO, pH, and Eh measurements were made at the wellhead. Probes and electrodes contacted groundwater in a flow-through cell that was designed to minimize the contact between groundwater and air. Groundwater flow rates through the cell were approximately 3.2×10^{-5} m^3 s^{-1}, and the groundwater residence time in the cell was approximately 120 seconds. Groundwater was kept circulating during DO and temperature measurement; however, flow was stopped before taking final pH and Eh readings to eliminate any streaming potential (4,5). The DO meter (YSI Incorporated 51B) and probe (YSI Incorporated 5739), pH/mV meter (Orion Research Incorporated 407 A/F), pH electrode (Orion Research Incorporated 91-05), and combination redox electrode (Orion Research Incorporated 96-78) were calibrated and maintained according to the manufacturers' instructions. Reported temperature, DO, and pH values were read directly from the respective meters. Field Eh measurements were corrected for temperature and referenced to the standard hydrogen electrode (SHE). Reported Eh values are relative to the SHE.

Groundwater samples were collected following the procedures specified in the FEMP (FMPC) RI/FS Work Plan (6) and analyzed for general chemistry, i.e., metals and anions, using U.S. EPA-approved methods (7,8). Most metals were analyzed by inductively coupled argon plasma spectrometry using Method 200.7. Arsenic (Method 206.2), lead (Methods 239.1, 239.2), mercury (Method 245.1), molybdenum (Methods 246.1, 246.2), and selenium (Method 270.2) were analyzed by atomic absorption spectrophotometry. Ammonium was determined by distillation combined with a colorimetric or potentiometric method (Method 350.2). Chloride was analyzed by mercuric nitrate titration following Method 325.3, and fluoride was determined potentiometrically by Method 340.2. Nitrate, total phosphorus, and sulfate were determined by colorimetry using Methods 352.1, 365.2, and 375.4, respectively. Alkalinity was determined by titrimetry at a field laboratory following Method 310.1.

Uranium speciation in groundwater from seven selected wells was simulated using the EQ3NR geochemical code, a solubility/speciation computer program developed by Lawrence Livermore National Laboratory (9). Version 3245R110 of the EQ3NR code was used, and the thermodynamic database was last modified in February 1988. Major and minor cations and anions, pH, Eh, and temperature measurements, and an arbitrary dissolved uranium concentration "spike" of 0.5 milligrams per liter (mg L^{-1}) were provided as input to EQ3NR. The EQ3NR code was also used to determine whether the precipitation of uranium-bearing minerals could effectively control uranium concentrations in the Great Miami Aquifer. Representative groundwater samples from two wells were modeled.

RESULTS

Groundwater in the Great Miami Aquifer is classified as fresh water; total dissolved solid concentrations range from 500 to 700 mg L^{-1}. The dominant dissolved constituents are calcium, magnesium, bicarbonate, and sulfate. Table I shows the simple statistics for pH, Eh, and redox-sensitive constituents in Great Miami Aquifer groundwater. Background dissolved uranium concentrations range from less than 0.001 to 0.003 mg L^{-1} (3).

Based on the results shown in Table I, two distinct regions or zones of groundwater chemistry exist in the aquifer beneath the FEMP. In an area of the Great Miami Aquifer located

TABLE I

Groundwater Chemistry - Oxidizing Versus Reducing Zone

Well Series	pH (s.u.)	Eh (mV)	Dissolved Oxygen (mg L^{-1})	Iron (mg L^{-1})	Manganese (mg L^{-1})	Nitrate (mg L^{-1})	Ammonium (mg L^{-1})
Oxidizing Zone							
2000 (n = 17)							
average	7.0	441	3.6	0.124	0.010	8.1	0.164
std. dev.	0.2	30	3.0	0.122	0.006	4.1	0.082
3000 (n = 4)							
average	7.1	434	4.2	0.113	0.017	10.3	0.132
std. dev.	0.2	29	2.5	0.091	0.013	2.1	0.004
Reducing Zone							
2000 (n = 13)							
average	7.2	167	0.7	2.059	0.233	1.1	0.481
std. dev.	0.3	53	0.8	1.518	0.137	1.7	0.569
3000 (n = 28)							
average	7.2	155	0.4	2.135	0.379	0.8	0.358
std. dev.	0.2	55	0.3	1.877	0.559	1.7	0.476
4000 (n = 6)							
average	7.3	134	0.3	2.254	0.403	0.4	0.235
std. dev.	0.1	61	0.2	1.473	0.228	0.2	0.137

immediately beneath and downgradient of Paddys Run, groundwater Eh measurements range from 380 to 489 millivolts (mV) and average over 400 mV (Table I). Groundwater in this relatively-oxidizing zone contains significant concentrations of dissolved oxygen (greater than 1 mg L^{-1}), concentrations of iron and manganese are below detection or very low, and dissolved nitrogen is present primarily as nitrate (Table I). In contrast, Eh measurements ranging from 75 to 299 mV and averaging approximately 150 mV occur in an area of the aquifer located primarily downgradient of the oxidizing zone and deeper in the aquifer. This relatively-reducing groundwater zone is characterized by higher concentrations of iron and manganese, the absence of significant dissolved oxygen concentrations, and a greater proportion of dissolved nitrogen is present as ammonium (Table I). Concentrations of dissolved oxygen less than one mg L^{-1} are not considered to be significantly different from zero mg L^{-1}, due to the sensitivity of the field analytical technique.

The location of the relatively-oxidizing and -reducing zones in the Great Miami Aquifer are shown in Figs. 3 and 4. The area of relatively-oxidizing groundwater is not as extensive in the middle of the aquifer (Fig. 4) as it is at the water table (Fig. 3). Relatively-oxidizing groundwater is not found in any 4000-Series well, and thus, the relatively-oxidizing zone apparently does not extend to the bottom of the aquifer.

Table II presents the results of the dissolved uranium speciation modeling. Included in Table II are groundwater Eh, pH, dominant uranium species, and percent of each species relative to the total dissolved concentration of uranium. The sampling locations of the modeled groundwaters are shown in Figs. 3 and 4. EQ3NR predicts that uranium will be present in the +6 valence state and predominantly as the uranyl-phosphate complex, $UO_2(H_2PO_4)_2o$, and uranyl-carbonate complexes $UO_2(CO_3)_2$-2 and $UO_2(CO_3)_3$-4. Modeling indicates that if phosphate is present the formation of the uranyl-phosphate complex is favored. The uranyl-carbonate complexes will form only when the uranium molar concentration exceeds one-half of the phosphate concentration. Thus, differences in uranium speciation from one sampling location to the next may be due primarily to differences in the dissolved phosphate concentration. Differences in uranium speciation were not related to variations in groundwater redox conditions. Speciation was similar in groundwater samples from the relatively-oxidizing and relatively-reducing zones.

The uranium concentrations at which Great Miami Aquifer groundwater becomes saturated with respect to uranium-bearing minerals are shown in Table III. Monitoring Well 2046 is located in the relatively-oxidizing zone (Fig. 3), and Well 3054 is located in the relatively-reducing zone of the aquifer (Fig. 4). Solubility modeling predicts that saturation with respect to soddyite, $(UO_2)_2(SiO_4)\cdot 2H_2O$, will control groundwater uranium concentrations in both aquifer zones. However, predicted saturated concentrations are greater in the relatively-oxidizing zone, 1.69 mg L^{-1}, compared with 0.277 mg L^{-1} in the relatively-reducing zone. Precipitation of haiweeite, $Ca(UO_2)_2(Si_2O_5)_3\cdot 5H_2O$, could maintain uranium concentrations at similar levels in Great Miami Aquifer groundwater (Table III). Well 2046 groundwater was not modeled for saturation with respect to coffinite, $USiO_4$, and uraninite, UO_2, because uranium concentrations in excess of that required for schoepite, $UO_2(OH)_2\cdot H_2O$, to precipitate are needed to reach saturation with respect to coffinite and uraninite. However, in the relatively-reducing zone, modeling predicts that enough uranium will be present as U^{+4} for groundwater to be saturated with respect to coffinite or uraninite at dissolved uranium concentrations of approximately 10 mg L^{-1}.

TABLE II

Predicted Uranium Speciation in Groundwater

Well[a]	Eh[b] (mV)	pH (s.u.)	Species	Percent
Relatively-Oxidizing Zone Wells				
2046	441	7.0	$UO_2(H_2PO_4)_2^o$	>99
2061	415	7.0	$UO_2(CO_3)_2^{-2}$	59
			$UO_2(CO_3)_3^{-4}$	24
			$UO_2(H_2PO_4)_2^o$	15
			$UO_2(CO_3)^o$	2
3014	455	6.8	$UO_2(H_2PO_4)_2^o$	82
			$UO_2(CO_3)_2^{-2}$	14
			$UO_2(CO_3)_3^{-4}$	3
			$UO_2(CO_3)^o$	1
Relatively-Reducing Zone Wells				
2013	137	7.4	$UO_2(H_2PO_4)_2^o$	92
			$UO_2(CO_3)_3^{-4}$	5
			$UO_2(CO_3)_2^{-2}$	3
2068	159	8.1	$UO_2(CO_3)_3^{-4}$	61
			$UO_2(H_2PO_4)_2^o$	32
			$UO_2(CO_3)_2^{-2}$	7
3001	81	7.6	$UO_2(H_2PO_4)_2^o$	92
			$UO_2(CO_3)_3^{-4}$	6
			$UO_2(CO_3)_2^{-2}$	2
3054	116	7.1	$UO_2(CO_3)_2^{-2}$	39
			$UO_2(H_2PO_4)_2^o$	37
			$UO_2(CO_3)_3^{-4}$	23
			$UO_2(CO_3)^o$	1

[a] See Figs. 3 and 4 for well locations.
[b] Eh was measured in the field using a platinum redox Ag/AgCl reference combination electrode.

DISCUSSION

Other studies have documented the evolution of groundwater chemistry along the flow path on regional (10) and local (11) scales. At the FEMP, surface water infiltrates into the Great Miami Aquifer through the bottom of the Paddys Run channel. Initially, this water is chemically identical to Paddys Run stream water, i.e., contains significant levels of dissolved oxygen, along with nitrate and other constituents. The infiltrating water reaches the groundwater table and mixes to some extent with groundwater. As the relatively-oxidizing groundwater flows downgradient, biologically-mediated reactions (and possibly some strictly inorganic reactions) will consume dissolved oxygen and reduce nitrate. After dissolved oxygen is consumed, secondary iron and manganese oxide and oxyhydroxide coatings on aquifer solids will be reduced and will yield the dissolved iron and manganese concentrations that are observed in relatively-reducing groundwater. The boundary between the relatively-reducing and relatively-oxidizing zones is a rather narrow area, as confirmed by the strongly bimodal distribution of Eh measurements and an abrupt change in the concentration of some redox-sensitive constituents over relatively small distances. This boundary most likely coincides with the stability boundary for secondary iron and manganese oxyhydroxide coatings in the aquifer. Groundwater redox equilibria is not inferred from the chemistry data; redox disequilibria is commonly the rule in natural systems (12, 13). However, the observed correlation between measured Eh values and the behavior of redox-sensitive parameters suggests that the concept of redox equilibria is a useful framework for describing and interpreting groundwater chemical evolution along the flow path.

Uranium speciation is similar in both the relatively-oxidizing and relatively-reducing groundwater zones (Table II). As geochemical modeling predicts that the predominant uranium species are neutral- and negative-charged complexes, uranium adsorption onto clay minerals may not occur. The zero point of charge (ZPC) for goethite, FeOOH, and amorphous iron hydroxide, $Fe(OH)_3(am)$, is pH 7.8 and 8.5, respectively (13). At pHs lower than the ZPC, these solids have a net positive surface charge, and if present as grain coatings

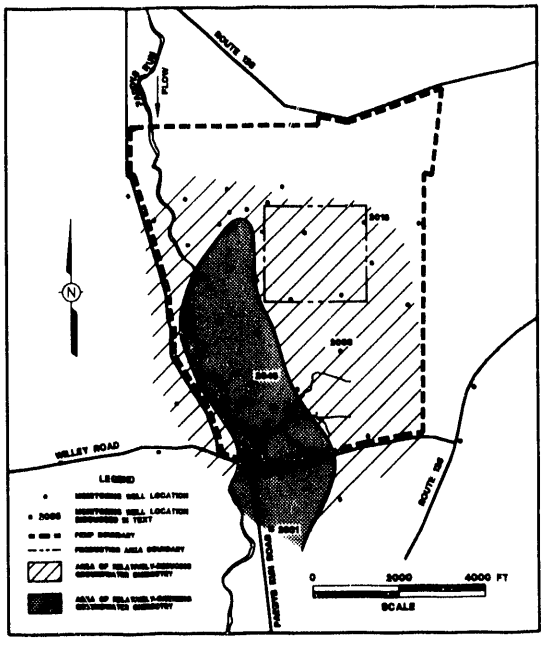


Fig. 3. Groundwater geochemical zones 2000-series wells (top of Great Miami Aquifer water table).

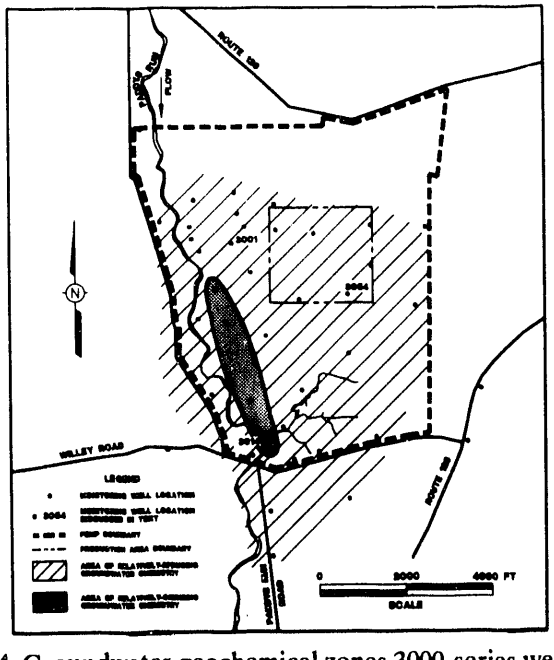


Fig. 4. Groundwater geochemical zones 3000-series wells (middle of Great Miami aquifer).

in the oxidizing recharge zone, they may represent a substrate for adsorption of negative-charged uranyl-carbonate species. Based on a study of uranium adsorption on amorphous ferric oxyhydroxide by Ames et al. (14), an empirical uranium adsorption coefficient ranging from 0 to 3.9 L Kg^{-1} has previously been determined for the Great Miami Aquifer (3). The effectiveness of anion exchange resins in removing uranium from groundwater during pilot and field studies (15) supports speciation modeling results that predict uranium will form negative-charged complexes in the groundwater beneath the FEMP. If a significant proportion of dissolved uranium is speciated as the $UO_2(H_2PO_4)_2o$ complex, the potential for sorption may be decreased. However, if the $UO_2(H_2PO_4)_2o$ complex is a strongly polar molecule, some sorption may take place; although, the potential for sorption of $UO_2(H_2PO_4)_2o$ is expected to be less than that of $UO_2(CO_3)_2$-2 and $UO_2(CO_3)_3$-4.

Results of solubility modeling suggest that precipitation of uranium-bearing minerals will not be an effective control on the uranium concentration of infiltrating water. Uranium concentrations must exceed 1.7 mg L^{-1} (Table III) before the precipitation of soddyite or haiweeite could control dissolved uranium concentrations in the relatively-oxidizing areas of the Great Miami Aquifer. However, modeling predicts that precipitation of these minerals could decrease or limit downgradient uranium concentrations to less than 0.3 mg L^{-1} (Table III) in the relatively-reducing areas of the aquifer. Aside from precipitation of soddyite and haiweeite, solubility modeling has indicated that precipitation of other uranium-bearing solids would limit uranium concentrations to no less than approximately 10 mg L^{-1} in groundwater.

Soddyite has been identified in uranium deposits in the Jackpile sandstone of the Grants, New Mexico uranium district. Granger (16) reports that soddyite was identified very close to, if not in contact with, an intrusive diabase sill. Granger indicates that at the time (1963) this was the first known occurrence of soddyite in sedimentary rock. Hemingway (17) reports that soddyite was identified by X-ray diffraction in an unsuccessful attempt to synthesize coffinite from crystalline and noncrystalline mixtures of uranyl and silica. Heating material for three days at 518 K produced a phase identified as soddyite. Both soddyite and haiweeite are hydrated uranyl-silicate phases that may form from the alteration of coffinite; however, based on reports in the literature,

TABLE III

Predicted Saturated Uranium Concentrations in Groundwater

Uranium-Bearing Solid	Well 2046[a]	Well 3054[b]
	Saturated Uranium Concentration (mg L^{-1})	
Soddyite $(UO_2)_2(SiO_4)\cdot 2H_2O$	1.69	0.277
Haiweeite $Ca(UO_2)_2(Si_2O_5)_3\cdot 5H_2O$	1.73	0.284
Coffinite $USiO_4$	c	9.77
Uraninite UO_2	c	12.7
Schoepite $UO_2(OH)_2\cdot H_2O$	731	512

[a] Well 2046 is in the relatively-oxidizing zone. See Fig. 3 for location.
[b] Well 3054 is in the relatively-reducing zone. See Fig. 4 for location.
[c] Not modeled.

it appears that, at least soddyite, would not be expected to precipitate from groundwater under the conditions observed in the Great Miami Aquifer. The activation energy barrier to nucleation, precipitation kinetics, colloidal transport, and organic complexation are factors that may cause uranium concentrations in groundwater to exceed those predicted by equilibria with hydrated uranyl-silicate phases.

CONCLUSIONS

Within the FEMP, Paddys Run flows directly on the sand and gravel aquifer. Consequently, the stream loses water to the aquifer, and recharge is focused along the Paddys Run channel. The occurrence of a zone of relatively-oxidizing groundwater beneath and immediately downgradient of Paddys Run strongly supports this and confirms that Paddys Run is a potential contaminant pathway, within the FEMP.

The chemistry of several redox-sensitive constituents changes or evolves as groundwater moves downgradient from the recharge zone. However, geochemical modeling has shown that uranium will be present as negative- and neutral-charged complexes throughout the study area of the Great Miami Aquifer. Some adsorption of uranium complexes may occur onto ferric oxyhydroxide grain coatings; however, sorption will be limited to portions of the aquifer where the coatings are stable, i.e., relatively-oxidizing areas. Solubility constraints could limit dissolved uranium concentrations to less than 1.7 mg L^{-1} in the relatively-oxidizing areas and below 0.3 mg L^{-1} in the relatively-reducing areas of the aquifer. However, these concentrations are greater than proposed health-based limits on uranium concentrations in groundwater. In addition, observed uranium concentrations in groundwater may exceed modeled concentrations due to such factors as precipitation kinetics and colloidal transport. Overall, results of this study indicate that uranium will be relatively mobile in the Great Miami Aquifer beneath the FEMP.

If contaminants are flushed or discharged into the Paddys Run channel, the potential exists for these contaminants to rapidly enter the Great Miami Aquifer over a substantial reach at the FEMP. Also, dissolved uranium may be relatively mobile in aquifer groundwater. Thus, as uranium is a major constituent of waste stored at the FEMP, remedial efforts and full-scale cleanup should be designed and implemented in a way that effectively prevents uranium-bearing material from reaching the Paddys Run channel.

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STATUS OF EXISTING FEDERAL ENVIRONMENTAL RISK-BASED STANDARDS APPLICABLE TO DEPARTMENT OF ENERGY OPERATIONS

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ABSTRACT

When conducting its environmental restoration, waste management, and decontamination and decommissioning activities, the U.S. Department of Energy (DOE) must comply with a myriad of regulatory procedures and environmental standards. An assessment of the status of existing federal standards that may be applied to chemical and radioactive substances on DOE sites found substantial gaps and inconsistencies among the existing standards, and technical issues associated with the application of those standards. Of 271 chemical and radioactive substances found to be important across environmental media at the Hanford, Savannah River, and Oak Ridge Sites, 96 (35%) are unregulated by federal regulations and are not covered by DOE guidelines, 48 (18%) are covered by single federal standards or DOE guidelines, and 127 (47%) are covered by multiple regulations or DOE guidelines. Inconsistencies and technical issues among standards include the promulgation of different standards under different regulations for a given substance in an environmental medium, the application of standards for purposes other than originally intended, and the inability to meet standards because of technical limitations. Given the lack of a complete, consistent set of standards or generic procedures for determining applicable standards, and given the existence of inconsistencies and technical issues among the existing set of standards, DOE may be faced with lengthy negotiations of standards on a case-by-case basis. Such negotiations could result in inconsistent cleanup levels, high costs, potential delays, and missed regulatory milestones. Actions that DOE could take to resolve these issues include working with the regulatory agencies to develop 1) specific risk-based standards and generic procedures for determining risk-based standards for individual contaminants and contaminant mixtures; 2) consistent, accepted methods for assessing cumulative risk to humans for contaminant mixtures; 3) consistent, accepted methods for assessing ecological risk; and 4) methods for assessing and comparing risk to the public from contamination left in place, risk to the public from transportation of contaminated materials, and risks to environmental restoration workers. DOE could also develop or adopt innovative approaches to working with regulators in determining standards, including 1) negotiated rule making among all stakeholder groups, 2) negotiated, time-phasing of activities based on relative risks and performances of existing and future technologies, and 3) reopener conditions where interim solutions are needed but cannot achieve desired levels of protection or standards.

INTRODUCTION

When conducting its environmental restoration, waste management, and decontamination and decommissioning activities, the U.S. Department of Energy (DOE) must comply with a myriad of regulatory procedures and environmental standards. This paper assesses the status of existing federal risk-based standards that may be applied to chemical and radioactive substances on DOE sites. Gaps and inconsistencies among the existing standards and the technical issues associated with the application of those standards are identified. Finally, the implications of the gaps, inconsistencies, and technical issues on DOE operations are discussed, and approaches to resolving the gaps, inconsistencies, and technical issues are identified.

BACKGROUND

DOE owns 45 sites in 26 different states where it currently operates or has operated facilities supporting national security interests. The first site, established in 1942 to support World War II efforts, has operated since 1944. Additional sites were added as the nation's security needs increased. These facilities generated, treated, stored, and disposed of hazardous, radioactive, and mixed wastes. Over 4000 active and inactive waste sites have been identified at DOE facilities nationwide.

During four decades of operations, DOE facilities released chemicals and radioactive substances into the air, surface water, ground water, and soil via trenches, landfills, pipes, and stacks. Accidental spills also occurred. As a result, many cubic miles of soils and ground water at these sites became contaminated with radioactive, hazardous, and mixed wastes. These contaminated media will require remediation under

* Pacific Northwest Laboratory (PNL) is operated for the U.S. Department of Energy by Battelle Memorial Institute under Contract DE-AC06-76RLO 1830.

the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) of 1980 [as reauthorized in 1986 by the Superfund Amendments and Reauthorization Act (SARA)], or under the corrective action requirements of the Resource Conservation and Recovery Act (RCRA) of 1976 (as amended). DOE's sites also contain numerous old production reactors and other facilities that are no longer operable. These facilities must be decontaminated and decommissioned in accordance with RCRA and other statutes. All operating facilities must also have, and be in compliance with, RCRA operating permits from the U.S. Environmental Protection Agency (EPA) or from the state regulatory agency to which RCRA permitting responsibility has been delegated. Other environmental statutes that mandate regulations applicable to DOE's operations include the Clean Air Act (CAA); the Clean Water Act (CWA); the Safe Drinking Water Act (SDWA); the Atomic Energy Act (AEA); the Toxic Substances Control Act (TSCA); Insecticide, Fungicide, and Rodenticide Act (FIFRA). Several DOE Orders and Executive Orders also address environmental regulatory issues.

APPROACH

This paper identifies legally binding standards and DOE guidelines that could be applicable to important contaminants on three representative DOE sites, thereby identifying the gaps, inconsistencies, and technical issues associated with the application of those standards. This approach is not intended to identify all chemical and radioactive substances across DOE sites. Rather, it uses three major sites as representative test cases by which gaps, inconsistencies, and major technical issues associated with standards can be identified. This report does not consider non-legally-binding criteria, advisories, guidance, or proposed standards that have been developed by agencies other than DOE, although the use of such criteria and standards is often required by regulatory agencies on a case-by-case basis.

DOE's Hanford, Savannah River, and Oak Ridge Sites were chosen for review because among them, a majority of the substances important to the DOE mission should be identified. Information sources consisted of annual site environmental reports and associated documents. Substances were considered to be important at the sites if they were present in excess of specified federal regulations or standards, if they were unregulated substances, or if large inventories of the substance exist on the site.

Potentially applicable standards were identified from DOE Orders, Executive Orders, and regulations promulgated pursuant to the CAA, CWA, CERCLA, FIFRA, AEA, NWPA, RCRA, SDWA, and TSCA. Potentially applicable quantitative standards were most often risk-based or technology-based. Risk-based standards are set based the possibility of suffering harm from a substance or action, whereas technology-based standards are set based on the performance level of the technology under consideration. Other technical bases (e.g., welfare-based) that were identified are typically combinations of risk-based and technology-based standards.

RESULTS

The types and distribution of contaminants on DOE sites are discussed briefly below. Also discussed are the gaps, inconsistencies, and technical issues associated with the standards that could potentially apply to those contaminants.

CONTAMINANT CHARACTERIZATION AND DISTRIBUTION

A total of 271 chemical and radioactive substances were determined to be important at Hanford, Savannah River, and Oak Ridge Sites. These included halogenated aromatic compounds (N = 6), halogenated aliphatic compounds (N = 16), halogenated pesticides and herbicides (N = 6), nonhalogenated nitrated compounds (N = 1), nonhalogenated simple aromatic compounds (N = 4), nonhalogenated polynuclear aromatic compounds (N = 5), nonhalogenated organic compounds with polar groups (N = 53), nonpolar aliphatic compounds (N = 4), metals and metal compounds (N = 77), inorganic nonmetals and nonmetal compounds (N = 34), and radionuclides (N = 65). Among the 206 chemical substances, 19 were detected in air, 48 in surface water, 136 in ground water, 43 in soil, 2 in flora and fauna, and 134 in tank wastes. Among the 65 radioactive substances, 21 were detected in air, 8 in surface water, 17 in ground water, 31 in soil, 14 in flora and fauna, and 35 in tank wastes.

GAPS AMONG STANDARDS

Of the 271 chemical and radioactive substances, 96 (35%) are unregulated by federal regulations and are not covered by DOE guidelines, 48 (18%) are covered by single federal standards or DOE guidelines, and 127 (47%) are covered by multiple regulations or DOE guidelines. If only chemical substances are considered, excluding radionuclides, the percentages change somewhat. Of the 206 chemical substances, 94 (45%) are unregulated, 47 (23%) are regulated by single standards, and 65 (32%) are regulated by multiple standards. No specific standards were identified for 2 (3%) of the 65 radionuclides, although the general exposure guidelines listed in DOE Order 5400.5 apply to all radionuclides. Only one radionuclide (2%) is regulated by a single standard or guideline, and the remaining 62 (95%) are regulated by multiple standards or guidelines. Most standards for radioactive substances are found in DOE Orders.

INCONSISTENCIES AND TECHNICAL ISSUES

Inconsistencies and technical issues among standards and regulations appear primarily in two forms. First, different standards may be promulgated under different regulations for a given substance in a specific environmental medium. Second, technical issues may arise during the execution of activities intended to comply with those standards. Such technical issues include the application of standards for purposes other than originally intended, and the inability to meet standards because of technical limitations.

Cross-cutting Standards Issues

The major cross-cutting issue that must be considered is the evaluation of cumulative risk. Under many of the above regulations, contaminants have been assigned standards based on their specific risk potentials. This risk value for carcinogens is typically selected in the range of 10^{-4} to 10^{-6} risk of excess cancer deaths. When organisms are exposed to mixtures of multiple contaminants, the actual risk is determined by the degree to which the effects of those contaminants are additive, antagonistic, or synergistic. At present,

however, very limited information exists regarding the types and magnitudes of interactive effects that can be expected under various contaminant mixtures, environmental conditions, and types of receptors. The available limited information precludes the development of consistent, universally accepted procedures for evaluating the cumulative risk of all substances in a sample.

A related issue is the lack of procedures for assessing risk from radioactive mixed wastes. Historically, hazardous and radioactive wastes have been regulated separately, with mixed waste being treated as one or the other type. Despite many attempts to approach the issue of combined risks of mixed waste, none have been successful.

Inconsistencies between CWA Water Quality Criteria and SDWA Maximum Contaminant Levels

In some cases, water quality criteria for water and fish ingestion promulgated pursuant to the CWA and Maximum Contaminant Levels (MCLs) promulgated pursuant to the SDWA afford different levels of protection for the same substances because of different assumptions regarding exposure and dose rates. Because these standards and criteria potentially regulate substances in the same media, the application of one or the other standards may result in different levels of protection. Inconsistencies between criteria for water and fish ingestion and MCLs exist for six halogenated aliphatic compounds, three halogenated pesticides and herbicides, and two metals and metal compounds.

Inconsistencies within CWA Standards

Water quality criteria are non-enforceable, risk-based guidelines that are intended to protect aquatic life and human health. They are used in determining appropriate limits for discharges of effluents to surface waters. Water quality criteria define acceptable pollutant concentrations in receiving water, not discharges, and are adaptable to a wide variety of circumstances. These criteria have generally been used as originally intended to regulate point source discharges of pollutants to surface waters. Occasionally, water quality criteria are used as "applicable or relevant and appropriate requirements" (ARARs) under CERCLA remediation activities when no other standards are applicable. (1)

Inconsistencies within CERCLA Standards

A major technical feasibility problem encountered during CERCLA remediation efforts is the treatability of ground water. During CERCLA ground water remediation efforts, MCLs are usually set as the initial cleanup goals, pending a review of the feasibility of achieving those goals during the remedial action process. The remediation technology used to date consists of pumping and treating ground water. A study involving 19 sites where pumping and treating has been conducted for up to 10 years (2) found that the method removes substantial amounts of the contaminants and that the site-specific "cleanup targets" were generally achieved. However, standards that have been promulgated under the SDWA have yet to be achieved in most cases. Two major factors that influenced this inability to achieve SDWA standards are the technical limitations involved in removing all of the water and the adsorption/desorption of contaminants to the soil matrix.

Inconsistencies within Radiation Protection Standards

Two sets of standards promulgated by EPA pursuant to the AEA and the NWPA are intended as radiation protection programs for specific sources of radioactivity: 40 CFR 191 ("Environmental Radiation Protection Standards for Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes") and 40 CFR 192 ("Health and Environmental Protection Standards for Uranium and Thorium Mill Tailings"). Unlike many of EPA's other regulations, these two regulations set standards based on an optimized cost/benefit analysis of existing technology rather than on risk. The cost/benefit approach is inconsistent with the non-radionuclide regulations promulgated by EPA, which are at least partly risk-based.

The major inconsistency among radiation protection standards is that the older standards, 40 CFR 141, 40 CFR 190, 40 CFR 191, 40 CFR 192, 10 CFR 60, and 10 CFR 72, are based upon the dosimetry system found in ICRP Publication 2(3), published in 1959, whereas the newer standards and guidelines, 40 CFR 61, DOE Order 5400.5, DOE Order 5480.11, and revised 10 CFR 20 are based on the dosimetry system in ICRP Publications 26 and 30. (4,5) Standards based on the old system are inconsistent with current approaches to radiation protection and are not directly comparable. For example, a 25-mrem whole body dose under the old ICRP system is an actual dose. Under the new system, a 25-mrem effective dose equivalent is a sum of the different dose terms for all radiated organs.

Inconsistencies within RCRA Standards

RCRA governs the management of solid waste. The major inconsistency within RCRA arises because solid wastes are classified within specific hazardous waste codes based on the source of the waste rather than on its chemical composition. This method of classification is not entirely consistent with the goal of treating specific wastes based on their characteristics.

Inconsistencies within SDWA Standards

The SDWA mandates the creation of primary and secondary standards to regulate the quality of water available to the public through community and non-community water systems. The primary standards, MCLs, are enforceable standards for specific contaminants that EPA has determined can adversely affect human health. They are set at levels that will protect human health, considering available technologies and cost. Because MCLs are set at levels that consider available technologies and costs, MCLs for different contaminants afford different levels of protectiveness for human health.

Although MCLs were promulgated as standards for drinking water at the tap, the EPA considers them as potential ARARs for CERCLA actions. Specifically, EPA (1) considers them to be ARARs for in situ cleanup of surface water or ground water that may be used for drinking water. MCLs may be conservative cleanup standards in CERCLA actions in cases where the surface waters or ground waters are treated before reaching the tap. Treatment may remove additional quantities of the target contaminants, such that levels below the MCLs are achieved. However, in cases where multiple contaminants exist in the water to be remediated, or multiple pathways for exposure result in extraordinary risks to the

human population, standards more stringent than MCLs may be needed and applied (1).

Inconsistencies within DOE Standards

DOE Orders provide standards that are subject-specific. In general, DOE Orders are complementary to and consistent with federal regulations. The only possible exception is DOE drinking water systems; in this instance, it is not clear whether the SDWA, DOE Orders, or both, apply.

DISCUSSION AND CONCLUSIONS

The cross-match between existing federal risk-based standards and chemical and radioactive substances on three major DOE sites demonstrates that major gaps exist among standards for substances that are important to DOE. In the absence of a complete set of standards, regulatory agencies will likely establish or negotiate applicable standards on a case-by-case basis, and in some cases elevate advisories and guidelines to legally enforceable status. Such negotiations could be lengthy and costly when contaminant mixtures are involved because of the lack of consistent, accepted approaches to deriving standards for mixtures. They are also likely to be lengthy and costly when assessments of tradeoffs among risks to the public near the site, the public along transportation corridors, and to environmental restoration workers are needed. While the case-by-case negotiation approach is feasible, it does not embody the degree of standardization that is needed to effectively streamline environmental restoration, waste management, and decontamination and decommissioning activities. Standardization and streamlining of DOE's environmental restoration and waste management activities would increase the cost effectiveness of those activities, help ensure a consistent approach to determining "how clean is clean", and help ensure that all necessary activities are completed within the desired 30-year time frame.

The EPA is now developing additional risk-based standards that will supplement those already promulgated. However, the number of such standards now being developed will not be sufficient to generate a reasonably complete set of standards within the next few years. Hence, DOE must decide how it can best fulfill its need for risk-based standards across its sites nationwide. Available alternatives include:

- no action, allowing standards to be decided or negotiated on a case-by-case basis between DOE and regulatory agencies
- the development of risk-based standards for individual substances in media where such standards are needed
- the establishment of generic procedures for developing standards that can be applied across DOE sites and facilities.

Combinations of these approaches are also possible.

None of these approaches will be without cost to DOE. Although the no-action approach will require minimal initial expenditures by DOE, it will require extensive negotiations with numerous regulatory agencies to determine applicable standards on a case-by-case basis. Such an approach could result in greatly varying levels of protectiveness and expenditures because DOE sites and facilities will be required to apply different standards to similar environmental restoration and waste management problems.

Past EPA experience indicates that the development of risk-based standards for individual substances in specific media requires extensive resources and long timelines. Among the three options listed above, this option is probably the most resource-intensive and probably requires the longest timeline to execute. It is likely that the time required to develop specific standards will far exceed DOE's 30-year goal for environmental restoration. Such standards are very defensible, however, because their degree of specificity (i.e., media and contaminants) is high and because they are supported by extensive research and development efforts.

The option of establishing generic procedures for developing standards that can be applied across DOE sites and facilities will require initial expenditures of research and development resources, although at much lower levels than the second option. The greater applicability of generic procedures for developing standards is achieved at the expense of some technical defensibility. When developing generic procedures, it is difficult to anticipate all of the combinations of substances and environmental conditions under which generic procedures will be applied. Hence, it is likely that some technical difficulties will be encountered when applying generic procedures for developing standards, and that some applications of generic procedures may be inappropriate or difficult to defend.

Among the standards development needs, the estimation of risk from exposure to mixtures of contaminants is probably the most difficult. The effect of exposure to multiple contaminants can be additive, antagonistic, or synergistic, depending on the specific contaminants being considered and on the receptor (e.g., humans or species of animals or plants). In many cases, not enough is known about the types and magnitudes of the effects that are likely to occur for specific chemical mixtures under specific environmental circumstances. Hence, accepted procedures for estimating such risks are typically lacking. Because of the difficult technical problems associated with the assessment of risk from contaminant mixtures and the prevalence of chemical contaminants and radioactive mixed wastes on DOE sites, DOE should place high priority on the development of consistent methods for assessing risks to contaminant mixtures. High priority should also be placed on the development of consistent methods for assessing and comparing risks to the public from contamination left in place, risks to the public from the transportation of waste materials, and risks to environmental restoration workers. Such comparisons will be needed in the risk management decision process.

In addition to filling gaps among existing standards, DOE will also need to resolve or reach agreement on appropriate actions in cases where inconsistencies and technical issues exist. Major technical issues include the appropriateness of applying standards for purposes other than they were originally intended, the inability (in some cases) of existing technologies to achieve regulatory compliance, and differences in the technical bases for related or similar standards. Resolution of these inconsistencies will help ensure that levels of protectiveness are directly comparable among standards, and that non-compliance and incurring unacceptably high costs during the execution of environmental restoration, waste management, and decontamination and decommissioning activities are avoided.

An additional technical issue that does not yet greatly affect DOE's environmental restoration and waste management activities, but that may in the future, is ecological risk. Recently, the Science Advisory Board (SAB) of EPA (6) recommended that "EPA should attach as much importance to reducing ecological risk as it does to human health risk." This recommendation is based on the recognition that "productive natural ecosystems are essential to human health and to sustainable, long-term economic growth" and that "natural ecosystems are valuable in their own right." Although most federally promulgated risk-based standards protect human health, some have been promulgated to protect living resources. Because exposure scenarios for toxic substances differ between humans and living resources, and because degrees of toxicity for individual substances differ between humans and living resources, protection of human health through the application of risk-based standards cannot be assumed to afford an adequate level of protection to living resources. The EPA is presently in the initial stages of developing procedures for assessing ecological risk. Initial efforts have been focussed on the extrapolation of the single species human health risk assessment model to multispecies ecological systems. This extrapolation is proving to be a challenging task in which the DOE, through cooperative efforts with EPA, could greatly contribute to the development of ecological risk assessment procedures and standards.

In its development of risk-based standards and risk assessment procedures, DOE should establish cooperative working relationships with the major responsible regulatory agencies. If working relationships are not formed, DOE may find that the responsible agencies are reluctant to accept the standards development procedures that it establishes. Moreover, good working relationships will help ensure that DOE is not duplicating standards development activities of other agencies.

DOE may also work with other agencies to develop new and innovative approaches to setting standards and ensuring regulatory compliance, particularly where existing technologies are not capable of achieving existing standards. Such approaches could include negotiated rulemaking among all stakeholder groups, time-phasing of cleanup activities based on relative risks and the performances of existing and expected future technologies, and reopener conditions where interim solutions are needed but cannot achieve the desired cleanup or protection level. The granting of variances (especially for innovative technologies) and agreement through mediation or arbitration may also be used where no viable or expedient means of achieving compliance is, or likely will be, available in the near future.

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STRATEGY FOR INTEGRATED CERCLA/NEPA RISK ASSESSMENTS

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ABSTRACT

The U.S. Department of Energy (DOE) has established a policy whereby, for remedial actions, the procedural and documentational requirements of the National Environmental Policy Act (NEPA) are integrated with those of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), as amended. However, the objectives of risk assessment under NEPA and CERCLA differ somewhat. Until its recent application at contaminated sites, NEPA analysis has typically been applied to impacts from taking actions at clean sites (e.g., for construction activities), and a somewhat loosely structured process has historically been used to estimate relative risks for NEPA. Decisions such as cleanup levels were not made on the basis of the risk estimates, and they therefore tended to be conservative and were not discussed in detail. In contrast, risks estimated for Superfund (CERCLA) sites are used to focus the decision-making process for those sites and support national prioritization for cleanup, and the U.S. Environmental Protection Agency (EPA) has developed a detailed framework for preparing baseline health risk assessments for these sites.

The purpose of this paper is to discuss issues related to integrating the CERCLA and NEPA approaches into the risk assessments that have been prepared for a DOE remedial action project at the Weldon Spring site near St. Charles, Missouri. These issues are grouped into three basic categories: general assumptions for the impact evaluation, data management, and presentation of the methodology and results. This paper is not intended to represent DOE policy and guidance, nor does it represent the only approach that can be used for integrated risk assessments. It merely discusses the process that was used for the Weldon Spring project, articulating the issues that were encountered and how they were addressed.

INTRODUCTION

Prior to the somewhat recent application of NEPA to cleanup actions at contaminated sites, the evaluation of impacts from federal actions under NEPA had historically been applied to proposed construction and operation activities at uncontaminated sites, e.g., construction and operation of highways or power plants. No direct impacts or risks are typically associated with the no-action alternative for such projects, and the objective of estimating risks for the various action alternatives is to support the determination of the environmentally preferable option. To meet this objective, only relative risk estimates were required. Hence, risks estimated for NEPA analyses tended to be conservative (often bounding-case) and the presentations limited (highlighting key results).

In contrast, risks estimated for remedial action projects are generally highest for the long-term assessment of the no-action alternative, e.g., under an assumed loss of institutional control resulting in unrestricted public access. The objective of estimating risks for these projects is not only to indicate the potential risks associated with the no-action alternative and support a relative comparison of alternatives but also to directly support the development of quantitative cleanup decisions. To meet this objective, the risk assessment process has been standardized under CERCLA. This process involves the stepwise quantification of potential impacts associated with contaminated sites and the presentation of results for all reasonable pathways.

Baseline risk assessments developed for Superfund sites play a direct role in cleanup decisions for those sites, including their recent use to support DOE site prioritization efforts. Therefore, such assessments must be prepared with considerable deliberation using reasonable assumptions. The approaches for assessing impacts or risks in accordance with CERCLA and NEPA are currently being integrated at sites across the country -- including the Weldon Spring site -- in order to facilitate completion of the compliance process, optimize resources, and ensure document and decision consistency. Our challenge is to integrate the general assessment process that has been used under NEPA into the standardized process that EPA has developed for CERCLA sites, recognizing the differences between the two and the reasons for those differences.

SITE BACKGROUND AND DOCUMENTATION OVERVIEW

The Weldon Spring site is located about 48 km (30 mi) west of St. Louis, Missouri, and is surrounded by federal- and state-owned land, much of which is wildlife management area. The site consists of two noncontiguous areas: an 88-ha (217-acre) chemical plant area and a 3.6-ha (9-acre) limestone quarry. Both areas are radioactively and chemically contaminated as a result of processing and disposal activities that took place over 20 years ago. The quarry was listed on EPA's National Priorities List in 1987, and the chemical plant area was added to the listing in 1989. These areas are fenced and closed to the public.

Several interim response actions have been conducted at the site, both removal actions and an interim remedial action. These actions have been taken to respond to ongoing releases and to existing health and safety threats on-site. Potential health and environmental impacts have been evaluated at a scope and level of detail appropriate for each specific action,

considering both the CERCLA and NEPA processes. The CERCLA analyses for various removal actions have been documented in engineering evaluation/cost analysis (EE/CA) reports that were written to meet the requirements of NEPA, typically at a level appropriate for an environmental assessment (EA). The CERCLA analyses for the interim remedial action at the quarry were documented in a focused remedial investigation/feasibility study (RI/FS), also written to meet NEPA requirements consistent with an EA-level analysis.

Risks estimated for the removal actions emphasized impacts during the action period, and baseline risks were addressed qualitatively as part of the justification for the action in accordance with the CERCLA process. For the interim remedial action at the quarry, health risks were quantified for both baseline conditions and the remedial action period. Although the available EPA guidance addresses baseline risk assessments, i.e., no-action conditions, the process was also applied to the estimation of health risks for the remedial action period.

For removal actions with no off-site releases -- such as decontaminating and dismantling the existing chemical plant buildings and storing the debris on-site pending upcoming disposal decisions -- no significant public health impacts were expected. Therefore, workers were identified as the likely human receptors. This assessment included a population dose, which has typically been presented in NEPA analyses. The primary exposure pathways addressed in the assessment were those considered most likely to contribute to potential worker exposures -- i.e., inhalation and external gamma irradiation. Available characterization data (screening-level data for most buildings) were used because no additional information was needed to justify the action on the basis of a potential health and safety threat under current conditions. In addition, the data were sufficient to assess the nature and general magnitude of risks that could result from taking the action. A commitment was made in the EE/CA to conduct additional testing during the action to provide more detailed information for refining the worker protection program and to support subsequent treatment and disposal decisions for the building material.

For removal actions with off-site releases -- such as constructing and operating water treatment plants at the quarry and the chemical plant area to treat impounded surface water, with effluent discharges to a nearby river -- workers were not considered the primary human receptors because they were not expected to be exposed to contaminated water. Rather, the local population was considered the primary potential receptors because drinking-water supply facilities with intakes on the river are located downstream. Therefore, the assessments focused on the general public and addressed ingestion as the primary exposure pathway, considering both water and fish. Available data were used because no additional information was needed to justify the actions on the basis of a potential health threat under current conditions. A commitment was made to operate the effluent ponds in a batch mode to ensure that discharge limits established in coordination with the state of Missouri were met prior to each release; hence, these limits were used for the calculations. Worker doses were also estimated for potential exposures via external gamma irradiation due to temporary storage on-site of containerized process sludge from the treatment plants, pending disposal decisions for the project.

The interim remedial action for the project involved the removal of bulk solid wastes that had been disposed of in the quarry, with transportation to the chemical plant area for temporary storage pending comprehensive disposal decisions for the project. This action represented one of the major steps toward quarry remediation, and a baseline risk evaluation (BRE) was prepared as part of the focused RI/FS. The evaluation presented an integrated analysis of the no-action alternative. That is, the BRE addressed potential health and environmental impacts associated with no further action beyond the water treatment action previously documented in the EE/CA. Impacts to workers and the general public associated with waste excavation, transport, and storage were addressed in the FS.

The quarry action addressed the removal of bulk wastes that could be readily excavated; it was scoped to respond to an immediate problem: the release of radon from these wastes into the air at levels exceeding state limits, and the release of radioactive and chemical contaminants into the underlying groundwater with potential transport to a nearby county well field. Because the action constituted an early stage of overall quarry remediation, cleanup criteria were not developed in the RI/FS. These criteria will be developed during the next stage of quarry remediation, which will be documented in a separate RI/FS within the next few years. An updated baseline (or "rebaseline") assessment will be presented in this upcoming documentation to address changed conditions at the quarry after the solid wastes have been removed; an evaluation of potential health risks combined across multiple pathways will be included in this assessment. The BRE was tailored to the stage of quarry cleanup being addressed. Therefore, the time period assumed for the duration of potential exposures was 10 years due to (1) the intermediate stage of the response, (2) the expectation of continuing cleanup activities at the quarry, and (3) the more appropriate inclusion of long-term considerations at the next stage of cleanup -- i.e., in the future RI/FS from which cleanup criteria and final decisions will be developed.

A hypothetical trespasser and a hypothetical passerby were identified as the human receptors to be evaluated in the BRE. The exposure pathways considered for the trespasser were those associated with surface soil, including incidental ingestion, inhalation, dermal contact, and external gamma irradiation. For the passerby, inhalation and external gamma irradiation were evaluated. Although the available characterization data were somewhat limited, no additional data were collected because (1) no more information was needed to justify the action on the basis of risk, (2) cleanup criteria were not being established, and (3) a commitment was made for further characterization of the quarry material at the storage area to support subsequent treatment and disposal decisions. This approach is consistent with EPA's strategy for streamlining the RI/FS process.

To support risk estimates in the FS for the quarry action, limited additional data were collected to confirm information from previous studies on the relative activity concentrations of radionuclides in the uranium and thorium decay series. This information was used to estimate potential risks associated with waste excavation and transportation during the remedial action period for both workers and local public receptors within an estimated radius of potential impact. A hypothetical passerby and nearby resident were evaluated for the quarry

area, as were an on-site office worker at the chemical plant area and a student at a nearby high school. Inhalation was addressed as the primary exposure pathway for general public receptors; external gamma irradiation was also addressed for the passerby at the quarry. Exposure pathways considered for workers in the area of cleanup activities included external gamma irradiation, inhalation, and incidental soil ingestion.

The environmental analyses included in the compliance documents for these interim actions addressed the nature and duration of disturbance, areas and types of habitat disturbed, transportation impacts, and potential impacts and associated mitigative measures for various environmental resources. These evaluations were primarily qualitative and included discussion of threatened and endangered species, critical habitats, and other ecological resources; archeological and cultural resources; and soil, air, and water resources. A floodplain assessment was prepared for the quarry water treatment plant action. Consultation with other agencies was also addressed.

An integrated remedial investigation/feasibility study-environmental impact statement (RI/FS-EIS) is currently being prepared to address comprehensive cleanup decisions for the Weldon Spring project. As for the quarry interim remedial action, the risk assessment prepared for this component of site cleanup represents an integrated analysis of the no-action alternative. That is, an integrated health and environmental baseline assessment (BA) is being prepared to assess potential health and environmental impacts for existing site conditions under both short-term and long-term scenarios, considering both the CERCLA and NEPA approaches.

Similar to the quarry action, groundwater is outside the scope of the current decision-making process for the chemical plant area. This has been defined as a separate operable unit, and a separate RI/FS will be prepared within the next several years to address groundwater at the chemical plant area. A BA will be prepared for this RI/FS that will evaluate updated conditions for the site, reflecting cleanup decisions that will be made from the RI/FS-EIS and including a comprehensive risk assessment for multiple pathways.

DISCUSSION

A number of specific issues have been raised in the process of incorporating into the CERCLA risk assessment process those elements that have historically been associated with risk analyses under NEPA. Because EPA is continuing to develop guidance for baseline ecological assessments to include quantitative evaluations, this paper focuses on integrating the human health assessment in accordance with the guidance provided by EPA for baseline risk assessments. (Note that EPA is also in the process of developing guidance for assessing impacts of remedial action alternatives.) The specific issues can be grouped into three categories: general assumptions, data management, and presentation. The issues within each of these categories and their proposed resolutions are identified in the following discussion.

General Assumptions

Issues related to the general assumptions used to evaluate potential impacts include: definition of baseline conditions, determination of the time period assumed for future scenarios, identification of assumptions for maintenance of institutional controls and future land use, selection of appropriate receptors, and identification of reasonable exposure scenarios. These issues are discussed individually below.

Baseline Conditions. As an example of how this issue was addressed for the Weldon Spring project, the baseline definition of the quarry on which the BRE was based did not include the quarry pond because the environmental compliance process for the removal and treatment of this surface water had already been completed and design and implementation activities were under way. Similarly, groundwater at the quarry was not included in the BRE because (1) decisions for this medium were beyond the scope of the interim action for the bulk wastes (groundwater will be addressed in the upcoming RI/FS), (2) conditions are expected to change as a result of source (bulk waste) removal, and (3) additional characterization data will be collected at the quarry to support upcoming cleanup decisions. Text and figures were included in the documents to explain the staged approach for the risk assessments and remediation decisions. In keeping with the staged responses, the upcoming RI/FS for the quarry will contain an updated baseline (or "rebaseline") no-*further*-action assessment that presents information for both groundwater and the residual solid material in the quarry as support for cleanup decisions related to the final stage of quarry remediation.

As a second example, certain site conditions evaluated in the BA being prepared for the chemical plant area are changing due to interim actions. Part of the problem is that the BA is a component of a very complex RI/FS-EIS for which the planning and preparation has spanned several years. This RI/FS-EIS addresses final alternatives from which subsequent decisions will be made for a number of contaminated media; therefore, it must include detailed risk estimates to support the final cleanup criteria that will be generated from the analyses. During the time it has taken to approach completion of the RI/FS-EIS, decisions have been finalized for a number of interim actions. Because the chemical plant area consists of a variety of contaminated areas and media, it was determined that the BA should present a comprehensive initial snapshot of the area so that the interrelationships between different media could be understood and the focus of remaining decisions for site remediation could be explained.

Therefore, the BA includes certain features such as buildings and surface water impoundments that currently exist but are soon expected to change as a result of interim actions. In a sense, this approach provides confirmation of interim actions such as dismantling contaminated buildings; therefore, only screening-level calculations are presented for these features in the BA. Calculations associated with media for which cleanup decisions have yet to be made -- i.e., soil and sediment -- are presented in much greater detail. To provide the link between the BA and these changed site conditions, an updated "rebaseline" risk assessment is presented in the FS component of the RI/FS-EIS; this rebaseline assessment excludes those features for which decisions have been made. By this staged approach, the short-term and long-term future scenarios can focus on remaining decisions for the site. To limit redundancy and streamline the preparation of the rebaseline assessment, liberal reference has been made to the detailed data and methodology discussions in the BA, with callouts of specific sections and tables to facilitate cross-referencing. Figures were also included to highlight the changed site conditions.

Time Period. The time period of a risk evaluation under NEPA has not typically been a standard assumption, although 1,000 years has often been used for the long-term analysis of radioactively contaminated sites. Under CERCLA, the time period can be selected to focus cleanup decisions being made at each stage of the project. The time periods used for the various risk assessments prepared for the Weldon Spring project have been determined specifically for each action. For example, to estimate risks associated with the water treatment actions in the EE/CAs, a time period of 10 years was used to correspond to a reasonable estimate of the discharge duration, i.e., the 10-year operational period of the plants.

For the quarry BRE, the time period for the duration of future trespasser or passerby exposure was conservatively assumed to be 10 years because cleanup activities were already under way and quarry conditions are very likely to change within the next few years. For the chemical plant area BA and the rebaseline assessment in the FS, the duration of potential short-term (current) exposures was 10 years for reasons similar to those identified for the BRE, i.e., DOE's commitment to a timely response and demonstrated progress with its staged response strategy.

The time period for the future hypothetical scenarios in the BA was conservatively assumed to be 30 years. Although a longer time would typically be selected for the future scenario of a comprehensive baseline risk assessment under CERCLA, the chemical plant BA was tailored to evaluate the area under the first major phase of staged response actions. The time period assumed for the scenario in the FS rebaseline assessment extends to at least 100 years, and that for the groundwater operable unit RI/FS will extend to 200 years and beyond (e.g., to 1,000 years). An explanation of the staged assessments is included in the documents.

Institutional Controls and Land Use. Under NEPA, DOE has typically assumed that institutional controls can be maintained at a site for no longer than 100 years. Under CERCLA, the site is evaluated assuming that controls are lost, even in the near term. The DOE currently maintains institutional controls at the Weldon Spring site, and a perception problem for the local public is possible if hypothetical risks are estimated that would not actually occur because such exposures would be precluded by access restrictions. However, DOE does not maintain such controls at all sites at which it is undertaking remedial action. Therefore, this assumption may be realistic rather than hypothetical for certain assessments. In addition, an assumed loss of such controls is essential to the determination of the major problems at a site, which is very important to the development of site cleanup decisions. That is, by assuming a loss of institutional control, the areas and media that could pose risks in the absence of cleanup can be emphasized. This information is very useful for site prioritization efforts.

Loss of institutional control has been assumed for each of the baseline and rebaseline assessments prepared for the Weldon Spring project so that the assessments can serve their decision-making purpose. To limit the possible misinterpretation of estimates (e.g., public health concerns) under this hypothetical loss of control scenario, an explanation has been included in the documents to indicate that the scenario is highly unlikely and to clarify the reason for the assumption. Reasonable projections of future land use should be identified in the documents to support the selection of receptors and exposure scenarios for evaluation. These projections should consider the time period of the evaluation as well as current ownership of surrounding land and possible development plans.

In the BA prepared for the chemical plant area, existing land use was assumed for the future because the time period was 30 years. Combining the fact that the surrounding land use is primarily recreational with an assumed hypothetical loss of institutional control at the site, recreational use of the site was evaluated for the future scenario. In the rebaseline assessment of the FS, it was assumed that with hypothetical loss of institutional control over the next 100 years, the site might be used for a residence and/or for a wildlife area ranger station.

Receptors. In addition to estimating individual risks for the general public from radioactively contaminated sites, population doses have generally been estimated under NEPA for exposure to radionuclides (but not chemicals) over a given radius, e.g., 80 km (50 mi), without explicitly evaluating contaminant fate and transport. Such explicit evaluation could be used to identify a site-specific radius of impact in order to evaluate potentially affected individuals and populations. Under CERCLA, contaminant fate and transport are explicitly addressed and risks are estimated for individual receptors that could be exposed. Risks are not generally estimated for populations. Because the estimates presented in CERCLA documents are not conservative or "worst-case," site-specific information should be used in place of generic assumptions to determine areas of potential impact and reasonable receptors.

In integrating the risk assessments prepared for the Weldon Spring project, a discussion of the rationale for selecting specific receptors has been included in the documents. A conceptual model is presented in the baseline assessments, and site-specific information was used to determine potentially affected members of the general public during the action period. For example, to support the risk estimates for the air pathway, two computer models were used to determine the area that could be affected by the bulk waste action for the quarry; this information was presented in the quarry FS. To estimate population doses, additional modeling was used to estimate a reasonable radius of impact during the cleanup period. Population doses and risks are presented for both the reasonable radius of impact and the 80-km (50-mi) radius in the FS for the chemical plant area.

For the water treatment actions, information was obtained from the state of Missouri to determine the population served by the water treatment facilities and the amount of fish ingested from the affected stretch of river; this information was used to estimate risks from drinking water and eating fish. Radiological risks were estimated for both an individual and a conservatively estimated population. (The discussion included a comparison with risks estimated for background levels of the contaminant evaluated to limit possible misinterpretation.) Fishing information for local lakes was also obtained from the state of Missouri to support the evaluation of potential impacts from fish ingestion that was presented in the BA. The BA also included a related discussion of contaminant fate and transport to explain the rationale for this evaluation.

Past NEPA analyses for long-term storage or disposal sites have also differed from the CERCLA approach in assuming that a "resident intruder" would live on the waste containment cell. This assumption has been used to estimate

bounding-case health risks under the long-term future scenario. Under CERCLA, risk estimates are to be reasonable rather than bounding; and, although residents are commonly addressed (as appropriate to projected land use conditions), they are not assumed to live on top of a disposal cell. To resolve this issue, the resident intruder has been addressed qualitatively in the FS prepared for the chemical plant area. The rebaseline assessment in the FS quantitatively evaluates an on-site resident not living on the disposal cell in order to support the development of soil cleanup criteria, including a determination of residual levels that would be most protective and reasonably achievable (i.e., "as low as reasonably achievable" or ALARA).

For workers, radiological impacts have typically been quantified as part of NEPA analyses for contaminated sites, and individual and population doses are commonly estimated. However, impacts from nonradiological contaminants have not historically been evaluated for each pathway because awareness of the need to address chemical exposures has only recently developed. Such exposures are evaluated as part of CERCLA assessments, but population estimates have not yet been associated with these assessments. To integrate these factors, exposure to both radiological and chemical contaminants via various pathways has been addressed in worker risk assessments for the Weldon Spring project, as appropriate to the focus of the action. For example, the EE/CA for decontaminating and dismantling the buildings addressed inhalation exposure to asbestos, radon, and suspended radioactive particulates as well as external gamma exposure. A range of pathways is addressed for the remedial action worker in the chemical plant area FS, including inhalation, incidental ingestion, dermal absorption, and external gamma exposure. Risks to an on-site office worker (i.e., nonremedial action worker) have also been evaluated. Radiological population risks for the cleanup workers have been presented as part of the analyses.

A second issue for the worker assessment is that the available EPA guidance addresses baseline risk assessments. This guidance is not explicitly geared to address remedial action workers, although standardized guidance for the action period assessment is in preparation. To address this issue for the Weldon Spring project documents, basic elements of the baseline assessment process have been applied to the evaluation of workers during the remedial action period. In addition, an outdoor worker was addressed in the BA prepared for the chemical plant area because this receptor is present under existing conditions. That is, baseline risks were estimated for an on-site worker involved in routine maintenance activities.

Exposure Scenarios. The exposure scenarios that have been evaluated in the past under NEPA have typically highlighted the primary pathways and have often used conservative assumptions. Under CERCLA, reasonable maximum exposures are evaluated across multiple pathways (sometimes including quantification for pathways that do not contribute significantly to estimated risks); these pathways are defined by considering a range of possible scenarios. To resolve this issue, a broad range of exposure scenarios has been evaluated in the baseline assessments prepared for the Weldon Spring project, consistent with the stage of cleanup being addressed. The logic for these scenarios has been explained in the documents, and assumptions have been tabulated to highlight specific components of the exposure assessment.

For example, the BA evaluates a variety of scenarios and includes tabulated receptors, locations, and exposure pathways as well as intake parameters used for the exposure assessment. A matrix is also included for different receptors (e.g., a current trespasser and a future recreational visitor) to permit combinations across pathways to estimate reasonable maximum exposures. Assessments of the action period for removal actions have focused on the major pathways of concern, as appropriate to each limited scope. (The various exposure scenarios considered for these documents were highlighted in the overview discussion of compliance documentation.)

Data Management

Appropriate contaminant characterization data are critical to CERCLA risk assessments. A number of contractors have been involved over the years in data collection at the Weldon Spring site, and the reporting of sampling and analytical results has not always been consistent or complete. In addition, the site was listed on the NPL long after characterization began. Therefore, data management for the risk assessments was not as straightforward as it would have been had the standard EPA process for characterizing Superfund sites been followed from the start. For example, data quality objectives were not established by earlier contractors to specifically support risk analyses, and standard qualifiers did not accompany the laboratory results. A number of the data management issues for the Weldon Spring project reflect these site-specific factors. However, because these factors may be true for other DOE facilities and other basic problems were also involved, the approach used to resolve issues for the Weldon Spring project may be useful as "lessons learned" for other projects at which comprehensive characterization and data interpretation is just getting under way.

Issues associated with the management and interpretation of characterization data used in the calculations include: data availability and need, verification and validation, outliers and nondetects, comparison with background concentrations, and surface versus subsurface contamination. These issues are discussed individually below.

Availability and Need. Relative to comprehensive data collection, NEPA documents have typically been prepared earlier in the decision-making and response process than are CERCLA documents. In addition, the purpose of past NEPA risk assessments differed from that of CERCLA assessments. Hence, available data have generally been compiled for use in the risk assessments; that is, a staged data collection effort and formal data review have not typically been conducted to support the assessments for past NEPA analyses. In contrast, the data are rigorously reviewed to identify gaps that should be filled to support the risk assessment under the CERCLA process. This rigor is important because the resultant risk estimates are used to develop quantitative cleanup criteria and identify areas for potential remediation. In integrating the two processes, data used in the baseline assessments for the Weldon Spring site have been evaluated in accordance with the CERCLA process. Additional data collection to address data gaps has been determined by the level of assessment required, considering the scope of the action and the decision to be made.

For example, the screening-level data available for the chemical plant buildings were considered adequate for the

level of assessment in the BA because the buildings were to be dismantled under a removal action and were not part of residual risk estimates for the site. In contrast, data for media that are being evaluated in terms of the need for and appropriate extent of cleanup as well as the magnitude of residual risk must be comprehensive enough to support cleanup decisions. This is especially important when "no action" may be the ultimate remedial action decision, e.g., for certain areas of sitewide soil. For the BA and rebaseline assessment in the FS, additional data were needed for a radiological source term analysis to assess the presence of specific isotopes in site soil and sludge. This information was needed to support the risk calculations and to determine the need for mitigative measures during the cleanup period, e.g., for remedial action workers, as well as to support the development of final cleanup criteria for the site.

Verification and Validation. A formal data verification and validation effort has not typically been conducted for past NEPA analyses, although general data management activities have been followed. Under CERCLA, site data are subjected to a formal verification/validation review to ensure the quality of data used in the risk assessment. In integrating the two processes, data used for the baseline assessments for the chemical plant area were subjected to a formal verification and validation review. Although EPA's standard Contract Laboratory Program qualifiers did not accompany the site data, the intent of the process was followed, using similar information from sampling, analysis, and recording activities. The database was computerized in a form that facilitated this and subsequent data management efforts. It is highly recommended that the data for all projects be computerized so discrepancies can be easily identified and corrected.

Outliers and Nondetects. In past NEPA analyses, a formal data evaluation process has not typically been applied to address outliers (such as unusually high values) or nondetects (samples where the parameter tested was not measured at the detection limit). Under CERCLA, outliers and nondetects in the database are identified and then reviewed to determine how they should be addressed in the risk assessment. In integrating the two processes, the soil data used for the BA and rebaseline assessment were sorted to identify outliers and nondetects. Then, two different approaches were used in the risk assessment. For the first, a location-specific (borehole-by-borehole) analysis was conducted to specifically highlight hot spots. For the second approach, a sitewide analysis was conducted using UL_{95} (representative average) values to provide more realistic "random use" risk estimates.

To address nondetects, the likelihood that the contaminant was present was estimated using historical data and other available characterization data (e.g., whether the contaminant had been found elsewhere and with what frequency it was detected at the site). In reviewing historical data for the Weldon Spring site, operational records were examined to determine whether the use of certain chemicals was ever indicated for the site. Then, to obtain averages for the sitewide analysis, nondetects for contaminants such as organic compounds that were not reasonably expected on the basis of site history and other information (e.g., detection frequency) were replaced with zero. For contaminants that could reasonably be expected to be present (e.g., naturally occurring radionuclides and metals) nondetects were replaced with either half the value or the full value of the detection limit, as appropriate to the specific parameter and limit.

Comparison with Background. Site characterization data have not typically been compared with information for local background, notably for nonradiological parameters, as part of past NEPA analyses. Under CERCLA, this comparison can be used to focus the selection of contaminants of concern for the risk assessment. In integrating the two processes for preparation of the chemical plant area BA, site data considered to represent background were compiled for various media (soil, surface water, and groundwater) in the general vicinity of the site. In addition, data from other locations in the state of Missouri and literature data for the United States and other areas were reviewed. This information was presented together with the characterization data to support screening decisions used to identify the contaminants of concern. This information was also useful in determining incremental risks (e.g., risks above those that could result from exposure to natural background concentrations of metals and radionuclides), which supported the development of cleanup criteria.

Surface and Subsurface Contamination. In past NEPA analyses, subsurface contamination has not typically been addressed in detail as part of cleanup criteria development, i.e., by hypothesizing specific scenarios under which the material could be brought to the surface. Under CERCLA, an evaluation such as an "excavation and surface redistribution" of subsurface soil may be included in the future scenario of a baseline assessment to support cleanup decisions. In integrating the two processes for the rebaseline assessment of the chemical plant area, locations with potential subsurface contamination were identified by reviewing the characterization data and site history (e.g., to evaluate burial areas and underground piping). To support the site characterization effort, blueprints were examined to determine locations of pipes and process lines or storage areas at which spills might have occurred; disposal records and cut-and-fill maps were also reviewed, as were operational records. This information was used to evaluate the data for subsurface contamination. The potential for future exposures at these locations was then evaluated by estimating health effects associated with excavating soil for the basement of a residence and redistributing this soil on the surface, e.g., to represent the new yard. This evaluation was presented in the future resident discussion of the rebaseline assessment in the FS. Leaching of buried contaminants to groundwater was also evaluated to support the cleanup determination of "action" or "no action" for subsurface contamination.

Presentation

Issues associated with presentation of the impact evaluation include: level of detail, combining radiological and chemical risk results, contribution of background levels to risk estimates, specific pathway and contaminant contributions to total risks, summary of results, and cumulative impacts. These issues are discussed individually below.

Level of Detail. For past NEPA analyses, risk results have typically been presented without indicating intermediate calculations or extensive explanations of the methodology. Under CERCLA, the methodology and assumptions are presented in a stepwise manner and in considerable detail. In integrating the two processes, the objective of a risk

assessment at a remedial action site must be emphasized, and considerable detail should be presented to support subsequent decisions. For example, intake equations and background information on the methodology and toxicity assessment were presented in the BA. In addition, assumptions used for the calculations were tabulated. This level of detail facilitates understanding not only by the reviewers but also by the public, demystifying the risk assessment process and allowing the interested lay person to repeat the calculations.

Combining Radiological and Chemical Results. Past NEPA analyses for radioactively contaminated sites have typically focused on radiological risks. Recent awareness of chemical contaminants at such sites has resulted in the inclusion of associated impacts in the assessments. Under CERCLA, both carcinogenic risks and noncarcinogenic health effects from exposure to chemicals are explicitly assessed. At issue is whether the results of these two analyses should be combined or presented separately in the documents. Because the assumptions, methodologies, and target endpoints used to assess radiological and chemical carcinogenic risks differ, the two results have been presented side by side in the assessments prepared for the Weldon Spring project. This helps keep radiological risks in perspective relative to background risks and the target incremental risk range for Superfund sites (which was developed without specific consideration of radiological risks). To reduce confusion between the carcinogenic and noncarcinogenic effects, the results for noncarcinogenic chemical effects were presented in decimal notation (e.g., hazard index of 0.1 or 1) rather than in scientific notation, which was used to indicate carcinogenic risks (e.g., 10^{-5}).

One instance where it may be appropriate to present the radiological and chemical results together is in the FS discussion that addresses cleanup criteria. For example, risk contours for the two different calculations can be combined to identify potential areas for cleanup. However, in general, it may be most appropriate to summarize results of the baseline radiological and chemical risk calculations separately but together (e.g., in separate columns of a single table).

Background Contribution. Under NEPA, incremental risks have not always been separated out for individual contaminants and pathways at contaminated sites. However, risks from natural radiation have been included in the assessments to place the site problem in perspective. Under CERCLA, excess risk is the target endpoint of the risk calculations, and contaminant and pathway contributions are commonly indicated. In integrating the two processes, the analyses for the Weldon Spring site have indicated the risk contribution from background concentrations of the specific contaminants evaluated.

For example, the risks presented in the water treatment EE/CAs for ingesting uranium from the affected river were assessed for both the naturally occurring concentration in the river and for the concentration assumed to result from the treatment plant discharge. For the rebaseline assessment in the FS, total risks are presented along with risks associated with a nearby background location. To support the development of cleanup criteria, risks are presented first as total risks and then as incremental risks (e.g., determined by subtracting an average background value from the measured contaminant concentration). The first approach satisfies requirements for presenting baseline information. The latter supports subsequent cleanup decisions. This also helps put in perspective the EPA target range for incremental lifetime carcinogenic risk of 10^{-4} to 10^{-6} relative to naturally occurring radionuclides (e.g., in the uranium and thorium decay series) and metals. The EPA has estimated that the lifetime risk from background radiation is about 10^{-2}; using the standard EPA process, the risks estimated for exposure to certain metals (such as arsenic and beryllium) at background levels in environmental media can be at the upper limit of the target range (e.g., for a residential scenario).

Pathway and Contaminant Contribution. Contributions from individual contaminants and exposure pathways to estimated risks have not typically been isolated in the documentation for NEPA analyses at contaminated sites. Under CERCLA, results are typically presented as individual pathway-specific and contaminant-specific calculations. In integrating the two processes, the baseline assessments prepared for the Weldon Spring site have presented the analyses in accordance with the CERCLA approach. This allows the assessment to focus on the contaminants and pathways that drive the cleanup decision while presenting supporting information for other contaminants and pathways, e.g., at the contaminant selection stage and in the fate and transport discussion. This approach also permits various combinations across multiple pathways so that reasonable maximum exposures can be identified for the different receptors.

Summary of Results. Risk results of past NEPA analyses have typically been presented in summary tables with generally limited discussion in the text. Under CERCLA, emphasis is placed on indicating the results of the health assessment in considerable detail. In integrating the two processes, the baseline assessments prepared for the Weldon Spring site have used figures and tables extensively so that the reader can quickly identify the media, pathways, exposure points, and receptors that are evaluated in detail and see the key results. Specific site locations with elevated risks or hazard indexes can be clearly indicated on figures. Tables can be used to indicate the range of estimated health effects for different hypothetical receptors and for various combinations of exposures.

Cumulative Impacts. Under NEPA, cumulative impacts must be specifically identified as part of the impact evaluation. Historically, this evaluation has related to the actions that might alter or increase existing environmental impacts on a resource such as a river because of the construction and operation of an additional facility such as a dam or power plant. As Superfund cleanups have progressed and the advantages of a phased cleanup strategy using interim actions and separate operable units for certain projects have become apparent, so has the relevance of cumulative impacts to the CERCLA assessments. In fact, EPA has recently raised this issue in risk assessment discussions. In each of the documentation packages prepared for the Weldon Spring project, cumulative health and environmental impacts have been determined by rolling forward the risks estimated for previously proposed actions and considering overlaps of location, impact type, time period, receptors, and exposure pathways.

Potential future actions should also be considered during each stage of the cleanup response in order to address reasonably foreseeable potential impacts. For example, the interim action for a water treatment plant at the quarry

preceded the similar action at the chemical plant area. For the earlier action, use of a single system to treat water from both areas was considered, but this was ruled out for various reasons. Although it was addressed as part of the scoping process for the action, the issue was not explicitly discussed in the first EE/CA. Hence, the discussion was incorporated in the second EE/CA to document its earlier consideration regarding reasonably foreseeable impacts. This discussion explained that a single plant was determined to involve additional risks, questionable effectiveness, and higher overall costs and was therefore eliminated as a viable option, precluding such potential impacts. Looking to the future when planning and documenting a phased cleanup strategy can help ensure that all relevant factors are considered at each decision stage, thereby strengthening the overall remediation approach.

CONCLUSIONS

The CERCLA risk assessment process was developed specifically for remedial action sites, and it should therefore serve as the driver in preparing integrated CERCLA/NEPA assessments for DOE sites. This approach is indicated in DOE policy, in which the RI/FS process is identified as the primary instrument for integration. Specific elements of NEPA that have not yet been explicitly identified in EPA guidance for CERCLA assessments should be folded into the integrated assessments in accordance with the DOE policy. For example, impacts during the cleanup period should be quantified in some detail (including worker impacts) and impacts to environmental resources other than biota should be clearly addressed.

The risk assessments prepared for a project should be scoped to reflect the major phases of site cleanup. By this approach, site conditions that have changed markedly as a result of interim actions can be addressed in a manner that will limit the redundancy of documentation and decisions. Those assessments that are part of interim actions for which cleanup criteria are not being established do not require the same level of detail as baseline assessments that are used to develop final cleanup decisions.

Exposure scenarios should be defined on the basis of "likely" and "reasonable" land use and receptor assumptions rather than "bounding-case" assumptions because the assessment must support quantitative cleanup decisions. To do otherwise could result in an inappropriate allocation of cleanup funds.

Data review for a project should begin early and should be rigorously pursued for all media for which the decision to remediate must be determined and for which cleanup criteria must be developed. Immediate focus on this data management task can help ensure that appropriate information is available for the risk assessment, i.e., that critical data gaps are filled. A delay in initiating this effort can significantly delay not only preparation of the risk assessment but also the entire decision-making process for a project.

Finally, the overall strategy and critical assumptions used in the risk assessment should be clearly presented in the document. More importantly, they should be presented to all review groups for discussion as they are developed, with regular updates as the document evolves. Because each site has unique problems and surrounding conditions, no single set of assumptions can be standardized. Therefore, to streamline the integration process for risk assessments at DOE sites, the importance of a sound strategy and early interagency involvement cannot be overemphasized.

ACKNOWLEDGMENTS

Work supported by the U.S. Department of Energy, Office of Environmental Restoration and Waste Management, under contract W-31-109-Eng-38. This paper simply presents the approach that has been used to prepare integrated risk assessments at a single site; it does not represent DOE policy or guidance. The authors wish to recognize the invaluable risk assessment input and issue resolution efforts of Steve McCracken, project manager, U.S. Department of Energy; Steve Woodbury and Carolyn Osborne, Office of Environment, Safety, and Health, U.S. Department of Energy; Daniel Wall, regional project manager, Region VII, U.S. Environmental Protection Agency; Dr. David Bedan, Missouri Department of Natural Resources; and Gale Carlson, Missouri Department of Health.

AN ASSESSMENT OF BASELINE ECOLOGICAL RISKS AT THE FERNALD ENVIRONMENTAL MANAGEMENT PROJECT, FERNALD, OHIO

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ABSTRACT

The Fernald Environmental Management Project (FEMP), formerly the Feed Materials Production Center (FMPC), is a Department of Energy (DOE) facility located near Cincinnati, Ohio, which produced pure uranium metals from the early 1950s until 1989. DOE is currently conducting a Remedial Investigation/Feasibility Study (RI/FS) under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), in order to remediate environmental impacts at the site. DOE is also preparing an environmental impact statement under the National Environmental Policy Act (NEPA) to evaluate environmental impacts of proposed remedial actions. Both CERCLA and NEPA require evaluation of ecological risks of baseline conditions and proposed remedial actions. A preliminary assessment of ecological risks examined the potential effects of FEMP contaminants in one operable unit (OU) at the site, OU5, Environmental Media. Radionuclides of potential concern in OU5 soils include uranium, cesium, radium, strontium, technetium, and thorium. Chemicals detected in terrestrial organisms include aluminum, arsenic, barium, cadmium, lead, mercury, vanadium, and zinc, as well as radionuclides. Chemicals of potential concern in surface water include a variety of metals as well as uranium and technetium. Radionuclides in OU5 do not appear to pose a hazard to terrestrial organisms. Estimated radiation doses to aquatic organisms continually exposed to the maximum uranium concentrations observed in on-property drainages ranged from 40 to 4000 rad per year. However, off-property radionuclide concentrations are very low, and it is unlikely that organisms in streams adjacent to the FEMP are exposed to toxic levels. Maximum arsenic levels in vegetation collected from the FEMP are consistent with values reported in the literature to be toxic to certain plants. However, signs of stress have not been observed in vegetation on or adjacent to the FEMP. Similarly, arsenic levels in plants and animals collected from the FEMP could be toxic to terrestrial mammals under worst-case conditions, but toxicity has not been observed in the field. Current and planned sampling of soils will clarify whether nonradioactive constituents constitute a hazard to terrestrial organisms at the FEMP. The maximum concentrations of aluminum observed in OU5 surface waters are comparable to those reported to cause chronic to acute effects in aquatic organisms. However, macroinvertebrate communities in streams adjacent to the FEMP do not exhibit any adverse effects of exposure to FEMP constituents. This preliminary assessment suggests that present ecological risks of the FEMP are low and are likely to be associated primarily with nonradiological effects. However, long-term ecological risks could be substantial if containment systems fail or wastes are penetrated by plants and burrowing animals.

INTRODUCTION

History of the Fernald Environmental Management Project

The FEMP is a DOE-owned facility which produced pure uranium metals from the early 1950s until 1989, when production was suspended. The facility has been operated by Westinghouse Materials Company of Ohio (WMCO) since 1986. The FEMP is located on a 1,050-acre site in a rural area approximately 18 miles northwest of downtown Cincinnati, Ohio (Fig. 1). Production facilities occupy approximately 136 acres in the center of the FEMP (Fig. 2). Land use outside the production area and waste storage areas includes 425 acres of grassland and woodlot leased for cattle grazing. Two pine plantations planted in 1973 are located in the northeast and southwest portions of the facility, and Paddys Run, an intermittent stream, runs roughly parallel to the western boundary of the FEMP, entering the Great Miami River about one-half mile south of the site. The storm sewer outfall ditch, a major tributary to Paddys Run, enters the stream near the southwest corner of the property, and a number of smaller ditches drain into the stream. Treated effluent from process operations and runoff collection systems is discharged to the Great Miami River through a National Pollutant Discharge Elimination System (NPDES) permitted outfall.

In April 1990, DOE signed a Consent Agreement with the U.S. Environmental Protection Agency (EPA) under CERCLA Sections 120 and 106(a), concerning environmental impacts associated with the FEMP. These impacts are related to past activities, which produced a variety of wastes, including general scrap and refuse, sanitary waste, contaminated and noncontaminated metal scrap, waste oils, asbestos, and fly ash. In addition, radionuclide wastes were disposed of in silos and in open pits. The major identified off-property impact of the FEMP is a plume of uranium-contaminated groundwater. Pursuant to the Consent Agreement, DOE is conducting a RI/FS to formulate and assess remedial activities at the FEMP. In addition, DOE is preparing an Environmental Impact Statement (EIS) to examine the environmental impacts of potential remedial activities in compliance with NEPA. In order to expedite remedial actions, separate RI/FS reports are being prepared for each of five operable units, as follows:

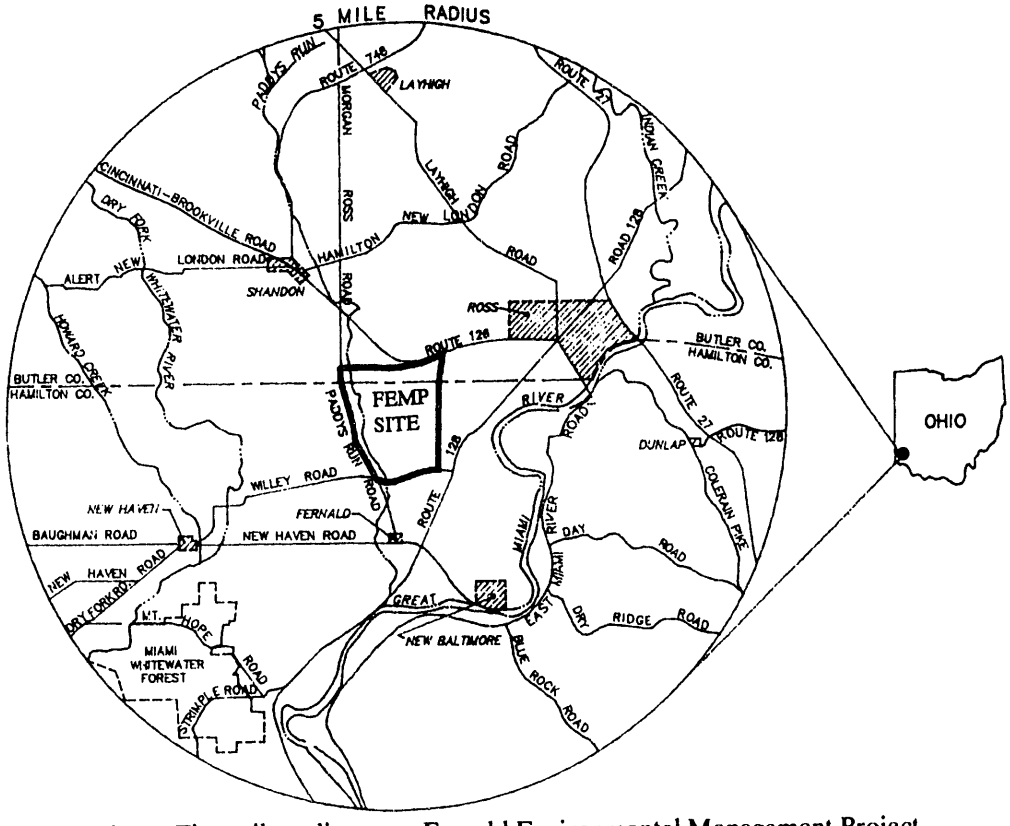


Fig. 1. Five-mile radius map, Fernald Environmental Management Project.

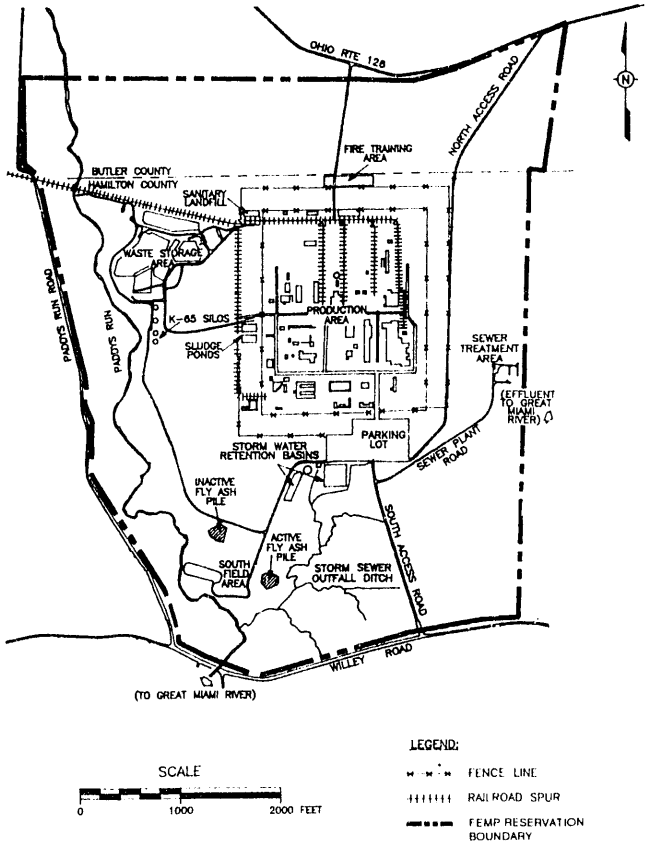


Fig. 2. Major features of the FEMP.

- Operable Unit 1 - Waste Pits 1 through 6, Clearwell, and Burn Pit
- Operable Unit 2 - Other Waste Units
- Operable Unit 3 - Production Area and Suspect Areas
- Operable Unit 4 - Silos 1, 2, 3 and 4
- Operable Unit 5 - All Environmental Media

The EIS will function as the lead NEPA document, in which the sitewide environmental database will be presented and common issues across operable units and cumulative impacts will be discussed. In addition, a NEPA analysis of operable unit impacts will be incorporated into the RI/FS documentation for each operable unit.

NEPA and CERCLA Requirements for Ecological Risk Assessment

NEPA requires evaluation of the environmental impacts of all proposed major federal actions, including remedial actions under CERCLA. Ecological risk assessment is the primary tool for assessing the potential effects of proposed remedial actions on the natural environment. Ecological risk assessment also plays a role in two more specific NEPA concerns, protection of sensitive environments, such as wetlands, and evaluation of cumulative impacts. The latter is of particular concern for the FEMP RI/FS, where separate remedial actions for different operable units may have cumulative effects not accounted for in the individual FS reports.

CERCLA requires that remedial actions at hazardous waste sites be protective of both human health and the environment. EPA guidance (1) requires that the Baseline Risk Assessment, which analyzes the effects of no action at a site, include an environmental evaluation, synonymous with

ecological risk assessment. EPA also requires evaluation of ecological risks in selecting remedial actions. The National Contingency Plan (NCP, 40CFR300) requires, as one of two screening criteria which all remedial actions must meet, that any remedial action must provide for overall protection of human health and the environment. Ecological risk assessment also assists in determining whether potential remedial actions meet the second screening criterion, compliance with applicable, relevant, and appropriate requirements (ARARs) of other federal and state laws. In particular, ecological information may be necessary for determining whether a proposed remedial action complies with location-specific ARARs, such as protection of wetlands. Further, two of the five balancing criteria, which establish the relative effectiveness of alternative remedial actions, require that remedial actions be evaluated on the basis of residual risk to the environment (long-term effectiveness) and environmental impacts of the remedial actions themselves (short-term effectiveness). Ecological risk assessment is thus essential for determining whether proposed remedial actions meet the requirements of the NCP and EPA guidance.

METHODS

Ecological and health risk assessment both consist of four basic steps (2,3): determine the contaminants of potential concern, assess exposure concentrations at likely receptors, determine the toxicity of contaminants at the exposure concentrations, and estimate the consequent risk to the exposed receptors. An additional requirement for ecological exposure assessment is delineating potentially affected habitats and identifying potentially exposed plant and animal species. These steps at the FEMP are described in detail below.

Contaminants of Concern

Chemicals and radionuclides present at the FEMP have been identified by continuing sampling and analysis of contaminants in waste units, ground and surface water, soils, sediments, and biota. Contaminants of potential concern are determined by their presence in waste units or environmental media at concentrations above background, eliminating substances from the list following the rules in EPA's human health evaluation manual (2). The discussion of contaminants of concern is limited in this paper to an example, OU5 (Environmental Media), due to the complexity of potential contaminants at the FEMP.

Exposure Assessment

Habitats and potential ecological receptors at the FEMP were described by Facemire et al. (4). In 1986 and 1987, terrestrial habitats were sampled along permanent transects, and Paddys Run was sampled at a number of fixed-point stations. The results included detailed species lists, abundance and ecological diversity estimates, and studies of population genetics in selected species. Aquatic organisms in the Great Miami River, adjacent to the FEMP, have been characterized by Ohio EPA (5) and Miller et al. (6).

In addition, two studies conducted for the RI/FS, threatened and endangered species surveys and wetlands delineation, focused on potential receptors and habitat descriptions. Remedial actions at the FEMP must comply with the Endangered Species Act, which requires federal agencies to avoid harm to endangered species or their habitats. The FEMP lies within the range of the Indiana bat (Myotis sodalis), a federally listed endangered species, and the cave salamander (Eurycea lucifuga), an Ohio state-listed threatened species. Habitat and population surveys of these organisms were conducted within and adjacent to the FEMP, but no individuals were captured on the property and no critical habitats were identified.

Remedial actions at the FEMP must also comply with ARARs affecting wetlands, for example Executive Order (E.O.) 11990, Protection of Wetlands. Jurisdictional wetlands (7) are identified by hydric soils, which are periodically depleted of oxygen as a result of flooding; hydrophytic plants, which are tolerant of these conditions; and wetlands hydrology, defined by permanent or periodic flooding or soil saturation. Wetlands at the FEMP were identified using the offsite delineation method (7), which relies on topographic maps, aerial photographs, soil surveys, and site-specific vegetation surveys. A limited onsite field reconnaissance was conducted to verify some areas left in question by the offsite delineation.

Exposure concentrations in environmental media were obtained by direct measurement and by fate and transport modeling following EPA guidance (8). Contaminant concentrations in biota were obtained by direct measurement and by modeling uptake. Vegetation, small mammals, and aquatic organisms were analyzed for isotopic uranium, cesium, and strontium. Uranium is the primary contaminant of concern at the site, while cesium and strontium were included because of their ready uptake and concentration by organisms. A subset of these samples was analyzed for nonradioactive contaminants.

Toxicity Assessment

Toxicity of contaminants of potential concern was assessed based on literature values for no effects levels and on regulatory criteria, for example EPA's Ambient Water Quality Criteria (AWQC) (9) and Ohio Water Quality Standards (10). In addition, several site-specific studies were conducted to examine the potential effects of FEMP effluent, soils, and sediments on aquatic organisms.

Runoff and wastewater from plant process operations is collected in a general sump, treated, and discharged under a NPDES permit into the Great Miami River. This effluent, which has an average uranium concentration of 560 pCi/l (11), was tested for acute and chronic toxicity to algae, invertebrates, and fathead minnows, following EPA protocols (12,13). Soils and sediments at the FEMP are contaminated with a variety of substances, principally radionuclides (11,14). In a preliminary study, two soil and two sediment samples were collected based on their relative radionuclide levels, and water-soluble extracts were prepared and tested for acute toxicity following standard protocols (15,16).

The composition of the macroinvertebrate community is a sensitive measure of impacts on water quality. Potentially contaminated runoff from the FEMP drains into Paddys Run, and treated effluent from the facility is discharged to the Great Miami River, as described above. In order to examine potential impacts of this contamination on aquatic organisms, the macroinvertebrate communities in Paddys Run and the Great Miami River were surveyed above, adjacent to, and below the influence of the FEMP. Organisms were sampled both from the natural substrate and via artificial substrate samplers, which were placed in the two streams for six-week periods to

be colonized. The substrates were then retrieved, returned to the laboratory, and all organisms counted and identified.

Risk Characterization

Radiation doses to terrestrial organisms were estimated from tissue uranium concentrations assuming a mean dose of 0.084 rad/year per pCi/g total isotopic uranium, based on a mean energy of 4.5 MeV/decay of isotopic uranium. Uranium concentrations in deer, a representative mammal at the FEMP, were estimated assuming consumption of 1200 kg per year of contaminated forage, with a forage-to-meat transfer factor of 3.4×10^{-4} days per kg (17). Radiation doses to aquatic organisms were estimated from surface water radionuclide concentrations using the constants of Killough and McKay (18) for total internal dose from exposure to the isotopes of uranium and technetium-99. Effects of nonradioactive chemicals in soils on terrestrial organisms were assessed based on measured concentrations in biota and on modeled uptake, comparing uptake to literature values for no effects levels. Effects of chemicals on aquatic organisms were estimated from surface water concentrations, comparing values to literature toxicity values and regulatory standards as described above.

RESULTS

Contaminants of Concern

Radionuclides of potential concern in Operable Unit 5 soils include the isotopes of uranium, cesium-137, radium-226 and -228, strontium-90, technetium-99, and the isotopes of thorium (14). Chemicals detected in terrestrial organisms include aluminum, arsenic, barium, cadmium, lead, mercury, vanadium, and zinc, as well as radionuclides. Organic constituents were analyzed but not detected in biological samples from the FEMP. Constituents of potential concern in surface water include uranium, technetium, and a variety of metals, for example, aluminum and chromium, but no organic chemicals.

Potential Receptors

Facemire et al. (4) described five habitat types at the FEMP: introduced grasslands, pine plantations, deciduous woodlands, riparian woodlands, and an inactive fly ash disposal area. A forested area approximately 50 acres in size in the northern part of the FEMP was delineated as jurisdictional wetland (Fig. 3). The small drainages on-property, not including Paddys Run and the storm sewer outfall ditch, were also delineated as jurisdictional wetlands. A total of 47 species of trees and shrubs, 190 species of herbaceous plants, 20 mammal species, 98 bird species, 10 species of amphibians and reptiles, 23 species of fish, 47 families of benthic macroinvertebrates, and 132 families of terrestrial invertebrates was recorded at the FEMP (4). Ohio EPA collected 76 species of fish from the Great Miami River in their most recent survey (5). No federally listed threatened or endangered species have been observed on the FEMP or in its immediate vicinity.

Exposure Assessment

Total isotopic uranium concentrations in vegetation collected from the FEMP ranged from detection limits of 0.6 pCi/g to 35.5 pCi/g (Table I). Uranium concentrations in soil

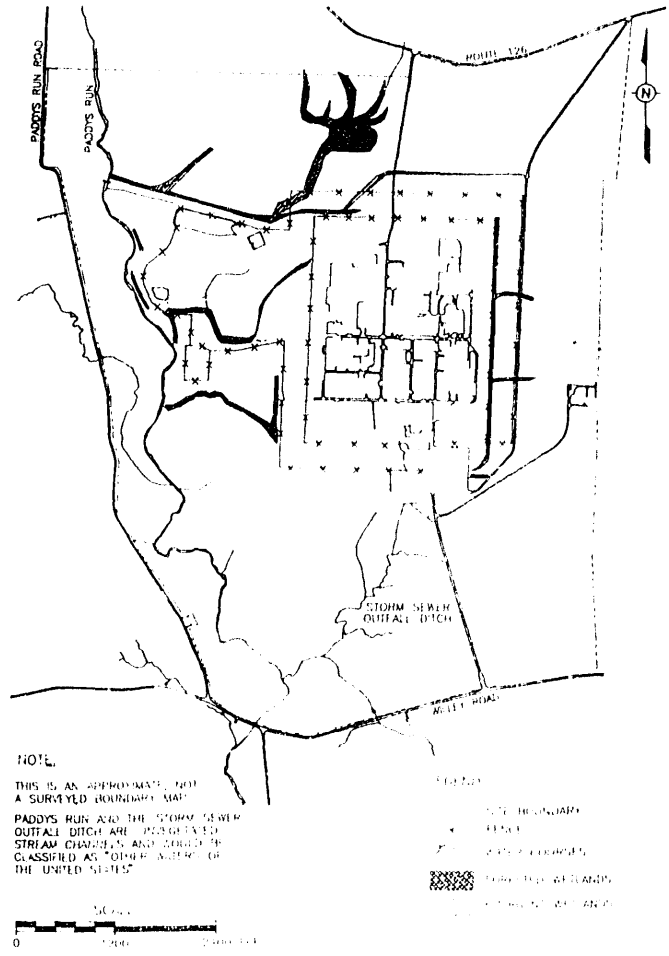


Fig. 3. Approximate boundaries of jurisdictional wetlands and other waters of the United States at the FEMP.

samples collected simultaneously with vegetation ranged from 2.7 pCi/g to 35.6 pCi/g. Cesium and strontium were found less frequently and at lower levels, consistent with uranium being the primary concern at the FEMP. Cesium-137 concentrations in vegetation ranged from detection limits (0.2 to 0.8 pCi/g) to 1.4 pCi/g. Detected strontium-90 concentrations ranged from 0.6 to 0.9 pCi/g, which were within the detection limits, for all samples, of 0.5 to 1.9 pCi/g.

Aluminum concentrations in plants ranged from 18 to 10,600 mg/kg (Table II). Arsenic ranged from less than 3 mg/kg (the detection limit) to 12 mg/kg, and barium ranged from 2.6 to 59.8 mg/kg. Cadmium and lead were detected in grass roots but not in leaves. Mercury ranged from 0.6 to 67.1 mg/kg, and vanadium from nondetected (1 mg/kg) to 20 mg/kg. Zinc ranged from 4.4 to 115 mg/kg.

Uranium was detected in one of nine mammal samples (Table I). Aluminum and mercury were detected in two of four samples, barium in one sample, and arsenic and zinc in all four (Table II). Cadmium, lead, and vanadium were not detected. Low levels of radionuclides were found in aquatic organisms collected from Paddys Run and were detected in only two samples from the Great Miami River (Table I).

Risk Characterization -- Plants

Estimated radiation doses to plants were low compared to those reported to be toxic (19). For example, the maximum radionuclide concentration of 35.5 pCi/g total isotopic uranium in vegetation would result in a radiation dose to plant

TABLE I

Total Isotopic Uranium Concentrations in Soils and Biota at the FEMP

Sample Type	Detection Frequency	Concentration Range (pCi/g)
Soil	28/28	2.7 - 35.6(13.1)[a]
Vegetation	64/96	<0.6[b] - 35.5(5.35)
Paddys Run Fish	3/10	<0.6 - 3.7(1.02)
Great Miami River Fish	0/16	<0.6
Paddys Run Invertebrates	4/5	<0.6 6.4(3.6)
Great Miami River Invertebrates	2/3	<0.6 - 6.5(3.27)
Mammals	1/9	<0.6 - 18.0(2.53)

[a] ( ), arithmetic mean, includes detection limit when appropriate.
[b] Concentration less than stated detection limit.

tissue of approximately 3 rad per year. This is 0.2 percent of the radiation dose of 1460 rad per year reported to reduce the growth of conifers, plants which are particularly sensitive to radiation (19).

Terrestrial plants from the FEMP contained a variety of metals. The maximum aluminum concentrations in FEMP vegetation exceeded reported background concentrations of up to 300 mg/kg (20). However, aluminum toxicity in plants typically occurs in acid soils (pH less than 5)(21), and the pH of soils at the FEMP ranges from about 5.5 to 8.5 (22,23). Arsenic concentrations in FEMP vegetation exceeded the concentrations of 0.01 to 5 mg/kg reported in plants from non-arsenic-rich soils (24). Concentrations of less than 1 mg/kg have been reported to induce signs of toxicity, while a 50 percent reduction in plant growth has been reported in seedlings containing 15 mg/kg arsenic (24). The latter value exceeds the maximum recorded in FEMP vegetation (Table II). Cadmium and zinc concentrations were similar to reported background concentrations of less than 1 mg/kg (25) and 3 to 7 mg/kg (26), respectively. Vanadium was within the 1.0 to 1.6 mg/kg reported in vegetation from uncontaminated sites (27). Vanadium levels in plant roots are typically higher than those in leaves (20), as observed at the FEMP. Vanadium toxicity has been observed in cabbage and bean leaves at 1.2 and 13 mg/kg and in roots from these plants at 265 and 881 mg/kg, respectively (28,29). These concentrations are greater than the maximum concentrations of 1 and 20 mg/kg detected in FEMP grass leaves and roots, respectively (Table II). Lead concentrations in vegetation were below the several hundred mg/kg required to induce phytotoxic effects (30). Background concentrations of mercury in vegetation have been reported to be approximately 10 mg/kg dry weight (31). Only the maximum concentration at the FEMP exceeded this value. However, since mercury is phytotoxic in very small concentrations (32), it is possible that the maximum mercury concentration in FEMP vegetation could cause toxic effects to plants. Background and toxicity values for barium were not found in the literature. Because the chemical behavior of barium is similar to calcium, the relatively low barium concentrations of 2.6 to 59.8 mg/kg in FEMP vegetation are probably not toxic to plants.

Although these data suggest that some metal concentrations in FEMP vegetation are consistent with values reported to be toxic, the ecological survey by Facemire et al. (4) reported no evidence that vegetation on the property was being stressed by FEMP constituents.

Risk Characterization -- Terrestrial Animals

The estimated dose to deer grazing exclusively on the most contaminated vegetation on the FEMP, 35.5 pCi/g, was approximately 3 mrad per year. Radiation exposures causing detectable chronic to acute effects in mammals and birds are several hundred rads (33,34,35). The dose to a mammal with a whole body concentration of 18.0 pCi/g total isotopic uranium (Table I) was estimated at approximately 2 rad per year.

Deer grazing on the FEMP could also be exposed to aluminum, arsenic, barium, mercury, and zinc (Table II). Background concentrations of arsenic in biota are typically less than 1 mg/kg wet weight (36), similar to FEMP levels, which are based on dry weight. A liver arsenic concentration that resulted in the death of a white-tailed deer was 19 mg/kg

TABLE II

Metal Concentrations in Vegetation and Mammals on the FEMP (mg/kg)

Metal	Grass Leaves		Grass Roots		Mammals	
	Detection Frequency	Concentration Range	Detection Frequency	Concentration Range	Detection Frequency	Concentration Range
Arsenic	5/5	5 - 13(9.2)[a]	4/5	<3[b] - 11(8.0)	4/4	8 - 20(14.5)
Aluminum	5/5	18 - 4950(1577)	5/5	1680 - 10600(5146)	2/4	<4 - 42(14.5)
Barium	5/5	2.6 - 12.5(6.0)	5/5	17.5 - 59.8(37.1)	1/4	<0.2 - 1(0.4)
Cadmium	0/5	<0.5	3/5	<0.5 - 0.9(0.7)	0/4	<0.5
Lead	0/5	<3	4/5	<3 - 12(6.4)	0/4	<3
Mercury	5/5	0.5 - 15.3(5.2)	5/5	0.6 - 67.1(15.3)	2/4	0.1 - 0.24(0.16)
Vanadium	1/5	<1 - 1(1.0)	4/5	<1 - 20(7.6)	0/4	<1
Zinc	5/5	4.4 - 13.0(8.9)	5/5	8 - 115(44.4)	4/4	10.9 - 51.8(33.3)

[a] ( ), arithmetic mean, includes detection limit when appropriate.
[b] Concentration less than stated detection limit.

fresh weight (36), approximately an order of magnitude lower than the 20 mg/kg dry weight in the liver of an FEMP deer (Table II). Chronic doses of 1 to 10 mg arsenic per kilogram body weight can induce toxic responses, as can dietary levels of 5 to 50 mg arsenic per kilogram diet (36). It is therefore possible that toxic effects could occur if deer exclusively ingested leaves from the areas sampled onsite where arsenic concentrations ranged from 5 to 13 mg/kg. However, there is no direct evidence that arsenic has caused any toxic effects on mammals at the FEMP. Mercury was detected in two of four mammal samples at less than 1 mg/kg, the concentrations reported as the background concentration in biota (31).

The highest aluminum concentration in the four mammal samples, 42 mg/kg (Table II), was much lower than the 300 mg/kg tolerated by rats over a 10-day period (37). The 1 mg/kg barium detected in one mammal sample was less than one percent of the lethal dose of 250 mg/kg reported by Venugopal and Luckey (38). Zinc concentrations in mammal samples from the FEMP were within the range of 67 to 120 mg/kg recorded in animals from uncontaminated areas (39). The levels of aluminum, barium, and zinc in vegetation and mammal samples from the FEMP are therefore unlikely to be toxic to mammals.

Risk Characterization -- Aquatic Organisms

Total estimated internal radiation doses to aquatic organisms in Paddys Run ranged from 0.1 to 10 rad per year, with a dose to muskrats of 0.015 rad per year (Table III). Comparable estimates for the Great Miami River were 0.039 to 3.6 rad per year, with a dose to muskrats of 0.006 rad per year. Estimated doses to aquatic organisms exposed to contaminated surface water from drainages on site ranged from 40 to 4000 rad per year at the maximum uranium level of 7.07 mg/l, but doses at the average concentration were ten times lower (Table III). EPA (40) reported that the lowest chronic radiation doses causing deleterious effects on fish, for example reduced fecundity or increased embryo mortality, were 0.59 to 10 rad per day. Thus only the highest dose rates reported in Table III approach the level at which the most sensitive aquatic organisms may experience reproductive effects. Further, flow in on-property drainages is intermittent and they do not provide significant habitat for aquatic organisms. Accumulation of radionuclides in tissue is an unlikely source of radiation exposure of aquatic organisms. The maximum uranium concentration of 6.5 pCi/g recorded in a macroinvertebrate sample would result in an internal dose of 0.54 rad per year.

Maximum and average concentrations of the chemicals in water samples collected in OU5 were compared with EPA criteria and concentrations causing toxic effects in the cladoceran Daphnia magna, a sensitive and widely used test species. The AWQC or the 50 percent lethal dose to D. magna was exceeded only by the maximum aluminum concentration in surface water (Table IV).

The results of effluent toxicity testing suggest that FEMP effluent would not be toxic to aquatic organisms following dilution in the Great Miami River, although slight enrichment of algal growth is possible. Toxicity was observed in 4 of 25 tests (five rounds of five test types each). The lowest effluent concentration causing toxicity was 6.25 percent, compared to an estimated 0.8 percent following dilution in the river. Preliminary results of macroinvertebrate surveys indicate that the FEMP has no negative impact on the macroinvertebrate communities of Paddys Run or the Great Miami River. A sampling site immediately downstream from the FEMP outfall in the river may be enriched by nutrients in the effluent, consistent with the observation that effluent may stimulate algal growth in laboratory toxicity tests. Soil and sediment toxicity tests showed that substances leachable from soils and sediments with a range of total isotopic uranium from 1.8 to 115 pCi/g had no acute effects on aquatic organisms.

CONCLUSIONS

A preliminary assessment suggests that the radionuclide contamination in OU5 at the FEMP does not pose a hazard to terrestrial organisms. Radionuclides in on-property drainages could affect reproduction in aquatic organisms exposed to the maximum concentrations observed. However, average on-property uranium concentrations were ten times, and off-property concentrations a thousand times, lower than the maxima. It is therefore unlikely that organisms in Paddys Run and the Great Miami River are routinely exposed to toxic

TABLE III

Estimated Internal Radiation Doses to Aquatic Organisms in Operable Unit 5 Surface Waters
Total Internal Dose (rad/y)[a]

Water Body	Aquatic Plants	Invertebrates	Fish	Muskrats
Paddys Run[b]	10	1	0.1	0.015
Great Miami River[c]	3.6	0.36	0.039	0.006
Other Areas[d] Maximum	4,000	400	40	5.8
Other Areas[e] Average	430	43	4.3	0.6

[a] Calculated from dose coefficients of Killough and McKay (18)
[b] Doses at the combined maximum concentrations of U-234 (5.0 pCi/l) and U-238 (6.8 pCi/l) recorded in Paddys Run during RI/FS sampling.
[c] Doses at the combined maximum concentrations of U-234 (2.2 pCi/l), U-238 (2.0 pCi/l) and Tc-99 (95.9 pCi/l) recorded in the Great Miami River during RI/FS sampling.
[d] Dose at the maximum total uranium concentration of 7,069 ug/l recorded in FEMP drainages. 60% of total was assumed to be U-238 and 40% assumed to be U-234, approximating percentages in Paddys Run samples.
[e] Dose at the average total uranium concentration of 766 ug/l recorded in FEMP drainages. U-238 and U-234 percentages calculated as in footnote (d).

TABLE IV

Aquatic Toxicity of Chemicals of Concern in Surface Water in Operable Unit 5 of the FEMP (ug/l)

Chemical	Maximum Concentration	Average Concentration	Ambient Water Quality Criterion[a]	Daphnia magna LC_{50} (Reference)
Paddys Run				
Aluminum	451	164.8	---	300 (41)
Beryllium	1.2	1.2	5.3[b]	1,000 (42)
Chromium	24.3	14.3	11[c], 210[d]	112 (43)
Uranium	17.7	10.7	---	6,000 (44)
Vanadium	17.7	12.3	---	
Zinc	36.8	24.0	47	120 (45)
Great Miami River				
Arsenic	6.0	3.4	48[b]	5,300 (45)
Uranium	7.0	2.7	---	6,000 (44)
Other Areas				
Uranium	7,069	766	---	6,000 (44)

[a] Criteria for chronic toxicity, from Ref. (9).
[b] Lowest observed effect concentration.
[c] Criterion for hexavalent chromium.
[d] Criterion for trivalent chromium.

concentrations of radionuclides. Maximum arsenic levels in vegetation collected from the FEMP are consistent with values reported in the literature to be toxic to plants. However, signs of stress have not been observed in vegetation on or adjacent to the FEMP. Similarly, arsenic levels in plants and animals collected from the FEMP could be toxic to terrestrial mammals under worst-case conditions, but toxicity has not been observed in the field. Current and planned sampling of soils will clarify whether nonradioactive constituents constitute a hazard to terrestrial organisms at the FEMP. The maximum concentrations of aluminum observed in OU5 surface waters are comparable to those reported to cause chronic to acute effects in aquatic organisms. Macroinvertebrate communities in streams adjacent to the FEMP do not exhibit any adverse effects of exposure to FEMP constituents. Uncertainties exist in this analysis due to a lack of knowledge of the effects of low level radiation and complex toxicant mixtures on ecological receptors. Complex chemical mixtures, such as those present at the FEMP and other DOE hazardous waste sites, may cause effects different than those predicted from studies of the effects of single toxicants, due to synergistic or antagonistic effects. Assessments of ecological risk based on such studies, for example the Daphnia magna data and the EPA criteria cited above, should therefore be treated with caution. Given these caveats, this preliminary assessment and others in progress suggest that present ecological risks of the FEMP are low and are likely to be associated primarily with nonradiological effects. However, if no remedial action is taken, long-term ecological risks could be substantial as a result of failure of containment systems or penetration of wastes by plants and burrowing animals.

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ASSESSING EXPOSURES AND RISKS IN HETEROGENEOUSLY CONTAMINATED AREAS: A SIMULATION APPROACH

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ABSTRACT

The U.S. Department of Energy (DOE) is responsible for cleanup activities at a number of facilities under its Environmental Restoration and Waste Management Program. The major goals of this program are to eliminate potential hazards to human health and the environment that are associated with contamination of these sites and, to the extent possible, make surplus real property available for other uses. The assessment of potential baseline health risks and ecological impacts associated with a contaminated site is an important component of the remedial investigation/feasibility study (RI/FS) process required at all Superfund sites. The purpose of this paper is to describe one phase of the baseline assessment, i.e., the characterization of human health risks associated with exposure to chemical contaminants in air and on interior building surfaces at a contaminated site. The model combines data on human activity patterns in a particular microenvironment within a building with contaminant concentrations in that microenvironment to calculate personal exposure profiles and risks within the building. The results of the building assessment are presented as probability distribution functions and cumulative distribution functions, which show the variability and uncertainty in the risk estimates.

INTRODUCTION

A hazardous waste site can pose threats to human health via transport of on-site contaminants through environmental media to human receptors. The U.S. Environmental Protection Agency (EPA) has developed a framework for assessing these potential threats in order to support cleanup decisions on the basis of risk at Superfund sites. This framework consists of a baseline risk assessment, which is prepared to:

- Estimate risks that could occur either now or in the future if no cleanup action were taken at the site;
- Help focus the need for cleanup by highlighting the environmental media and locations that are associated with unacceptably high risk estimates, as well as those that are not;
- Provide a basis for determining residual levels of chemicals that can remain on-site without adversely impacting human health;
- Permit risk-based comparisons between various alternatives considered for site cleanup (by identifying incremental protectiveness relative to the baseline case); and
- Provide relative consistency with the evaluation of human health threats associated with other hazardous waste sites.

In preparing the baseline risk assessment for a site, the relationship between the sources of a pollutant and the potential receptors are developed through an exposure assessment process. Quantifying human exposures to contaminants in the environment requires information on (a) contaminant sources and strengths, (b) fate and transport of these substances from the source to the human receptor(s), and (c) receptor activity patterns. When assessing exposures associated with Superfund sites, the first two factors may be well characterized because of the extensive sampling that is often conducted as part of the Superfund decision-making process. Receptor activity patterns, however, are usually less well defined. Only a few exposure scenarios are typically considered in a baseline risk assessment. These scenarios often use set values for parameters such as the frequency and duration of exposure for each receptor. Furthermore, few sites are uniformly contaminated, and they may include large areas that are free of contamination. Hence, it is possible that an individual traversing a site might come in contact with areas that would contribute little to his or her total exposure and risk. Research indicates that, in fact, receptor dynamics and microenvironment concentrations can be important to the appropriate characterization of human exposures (1-5).

The results of an exposure assessment are combined with toxicity information to provide an estimate of the health risks (carcinogenic effects) and health hazards (noncarcinogenic effects) for a site. This impact characterization forms the basis for recommending cleanup criteria and focuses the selection of remedial action alternatives. Thus, the uncertainty associated with exposure estimates at Superfund sites can directly affect the ultimate disposition of the site and potential cleanup costs.

Cleanup activities are currently being conducted by the U.S. Department of Energy (DOE) at the Weldon Spring site near St. Louis, Missouri. This site consists of a chemical plant area that has been inactive for more than 20 years and a noncontiguous quarry that was used for waste disposal. The

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Army produced nitroaromatic explosives at the 217-acre chemical plant area during the 1940s, and radioactive materials of the uranium and thorium series were processed there by DOE's predecessor during the 1950s and 1960s. The site is chemically and radioactively contaminated as a result of the past processing and disposal activities. In 1989, the EPA included the chemical plant area in its National Priorities List. Hence, site cleanup is being conducted in accordance with EPA's Superfund process under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), as amended. Site activities are also being conducted in compliance with the National Environmental Policy Act (NEPA).

An integral part of the CERCLA/NEPA process is the preparation of a comprehensive baseline assessment of human health and environmental impacts to support decision making for site cleanup. This paper focuses on one component of the baseline assessment prepared for the site in order to highlight the potential impact on exposure estimates that result from varying the exposure assumptions. This component is the characterization of human health risks associated with polychlorinated biphenyl (PCB) exposures in one of the contaminated buildings. Because of the heterogeneous nature of the PCB contamination, a nonstandard approach was used to account for variability in possible exposures. This paper describes the mathematical model that was used to quantify the human exposures and health risks associated with ingestion, inhalation, and dermal absorption of PCB's in air, dust, and spills on floors and benches in the building. This model explicitly accounts for contaminant heterogeneity and simulates the movement of a person through several microenvironments within the building. By this approach, data on human activity patterns relative to the time spent in a particular microenvironment can be combined with contaminant concentrations therein to calculate personal exposure profiles and potential risks.

METHODOLOGY

The Weldon Spring site is located in a rural area surrounded by federal and state land, including wildlife areas that total almost 7,000 ha. The site is fenced, and access by the general public is restricted. Nevertheless, potential exposures of the general public are evaluated by assuming that a hypothetical adolescent trespasser enters the building and is exposed either while walking or playing. The potential routes of exposure are inhalation of airborne particulates, incidental ingestion of residues and dust, and dermal contact with residues and dust.

Exposure Point Concentrations

The contaminated building is a 60-m by 110-m, one-story cinderblock structure that is divided in two by a wall that extends from north to south. The west half of the building is subdivided into small work bays and offices; the east half contains a main storage area and several smaller rooms that formerly housed an automotive repair shop, rest rooms, decontamination areas, and a shipping dock. Sampling for PCBs was conducted using two methods: (1) swipe sampling of floor and bench surfaces and (2) bulk sampling of spill residues and dusts. The biased sampling strategy focused on areas where PCBs were expected to be found. Concentrations in 22 surface swipe samples ranged from about 2 to $< 29{,}000$ $\mu g/100\ cm^2$; however, almost 40% of the samples were below the analytical detection limit (DL) of 1 $\mu g/100\ cm^2$. Concentrations in 11 bulk samples ranged from about 40 to 13,000 ppm, with 15% below the DL of 2 to 5 ppm. About 85% of the building was considered to be uncontaminated with PCBs.

Exposure point concentrations were estimated from these data by developing a strategy to address the non-detects (NDs), i.e., samples for which PCB concentrations were below the DL. Several statistical methods have recently been recommended for substituting values for the NDs (6-8), and these methods have been evaluated for application to soil data from the site by Özkaynak et al. (9). From this evaluation, it was determined that the maximum likelihood estimator method was suitable for most data sets for which the NDs ranged from a few percent to 50%. However, in this case, we found that replacing the NDs for the building PCB data with one-half the DL was adequate and did not introduce much bias in estimating the exposure point concentrations. This was largely due to the highly skewed distribution of PCB concentrations in the building samples. Because the PCB contamination is limited to several discrete areas within the building, the measured value at each of these areas was used as a location-specific exposure point concentration.

No air samples were taken for PCBs; thus, a dust resuspension model (10) was used to estimate PCB concentrations in air that could result from the resuspension of contaminated residue and dust during human activity in the building. Airborne concentrations of PCBs were estimated for each contaminated area as follows:

$$C_{air} = \frac{C_{sur}\,\Omega\,A}{V\,a} \qquad \text{(Eq. 1)}$$

where C_{air} is the PCB concentration in air (mg/m^3); C_{sur} is the surface contamination level (mg/m^2); Ω is the fraction of dust resuspended per hour (h^{-1}); A is the area of contamination within a room (m^2); V is the volume of the room (m^3); and "a" is the number of air exchanges per hour (h^{-1}).

Intake Equations

Human intakes of PCBs via various pathways -- that is, PCB exposures normalized for time and body weights -- were estimated consistent with EPA guidance (11). Intakes resulting from exposures via the air pathway were estimated as follows:

$$I_{ihl} = \frac{(C_{air})\,(IR_{ihl})\,(PM_{10})\,(ET)\,(EF)\,(ED)}{(BW)\,(AT)} \qquad \text{(Eq. 2)}$$

where I_{ihl} is the normalized intake for inhalation of resuspended contaminated dust (mg/kg-d); IR_{ihl} is the inhalation rate (m^3/h); PM_{10} is the fraction of resuspended dust with an aerodynamic mean diameter of less than 10 μm; ET is the exposure time (h/event); EF is the exposure frequency (events/yr); ED is the exposure duration (yr); BW is the body weight (kg); and AT is the averaging time (d).

Because the extent of PCB contamination was characterized by both bulk sampling and surface swipe methods, two algorithms were needed to estimate intakes resulting from incidental ingestion of contaminated residues. For data reported in ppm (i.e., bulk sample data), intakes were estimated following EPA guidance (11):

$$I_{ing} = \frac{(C_{rsd})\,(IR_{rsd})\,(FI_{rsd})\,(ET)\,(EF)\,(ED)\,(CF_1)}{(BW)\,(AT)} \quad \text{(Eq. 3)}$$

where I_{ing} is the intake for incidental ingestion of residue (mg/kg-d); C_{rsd} is the PCB concentration of the residue (mg/kg); IR_{rsd} is the residue ingestion rate (mg/h); FI_{rsd} is the fraction ingested from the contaminated residue; and CF_1 is a unit conversion constant (10^{-6} kg/mg). However, for data reported in μg/100 cm^2 (i.e., surface swipe data), the EPA guidance needs to be modified; for this case, intakes were calculated as follows:

$$I^*_{ing} = \frac{(C_{sur})\,(SA^*)\,(FR)\,(ET)\,(EF)\,(ED)\,(CF_2)}{(BW)\,(AT)} \quad \text{(Eq. 4)}$$

where I^*_{ing} is the intake for incidental ingestion of residue (mg/kg-d); SA^* is the exposed skin surface area that could come in contact with the mouth (cm^2/h); FR is the fraction of contaminant removed during contact; and CF_2 is a unit conversion constant (10^{-4} m^2/cm^2).

Similar to the ingestion pathway, two approaches were used to estimate intakes from skin absorption as a result of dermal contact with contaminated residue and dust. For data reported in μg/g (bulk samples), intakes were estimated following EPA guidance (11):

$$I_{der} = \frac{(C_{rsd})\,(SA)\,(AF)\,(AB)\,(EF)\,(ED)\,(CF_1)}{(BW)\,(AT)} \quad \text{(Eq. 5)}$$

where I_{der} is the intake via dermal absorption (mg/kg-d); SA is the exposed skin surface area (cm^2/event); AF is the residue-to-skin adherence factor (mg/cm^2); and AB is the absorption factor. However, for data reported in μg/100 cm^2 (surface swipes), intakes were estimated as follows:

$$I^*_{der} = \frac{(C_{sur})\,(SA)\,(FR)\,(AB)\,(EF)\,(ED)\,(CF_2)}{(BW)\,(AT)} \quad \text{(Eq. 6)}$$

where I^*_{der} is the intake via dermal adsorption (mg/kg-d).

Consistent with EPA guidance (11), health risks are assessed by estimating the reasonable maximum exposure (RME) expected to occur at a site. The RME is estimated for individual pathways and is combined across pathways as appropriate. Scenario-specific assumptions and intake parameters used to estimate the RME are given in Table I (12-20). In general, the parameter values selected are the 90th or 95th percentile upper-bound value of the parameter cumulative distribution; however, for some parameters, the 50th percentile value is recommended (11). The input parameters given in Table I have varying degrees of uncertainty associated with them. In addition, those parameters pertaining to exposure frequency and duration are often subjective judgments that are based on area demographics. Nevertheless, the RME approach ensures that the resultant health risk estimates will be conservative.

Stochastic Approach for Estimating Contaminant Intakes and Risk

The PCB contamination within the building is limited to a few discrete locations that represent only about 15% of the total building area. Because of the highly skewed distribution of exposure point concentrations in the building, a nonstandard approach was used for quantifying possible PCB exposures in addition to following the standard EPA approach. That is, risks from PCB exposures were first estimated on the basis of both the arithmetic mean of the exposure point concentration and the upper 95% confidence limit on the arithmetic mean of the exposure point concentration (UL_{95}), as recommended by the EPA (11, 21). The underlying assumption in this approach is that an individual will always come in contact with a contaminated area during each RME event. However, in this specific case, 85% of the building is free of contamination and, thus, a trespasser is more likely to come in contact with an uncontaminated area than a contaminated one.

For comparison, a stochastic model was developed to explicitly account for the heterogeneous nature of the PCB contamination as well as the uncertainty in defining the time spent at any specific exposure point. Equations (2) through (6) were implemented with the Monte Carlo spreadsheet program @RISK(22) to simulate the movement of a hypothetical trespasser through several microenvironments within the contaminated building. In the simulation, it was assumed that the trespasser comes in contact with a discrete area inside the building for 1 hour during each of five visits per year over a 10-year period. This interior area, i.e., the exposure point, was selected on the basis of the probability of entering a given room and the probability of coming in contact with a contaminated area within that room. (Only some of the rooms in the building are contaminated with PCBs, and not all surfaces in these rooms are contaminated.) The intakes estimated for each of the 50 visits were then summed to give the total intake for the trespasser scenario. For the modeling effort, a number of 50-visit runs (each of which constituted a single iteration) were combined to form a model simulation. Because cumulative exposure was estimated over a 50-visit scenario, the assumption that the trespasser would spend the entire hour of any given visit at one location does not bias the estimate of total exposure. Conceptually, the trespasser could spend 1/50th of 1 hour at each of the 50 locations selected in any iteration of a simulation.

As previously noted, substantial uncertainty can exist for each of the intake parameters given in Table I. Clearly, the assumptions used for these parameters are based on judgment and are inherently uncertain. In addition to exposure point concentration, the total extent of exposure at an exposure point is defined by three parameters: exposure time, frequency, and duration. The values selected for the length of each visit to the building and the number of visits per year are considered to be reasonable on the basis of current land use and demographics of the surrounding area. Security at the site reduces the likelihood of more frequent entry and limits the length of time a trespasser could remain on-site. The exposure duration of 10 years is considered reasonable for adolescent trespassing behavior, and it is also consistent with the time interval projected for site cleanup (which is already under way). This paper focuses on uncertainty related to the number of contaminated areas contacted during each visit and the time spent at a specific area during the visit.

The results of the exposure assessment are combined with toxicological information to provide an estimate of incremental cancer risk and the potential for noncarcinogenic health effects. Carcinogenic risks are assessed in terms of the increased probability that an individual will develop cancer over the course of a lifetime. To estimate incremental cancer risk, the intakes calculated with Eqs. (2) through (6) are multiplied by chemical-specific slope factors. Oral and inhalation slope factors for several Group A, B1, and B2 carcinogens have

TABLE I

Input Parameters for PCB Exposure Assessment

Variable	Parameter Description	Value	Reference
AT	Averaging time, period over which exposure is average	3.65×10^3 d (noncarcinogens) 2.56×10^4 d (carcinogens)	11
AB	Absorption factor[a]	0.032	12
AF	Residue to skin adherence factor	2.77 mg/cm^2	11
BW	Body weight, adolescent[b]	50 kg	13,14
ED	Exposure duration	10 yr	c
EF	Exposure frequency	5 events/yr	c
ET	Exposure time	1 h/event	c
FI_{rsd}	Fraction ingested from contaminated residue	1	c
FR	Fraction of contaminant removed during dermal contact	0.1	c
IR_{ihl}	Inhalation rate	1.2 m^3/h	15
IR_{rsd}	Residue ingestion rate[d]	10 mg/h	11
a	Number of air exchanges per hour	0.5 h^{-1}	c
Ω	Fraction of dust resuspended per hour[e]	10^{-4} h^{-1}	10
SA	Exposed skin surface area[f]	2,800 cm^2/event	13
SA*	Exposed skin surface area that could come in contact with the mouth[g]	475 cm^2/event	c
AE_{orl}	Oral absorption efficiency	0.9516	
SF_{ihl}	Inhalation slope factor	7.7 (mg/kg-d)$^{-1}$	17
SF_{orl}	Oral slope factor	7.7 (mg/kg-d)$^{-1}$	18
SF_{der}	Dermal slope factor[h]	8.7 (mg/kg-d)$^{-1}$	11
RfD_{orl}	Inhalation reference dose	8.6×10^{-7} mg/kg-d	19
RfD_{orl}	Oral reference dose	1×10^{-4} mg/kg-d	20
RfD_{der}	Dermal reference dose[h]	9×10^{-5} mg/kg-d	11

[a] Derived from data in Refs. 16 and 17.
[b] Estimated average body weight for an adolescent over the 10-year exposure period.
[c] Authors' best professional judgment considering scenario-specific and site-specific conditions.
[d] The EPA-recommended value of 100 mg/d adjusted to account for the fact that a receptor may be present at a contaminated area for only a certain portion of the exposure period.
[e] Assumes moderate activity within the building.
[f] Time-weighted average based on estimate of skin surface area and consideration of the type of clothing that would be worn during the exposure event.
[g] Derived from data for the surface area of a hand in Ref. 13.
[h] $SF_{der} = SF_{orl}/AE_{orl}$; $RfD_{der} = RfD_{orl} \times AE_{orl}$.

been derived by EPA and represent the lifetime cancer risk per milligram of contaminant intake per kilogram body weight, assuming that the exposure occurs over a 70-year lifetime. With some qualification (depending on available toxicological data), dermal slope factors can be estimated by dividing the oral slope factor by the oral absorption efficiency (11). For Superfund sites, the EPA has identified incremental lifetime cancer risks in the range of 10^{-4} to 10^{-6} (and lower) to be "acceptably protective" (23).

The measure used to describe the potential for the occurrence of noncarcinogenic effects in an individual is not expressed in probabilistic terms. Rather, these effects are evaluated by dividing the pathway-specific intake over a specified period of time by the EPA-established reference dose (RfD) for a similar exposure period. This ratio is termed the "hazard quotient" for a contaminant. For multiple chemical exposures and/or pathways, the individual hazard quotients are summed to determine an overall "hazard index." This hazard index approach could, however, overestimate the potential for adverse health effects for compounds that affect different target organs, do not induce the same type of effect, or do not act by the same mechanism. Thus, this method is only used for screening purposes. A second-stage analysis is conducted to segregate the effect and mechanism of action so

that appropriately grouped contaminants can be considered together. Dermal RfDs can be estimated, again with qualification, by multiplying the oral RfD and the oral absorption efficiency (11). A hazard index of less than one has been identified by EPA as being "acceptably protective" for Superfund sites (11, 23). Route-specific slope factors and RfDs used in this analysis are given in Table I.

RESULTS

Results from 100 simulations of 500 iterations indicate that the incremental cancer risk estimated from the mean exposure estimate of each simulation ranged from 4×10^{-6} to 8×10^{-5}; the mean risk of the 100 simulations was 1×10^{-5}. The risk calculated from the arithmetic mean of the exposure point concentration was 1×10^{-4}, an order of magnitude higher than that determined by the stochastic approach. The 95% upper-bound value of the incremental cancer risk estimated from the cumulative distributions ranged from 2×10^{-6} to 1×10^{-4}, and the mean upper-bound value for the 100 simulations was 9×10^{-5}. The risk calculated with the UL_{95} approach was 4×10^{-4}, a factor of 4 higher than that determined by the stochastic approach.

For noncarcinogenic effects, the hazard index estimated from the mean exposure estimate of each simulation ranged from 0.4 to 1; the mean hazard index of the 100 simulations was 0.7. However, the hazard index calculated from the arithmetic mean of the exposure point concentration was about 1. The 95% upper-bound value of the hazard index from the cumulative distributions ranged from about 0.2 to 10, and the mean value for the 100 simulations was about 9. The hazard index calculated using the UL_{95} was 4, which is less than half the value obtained using the average 95% upper-bound value predicted from the 100 separate simulations.

Although the values for incremental cancer risk and hazard index estimated from either the arithmetic means or the 95% upper-bound values predicted from either approach are within a factor of 10, it is obviously useful to characterize the entire distribution. Figure 1 shows a typical example of a cumulative distribution plot for the incremental cancer risk from one simulation. In this case (and in others examined), the distribution of risk is highly skewed because of contaminant heterogeneity. The risks estimated from the distribution values in the 90 to 99% range are very sensitive to the percentile selected. For the case shown in Fig. 1, the 95% upper-bound value of risk from the distribution is 1×10^{-4} whereas the 94% upper-bound value is 3×10^{-6}. That is, the estimate of risk decreased by a factor of about 30, with a 1% decrease in the cumulative percent at which the risk was evaluated. The results were similar for other simulation runs.

Results for 10 of the 100 simulation runs for estimating incremental cancer risk are presented in Fig. 2. In this example, the estimated mean values of the distributions from each simulation are relatively stable, with a coefficient of variation (CV) of about 30%. However, significant fluctuations can occur in the estimate of the 95% upper-bound value of the distribution, with the CV increasing to about 70% because of the highly skewed data set.

Increasing the number of simulations from 10 to 50 or 100 can significantly reduce the CV to about 15% for the mean and about 30% for the 95% upper-bound value.

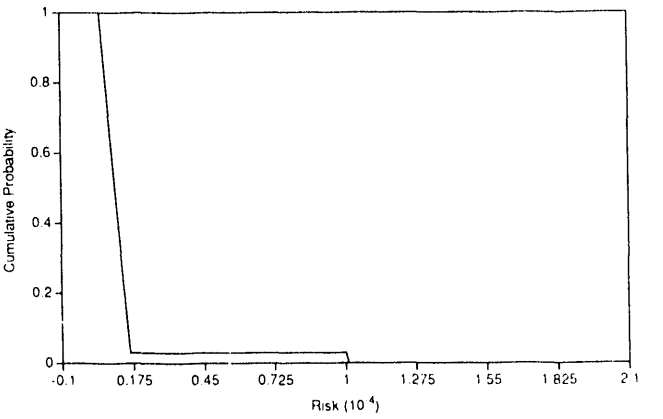


Fig. 1. Cumulative distribution plot of incremental cancer risk from one 500-iteration simulation run.

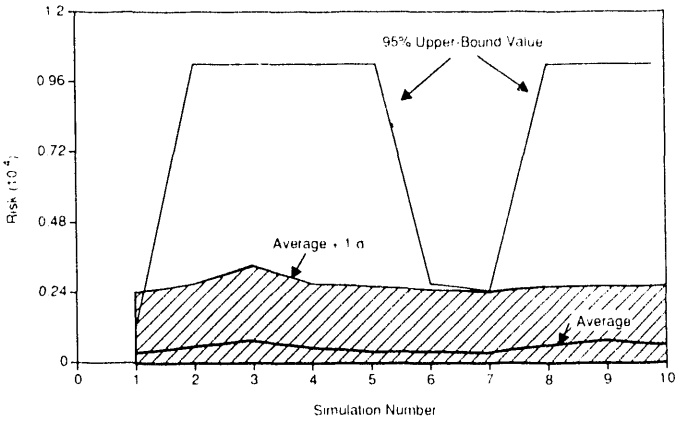


Fig. 2. Incremental cancer risk predicted from ten 500-iteration simulation runs.

CONCLUSIONS

From this analysis, we conclude that simulation methods can be very helpful in understanding potential variability in risk estimates when dealing with stochastic processes that are complicated and involve data that are not normally distributed. This is especially true when the exposure scenarios that are being modeled involve a relatively small number of potential encounters with source(s) of contamination; in such cases, using the central limit theorem and relying on the analytical solutions may be inappropriate. Moreover, numerical solutions, like those presented here, offer the advantage of readily incorporating parameter uncertainties, varying model inputs, and explicitly characterizing the nature (stability) of the various percentiles that may be considered to predict health risks. Our analysis did not indicate a substantial difference between the 95% upper-bound value of the predicted risk distribution and the simpler, EPA-recommended approach for calculating the RME risks, which is based on the upper 95% confidence limit of the arithmetic average contaminant concentration. However, the uncertainties associated with both of these estimates were found to be quite significant.

Using the stochastic model and implementing Monte-Carlo techniques, we were able to estimate the magnitude of

these prediction errors and to show that they were due primarily to the unique exposure conditions that exist inside the site buildings. We note, however, that such widely differing conditions of contamination and potential exposures are not that unusual. That is, contaminant concentrations in other media (e.g., soil) and the potential for human contact with contaminants in these media also typically require dealing with data that are widely and nonuniformly distributed. As demonstrated by the application presented in this paper, stochastic methods can be applied to predict the full distribution of health risks and associated uncertainties for receptors exposed to contaminants near a Superfund site. The methodologies presented in this paper can be used to address contaminant heterogeneity and receptor dynamics for discrete areas of contamination, as well as for an entire site. The resultant information, coupled with data from the application of a geographical information system, can provide the remedial action decision maker with a better picture of the distribution of potential risk at a site. This understanding may help to (1) prioritize site remedial actions, (2) focus cleanup activities on the locations that may present the greatest risk, and (3) lead to more efficient use of the funds available for remedial action activities.

ACKNOWLEDGMENTS

The work was supported, in part, by the U.S. Department of Energy, Office of Environmental Restoration and Waste Management, under Contract W-31-109-Eng-38.

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REMEDIAL INVESTIGATION/FEASIBILITY STUDY RISK ASSESSMENTS AT A SUPERFUND MIXED WASTE SITE

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ABSTRACT

This paper presents lessons learned during EPA and DOE review of RI/FS risk assessments for the Fernald Environmental Management Project (FEMP). It was found that various sensitive issues are difficult to resolve and have the potential to slow down the approval of all RI/FS documents. Some of the major sensitive topics are: background contaminant concentrations; fate and transport model, parameters; sensitive subpopulations; future land use; institutional controls; radiation slope factors; additive toxic effects; basis for remediation goals. The topics are presented along with the current status of their resolution.

INTRODUCTION

While performing one of the first CERCLA-driven large scale remediation efforts at a Department of Energy (DOE) facility, several risk assessment issues were identified as sensitive issues over which the DOE and the Environmental Protection Agency (EPA) would eventually need to negotiate and agree on a compromise position. The facility, the Fernald Environmental Management Project (FEMP) in Fernald, Ohio, originally had scheduled Record of Decision (ROD) dates as early as 1991. These ROD dates have been renegotiated. However, EPA review performed on several primary RI/FS documents indicated that risk assessment issues play a major role in the acceptance of the documents. The sensitive risk assessment issues and how they affect the entire remediation effort are discussed here.

Briefly, the stages of the risk assessment process are (see Fig. 1): Determination of chemicals of potential concern; exposure assessment; toxicity assessment; risk characterization; development of remedial action objectives; evaluation of remedial alternatives. Some of the major issues that arose during the development of both baseline risk assessments and assessments of remedial alternatives were: Determination of background chemical concentrations; identification of fate and transport, and exposure models and parameters; identification of receptor populations (including sensitive receptors, occupational receptors); future land use; use of institutional controls; use of radiation slope factors; evaluation of additive toxic effects; identification of the basis for remediation goals/cleanup levels.

Figure 2 shows a matrix describing the stages of the risk assessment process that are affected by each of these issues. Keep in mind that although we identify the major stage(s) affected, each issue ultimately affects all progressive stages as well.

As noted in Fig. 2, the stage of the risk assessment affected by most of the identified sensitive issues is the exposure assessment. In addition, the exposure assessment occurs early in the process, and since each subsequent stage is affected, these issues become of additional importance.

RISK ASSESSMENT ISSUES

Background Concentrations

Generally, only those chemicals that occur naturally in nature should be of concern when evaluating background chemical concentrations, unless there is reason to suspect an upgradient source of contamination. Because of the extensive and isolated nature of many DOE facilities, this is usually not the case for the facility as a whole. However, it becomes important when one on-site source is downgradient from another on-site source. Precise determination of background concentrations is important for the following reasons:

- If a chemical is detected below background in a given medium, it should not be considered a site-related chemical of concern and should not be evaluated further in the risk assessment process;
- Intake calculation may be based on above-background concentrations (which is generally the method used for radionuclides) or on total detected concentrations (which is generally the method used by EPA);
- Remediation goals may be limited to no lower than background concentrations to avoid presuming that a "pocket of cleanliness" could exist in a natural environment.

At the FEMP, it was determined that comparison to background would be performed in a manner consistent with the RCRA facilities monitoring requirements (1), which require that a tolerance interval be determined for the distribution of background data. A 95% tolerance interval is used to determine potential downgradient contamination. A background sample size of eight is considered large enough to establish a tolerance interval (1).

In cases where site-specific background data were not available (e.g. inorganics in soils), data from the United States Geological Survey and from the open literature citing local soils data were used. When data from the literature were used, it was sometimes necessary to establish a tolerance level of one standard deviation from the mean, due to the uncertainty of the data.

The issue of whether background should be subtracted from total measured concentrations to evaluate intake is currently being discussed. Most likely, background will be subtracted to determine increased lifetime cancer risk, but will be included in calculations to determine the potential that a toxic effect is unacceptable.

Fate and Transport, and Exposure Models

It was necessary to maintain a certain level of consistency between operable unit risk assessments at the FEMP. It was found that the exposure assessment stage was especially fertile ground for inconsistencies to occur, since the number of parameters and assumptions required to perform exposure

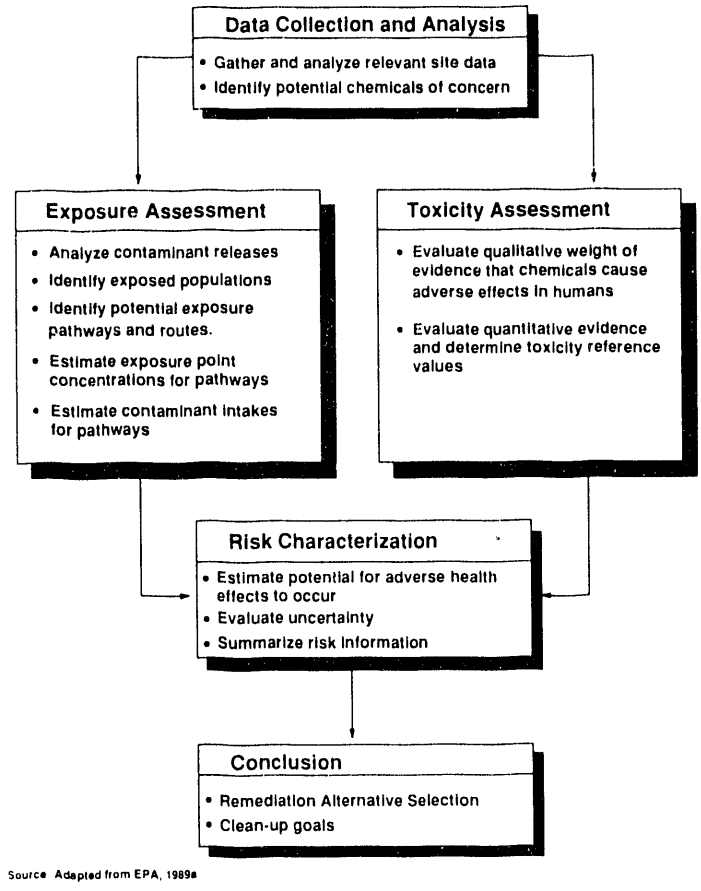


Fig. 1. Baseline risk assessment process.

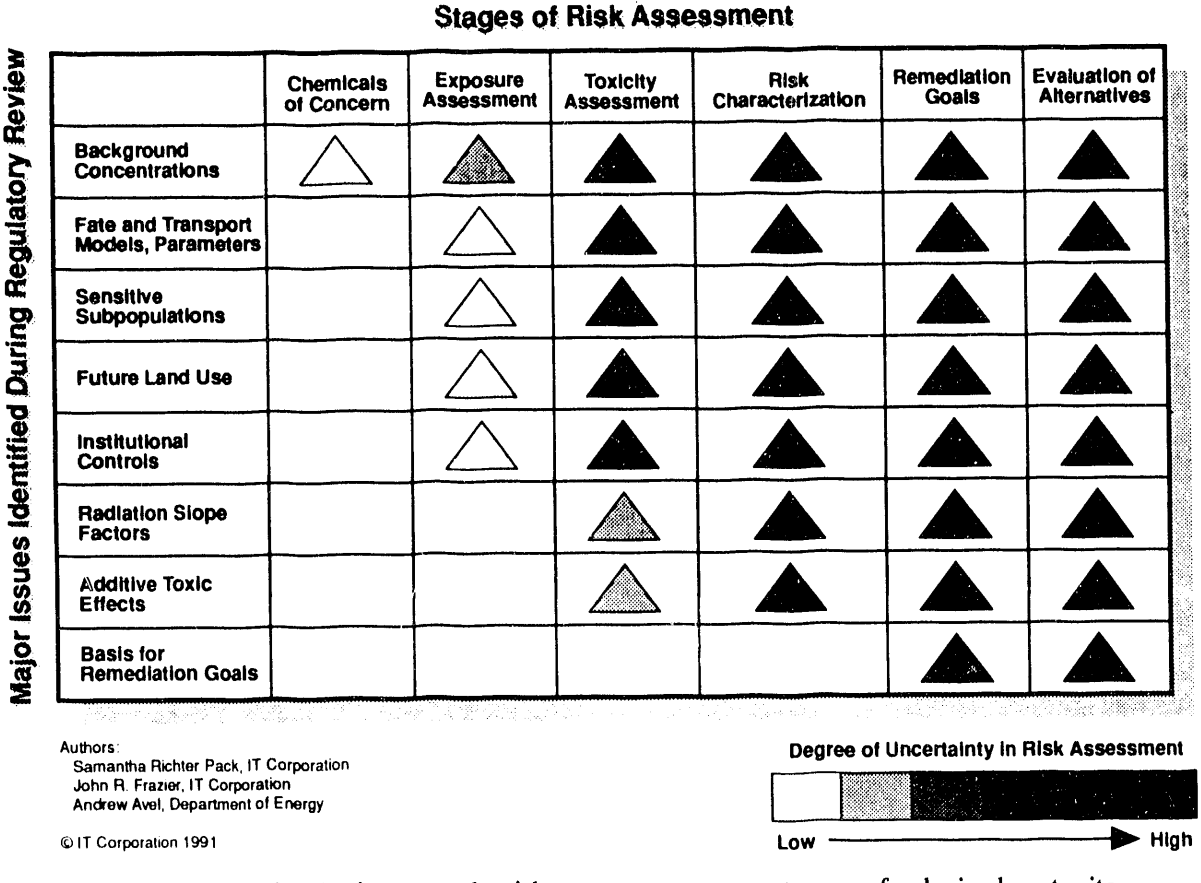


Fig. 2. Impact of major issues on the risk assessment process at a superfund mixed waste site.

assessments is so great. Keep in mind that at times circumstances occurred that lead to justifiable differences in the process of estimating exposure. For example, variation in hydrogeological characteristics or source unit characteristics for different portions of the site justify the use of different assumptions and parameter values (if available) for groundwater fate and transport modeling.

It was also found that selection of exposure pathways, models and parameters received more review comments than all other aspects of the risk assessment. In order to avoid responding to continuous review comments, an addendum to the RI/FS Work Plan was developed for completion of the risk assessment work at the site. It provides a compilation of methodologies and parameter values used in all FEMP RI/FS risk assessments, including: Intake and exposure models; Intake and exposure model parameter values; Transport models; Transport model parameter values; The method for estimating the committed effective dose equivalent (CEDE) from intake of radionuclides; The method for estimating injuries and fatalities from construction and transportation accidents for FS risk assessments.

The models and most of the parameters presented are used in one or more (but not necessarily all) of the baseline or FS risk assessments.

It was found that in order to obtain EPA approval of the Work Plan and the risk assessments, it was generally important to use models and parameters with which the Agency is familiar. A hierarchy of reference documents was developed to establish exposure assessment methodologies and parameter values. The hierarchy places an emphasis on methodologies and parameter values from EPA reference documents. Additional reference documents were used to provide methodologies that were not specifically addressed in the EPA guidance documents. The hierarchy is:

- U.S. EPA Risk Assessment Guidance for Superfund Volume I Human Health Evaluation Manual (2), including suggested reference materials and services
- U.S. EPA Superfund Exposure Assessment Manual (3)
- U.S. EPA Exposure Factors Handbook (4)
- Nuclear Regulatory Commission reports and guidance including Regulatory Guide 1.109 (5)
- National Council on Radiation Protection and Measurements reports
- U.S. DOE publications
- U.S. Department of Transportation publications
- U.S. Department of Labor publications
- Open literature.

Receptor Populations/Future Land Use/Institutional Controls

Three issues associated with receptor identification arose during EPA review of RI/FS documents. These issues were the identification of sensitive subpopulations, current occupational receptors and potential future receptors. By far the most important decision to be made was that concerning future potential exposures based on future land use since it was found that this receptor analysis was usually the one that would drive extensive remediation. In addition, it was found that identification of future receptors, future land-use assumptions and the issue of institutional controls were so closely linked, decisions regarding each had to be made in concert.

Of additional note, it was found that during state review of documents, the state suggested that current institutional controls (e.g. fences, security, etc..) not be considered in the current land-use scenario, and that a resident farmer be the current land-use receptor. This suggestion is not feasible at the FEMP since it is unreasonable to assume a farmer is currently on site, or could be on site "tomorrow". Current land use at the FEMP restricts potentially exposed members of the public to any location outside the FEMP property boundary, thus current land use receptors are the general public outside of the fence and onsite workers not directly involved in remediation efforts.

For the purpose of *quantitative* fate and transport and exposure modeling, it was necessary to determine a point(s) in time to serve as the temporal demarcation between current and future exposure scenarios for contaminant transport modeling. Several options are still being considered to address this need:

- Assume that the current land use of FEMP property will continue for a period up to 100 years, at which time future land-use conditions will begin. The use of 100 years as the time frame for the government to provide custodial care is taken from several sources, most notably, the preamble to the final rule for 10CFR61 (6). That preamble states that:

  "Based on work done by EPA, public comments on a preliminary draft of Part 61 and an advanced notice of proposed rulemaking, and four regional workshops, a clear consensus was developed which supported the 100-year limit" (6);
- Assume future land use begins at the point in the contaminant concentration versus time curve that the concentration reaches a peak;
- Assume that the concentration to which a future receptor is exposed is the integration of the area under the curve for the 70-year time period in the future resulting in the highest total concentration.

Once it is assumed that institutional controls are lost, it is assumed that a "resident farmer" has unrestricted access and use of the site. The future land-use scenario selection is extremely important for all subsequent risk management decisions, such as the determination of need for remediation and establishment of cleanup goals.

In the FS risk assessment, risk will be presented for each engineering alternative with and without proposed institutional controls such as water and land use deed restrictions.

Radiation Slope Factors

The Office of Radiation Programs (ORP) of the U.S. EPA has calculated cancer slope factors and unit risk values for selected radionuclides of potential concern at Superfund sites. These values are listed in EPA's Health Effects Assessment Summary Tables (HEAST), Table C (7) and are revised quarterly. EPA has specified that risk assessors use them for quantifying health risks (cancer incidence) for members of the public at Superfund sites (2).

The concept of slope factors originated with chemical risk assessments. Toxicologists have calculated slope factors for

chemicals to quantify risks of chemical-induced cancer based on chemical intake dose-response curves. It is only recently that EPA has adopted this methodology to quantify radiation-induced cancer risks. This is a new approach for radiological risk assessments which have been performed for many years by a conventional methodology.

At the start of the RI/FS at the FEMP, slope factors for radionuclides were not published by EPA. At a meeting between U.S. EPA, Ohio EPA, DOE, and their contractors, DOE agreed to comply with EPA's request to use the slope factor methodology for radiological risk assessments. Nevertheless, there are specific exceptions to this agreement that should be considered due to the incomplete and potentially inaccurate nature of entries in Table C of HEAST.

It was determined that slope factors would be used for risk calculations for radionuclides at the FEMP with the following exceptions: radon and radon progeny; radionuclides not listed in Table C of HEAST; external radiation exposures.

The conventional methodology for radiological risk assessment is used in these cases. However, it was determined that radiation doses would also be assessed using the conventional methodology for all external exposures and intakes of radionuclides, in order to compare potential radiation doses to pertinent radiation dose limits (applicable or relevant and appropriate guideline requirements, ARARs).

A recent twist to this issue has developed. EPA sent out notification on August 5, 1991, that states that distribution of HEAST Tables is being limited to EPA staff and EPA Superfund contractors (excluding Potentially Responsible Party (PRP) contractors). The EPA states that the reason for this is that the primary source for all toxicity information should be the Integrated Risk Information System (IRIS) database. As of August 21, 1991, radionuclide slope factors were not yet available on the IRIS database. Thus, if radionuclide slope factors are to be used at DOE facilities, they must be made available on the IRIS database.

Additive Toxic Effects

Sites that have both radioactive and chemical waste present a unique set of potential risks: radiological carcinogenesis, non-stochastic effects of radiation, chemical carcinogenesis and the non-carcinogenic effects of chemical toxicants. At present, governmental regulatory agencies have only marginally addressed the problem of quantifying the additive effects associated with mixed waste.

Assumptions about additivity become important when total risk is an issue, for example when developing cleanup levels. The NCP specifies that cumulative site risk be within the 10^{-4} to 10^{-6} range. The more chemicals that are assumed to produce an additive effect, the more chemicals that contribute to cumulative risk. As a result, residual allowable risk concentration become extremely low.

To address this issue, current regulatory policies pertaining to health effects from mixed wastes, and toxicological assessments that may address these health effects were reviewed. In both cases, information was scarce or non-existent, making definitive statements on methods for addressing this issue difficult.

In reviewing various regulations such as CERCLA, Resource Conservation and Recovery Act (RCRA), and the National Emission Standards for Hazardous Air Pollutants (NESHAP), it was found that no specific regulatory standards exist for estimating the combined risk from chemicals and ionizing radiation exposure in a mixed waste situation. However, the EPA has suggested when cancer is the endpoint being evaluated, substance-specific cancer risks should be summed to determined a site-specific total risk (2).

The NCRP (1989) reviewed the influence of environmental factors (in all cases, cigarette smoking) on radiogenic risk, and whether such factors interacted with ionizing radiation to increase or decrease cancer effects. (No studies on the combined effects from exposure to low-level radiation and chemicals were available for review.) In the four studies reviewed, the NCRP found that cigarette smoking affected radiation cancer in the following manner: lung cancer data - inconclusive; U.S. uranium miners (radon daughters) - synergistic effects; Swedish iron miners - additive; A-bomb survivors - additive.

In perhaps the most extensive study addressing the issue of the differences between radiological and chemical risk, the NCRP (8) stated that the *principles* for assessing carcinogenic risks of ionizing radiation and chemicals are *in essence* similar. However, differences do exist. Issues involved in these differences, some of which were addressed for the Savannah River study, are outlined below:

- While the risks of ionizing radiation can be inferred from one radionuclide to another, chemicals vary widely in molecular structure, metabolism, mechanism of action, potency and the stage in the cancer process during which they act. It has been argued that these differences make comparisons to radiation risk difficult. However, two responses to this argument exist. For both radionuclides and chemicals, carcinogenic effects have been noted in almost every organ of the body, so that major differences in distribution occur among radionuclides as well. In addition, although chemical carcinogens vary greatly in mechanism of action, metabolism, etc., they are compared among each other.
- Historically, risk from exposure to ionizing radiation has been calculated for exposures above background levels. While in the past, risks calculated for chemical carcinogens have been absolute values, the move towards calculating the risk above background exposure has begun.
- Of the 3500 potential carcinogens identified by the National Academy of Sciences (9), only 23 have been verified as human carcinogens by the International Agency for Research on Cancer (10). Ionizing radiation has been shown to be a human carcinogen. This is perhaps the greatest difference in comparing chemical carcinogens and radionuclides.
- Approximately 23 chemicals are known to cause cancer in man. (EPA only lists 10 Class A carcinogens). In these cases, epidemiological data have been used to estimate human risks using a linear model, as is the case with radiation carcinogenesis. In both cases, the only extrapolation required is from high occupational doses to low environmental doses.
- Hundreds of chemicals have been identified as carcinogens in laboratory animals. To infer risk using these studies requires extrapolation between small

rodents to humans using the linearized multistage model, and extrapolation from near toxic doses to low environmental doses. Radiological risk evaluation does not require interspecies extrapolation. However, according to recent studies (11), the human health risks estimated using animal data closely match human risks estimated using data from epidemiology studies.

Based on limited available information about combined effects from radiocarcinogenesis and chemical carcinogenesis, the following guidance is being used to perform the FEMP risk assessments:

- The health effects from radiocarcinogens and chemical carcinogens will be assumed to be additive. Risks will be presented both separately and combined. This additive risk will be used to provide an initial indication of the overall severity of a perceived hazard. Because of the use of the 95% upper-confidence bound on the dose-response curves, this assumption will lead to total risk that embodies more conservatism as the number of agents increases (EPA, 1989b). An explanation of the uncertainties associated with this assumption will be included.
- The health effects of noncarcinogenic toxicant will be assumed to be additive for toxicants that effect similar target organs.

Basis for Remediation Goals

Perhaps what will prove to be one of the most widely contested issues of the RI/FS process at DOE sites will be the issue of determining remediation goals, or cleanup levels. Resolution of this issue will likely be made at a national level, as opposed to a Regional EPA level since DOE sites across the country should logically be achieving similar levels of remediation, and since the dollars that may potentially be spent, or saved, based on agreed upon remediation goals is so great that it sends the issue to a national level.

Guidance published in the preamble of the NCP states that preliminary RGs should be based on readily available environmental or health-based ARARs, ambient water quality criteria, and other criteria, advisories or guidance (12). However, it has been found that many identified ARARs have not been derived from risk levels that would meet the CERCLA objectives of "protectiveness of human health". In other words, preliminary RGs developed with ARARs could be less stringent than criteria based on the 10^{-4} to 10^{-6} risk level.

Although CERCLA was designed to be implemented in conjunction with other environmental laws (ARARs), a problem arises when CERCLA *goals* (e.g. cleanup levels based on the 10^{-4} to 10^{-6}) are in conflict with these other laws. Chemical-specific standards promulgated under these laws generally are designed to regulate health risks to an acceptable level, which in several cases is greater than 10^{-4}. In other words, the definition of "acceptable risk" or "acceptable exposure" is inherently different in different pieces of legislation. Thus, while both ARARs and CERCLA risk-based criteria generally are considered health protective, the risk levels on which they are based are different. Many ARARs are based on technological limitations (e.g. MCLs) and thus often represent the most protective level that is actually achievable.

At the FEMP, preliminary RGs will be based on the CERCLA goal of meeting the 10^{-4} to 10^{-6} risk range. The 10^{-6} "point of departure" risk value will be used to determine preliminary RGs for individual contaminants in each pathway, assuming that the cumulative site-wide risk would not exceed 10^{-4}. The tables of preliminary RGs will also include any identified ARARs, background concentration levels and Contract Required Detection Limits (CRDL). The reasons for this position, which has yet to be approved by the EPA, are:

- It is a major goal of the CERCLA process to manage site risk to a 10^{-4} to 10^{-6} range;
- In the early stages of the feasibility study process, the more stringent criteria (risk-based in lieu of ARARs) should be used to guide technology and alternative development; it is premature at this stage to determine if, or to what extent, these risk goals can be met;
- Use of the less stringent criteria in the early stages of the FS could force the alternative selection process to be revisited if new technologies are found that can meet risk criteria;
- ARAR-based criteria, background concentrations and CRDL must be maintained in the tables as checks on reality. Many ARAR-based criteria were developed from a regulatory process in which the EPA and NRC were forced to address such considerations as technical feasibility, verification, uncertainty and cost: The risk in proceeding with the selection process using only risk-based values is that technologies could be screened out based on their inability to meet stringent risk goals even though these same technologies may eventually be found to be the only or most cost-effective technologies for meeting the final RGs. Therefore, a technology may be retained in the alternative evaluation process if it meets the ARAR but does not meet the risk goals.
- This flexibility must be retained in the FS process in case it is found that preliminary RGs cannot be reasonably or technologically met.

While preliminary RGs are developed early in the RI/FS process prior to complete site characterization, final RGs are developed after an alternative has been selected (12). Final RGs are, in effect, cleanup levels that must be achieved by the selected technology. While preliminary RGs will be risk-based, other factors will be considered in the development of the final goals. The major consideration will be identified ARARs. Other issues that will play a role in selecting final RGs include: Technological feasibility; Verification; Uncertainties in risk estimates; Historical precedence; Acceptable risk.

These issues, which are issues faced any time enforceable chemical-specific criteria are developed, are discussed in great detail in the risk assessment Work Plan.

SUMMARY

Several issues presented in this paper proved to be major stumbling blocks to document approval during the DOE and EPA review cycles for FEMP RI/FS documents. Each of the issues, in addition to several others, have been addressed in a Work Plan Addendum for review and approval by EPA.

Approval of this Work Plan will facilitate approval of all future FEMP RI/FS documents.

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ACKNOWLEDGMENT

Acknowledgment: We would like to acknowledge the following associates whose work has helped in preparing this paper: Ken Ladrach, IT Corporation and Dr. Show Fong, IT Corporation.

DEVELOPMENT OF AN ADJOINT SENSITIVITY METHOD FOR SITE CHARACTERIZATION, UNCERTAINTY ANALYSIS, AND CODE CALIBRATION/VALIDATION

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ABSTRACT

The adjoint method is applied to groundwater flow-mass transport coupled equations in variably saturated media. The sensitivity coefficients derived by this method can be calculated by a single execution for each performance measure regardless of the number of parameters in question. The method provides an efficient and effective way to rank the importance of the parameters, so that data collection can be guided in support of site characterization programs. The developed code will facilitate the sensitivity/uncertainty analysis in both model prediction and model calibration/validation.

INTRODUCTION

Sensitivity analysis is an integral part of the groundwater modeling effort. The adjoint sensitivity method is gaining popularity in waste management application because it is practical, effective, and easy to use. Often, we are interested in the responses of performance goals at a single point in the domain and for a specific time with respect to numerous system parameter variations. The adjoint method provides a single execution regardless of the number of parameters in question. The developed code will calculate the sensitivity coefficients that are defined as the first derivative of the chosen performance criterion with respect to system parameters. Performance criteria include pressure heads, velocities or travel time, and concentration of discharges to biosphere points. The parameters include saturated hydraulic conductivities, relative permeability, porosities, hydrodynamic dispersion coefficients, storage coefficients, and retardation. The sensitivity code will be applied in a variably saturated area for a coupled flow-contaminant transport system.

Sensitivity analysis provides a ranking of the parameters, to help with the data collection for the site characterization. The adjoint method is also an important component of both the uncertainty analysis and the parameter- identification procedure. Sykes et al. (1) used this method to perform a sensitivity analysis for steady-state groundwater flow. Towley and Wilson (2) used the method to analyze the uncertainty propagation of the estimated parameters. The method was also used in the parameter identification of groundwater flow by many authors including Jacquard and Jain (3), Chavent et al. (4), Neuman (5), Carrera and Newman (6), Sun and Yeh (7) and Lu et al. (8).

A general derivation of adjoint state nonlinear equations was given by Oblow (9) and Cacuci, et al. (10) for reactor thermal-hydraulic problems. Recently, Sun and Yeh (11) presented a general procedure for deriving the adjoint state equations, which is applicable for nonlinear and transientcoupled problems in the groundwater area. This paper applies the procedure to groundwater flow-mass transport in variably saturated media and to numerically implement it and incorporate it into computer code VAM2DH (12).

The developed program can achieve primarily the following objectives:

- Perform a sensitivity analysis of the uncertainties of the parameters used for flow and transport model predictions
- Provide guidance for data collection for site characterizations.

The method can be further developed to achieve the following objectives:

- Obtain a first-order calculation of uncertainties of the predicted pressure heads or contaminant concentrations for a given covariance matrix of model parameters
- Used as a module of an inverse code by incorporation of a generalized least-squares algorithm (13) to facilitate the model calibration and validation.

The site characterization program includes hydrological, geological, geochemical, and waste characterization. Currently, the sample collection practice is not directly related to the performance assessment goals. As a result, many samples that are analyzed in a laboratory are never used for a performance assessment study, whereas some important samples relevant to performance assessment goals are not collected. One of the reasons for the lack of a connection between sampling and performance assessment is that it requires an effort to discern the importance of the parameters relative to performance assessment goals. For a given set of executions of flow and transport codes, model results provide a sensitivity coefficient for only a single parameter. Because of the spatial variabilities of the flow system, it becomes prohibitively difficult for the user to track multiple files to keep solving the basic partial differential equations over and over again to answer all of the sensitivity questions that could arise. The proposed adjoint method is much more efficient than the above method, because only one additional set of coupled equations needs to be solved for each performance measure to compute the sensitivity coefficients for many system parameters. In addition, this can be done in a single execution. Thus, it will be simpler for the user and reduce costs both in employee effort and computer time.

To have a technically defensible performance assessment program at the Hanford Site, the calibration and validation of the numerical codes needs to be emphasized. Sensitivity and uncertainty analyses need to be an integral part of such model calibration and validations. The sensitivity code can be further developed to obtain a first-order second-moment algorithm for calculating the covariance of a set of performance measures arising from uncertainties in model parameters. The first-order second-moment method is an alternative to the use of the Monte Carlo techniques, which are costly both

in employee effort and computer time. However, the accuracy of this method depends on the significance of the neglected terms. The sensitivity code can also be further developed as an inverse code by incorporation of a generalized least-squares code (8).

COUPLED FLOW AND TRANSPORT EQUATIONS

Flow and transport equations in a variably saturated media can be written as

$$L_1 = (s_w s_s + \theta \frac{ds_w}{d\psi}) \frac{\partial \psi}{\partial t} - \frac{\partial}{\partial x_i}\left[K_{ij} k_{rw} \frac{\partial}{\partial x_j}(\psi + z)\right] - q = 0 \quad \text{(Eq. 1)}$$

and

$$L_2 = \theta s_w R \left(\frac{\partial c}{\partial t} + \lambda c\right) - \frac{\partial}{\partial x_i}\left(D_{ij} \frac{\partial c}{\partial x_j}\right) + \frac{\partial}{\partial x_i}(v_i c) + c\theta \frac{\partial s_w}{\partial t} - q c^* = 0 \quad \text{(Eq. 2)}$$

subject to the following initial and boundary conditions:

$$\psi(x_i,0) = \psi_o(x_i) \quad \text{(Eq. 3.1)}$$
$$c(x_i,0) = c_o(x_i)$$

and

$$\psi(x_i,t) = \psi_b \text{ on } B_1 \quad \text{(Eq. 3.2)}$$
$$c(x_i,t) = c_b \text{ on } B_1'$$
$$-v_i n_i = v_n \text{ on } B_2 \quad \text{(Eq. 3.3)}$$
$$D_{ij} \frac{\partial c}{\partial x_j} n_i - v_i n_i c = q_c^T \text{ on } B_2'$$

In Eqs. (1) and (2), ψ = pressure head (L), s_w = water phase saturation, s_s = specific storage (1/L), θ = effective porosity, K_{ij} = component of hydraulic conductivity tensor (L/T), k_{rw} = relative permeability with respect to water phase, x_i (i = 1,2) = spatial coordinates, t = time, z = vertical coordinate with upward positive, q = volumetric flow rate via sources (or sinks) per unit volume of porous media, c = solute concentration in the fluid (M/L^3), λ = nuclear decay constant, v_i = Darcy velocity, D_{ij} = hydrodynamic dispersion tensor, c^* = solute concentration in the injected fluid, and R = retardation and is given by

$$R = 1 + \frac{\rho_B k_d}{\theta s_w} \quad \text{(Eq. 4)}$$

where ρ_B = bulk density being defined as $(1-\theta)\rho_s$, ρ_s is the density of solid grains, and k_d = equilibrium constant. The components of v and D are given by

$$v_i = -k_{ij} k_{rw} \frac{\partial}{\partial x_j}(\psi + z) \quad \text{(Eq. 5)}$$

and

$$D_{ij} = \alpha_T v \delta_{ij} + (\alpha_L - \alpha_T)\frac{v_i v_j}{v} + D_d \tau \delta_{ij} \quad \text{(Eq. 6)}$$

where α_L = longitudinal dispersivity (L), α_T = transverse dispersivity (L), v = magnitude of velocity (L/T), D_d = molecular diffusion (L^2/T),) τ = tortuosity, and δ_{ij} = Kronnecker delta.

Equations (1) through (3) of the coupled problem can be represented by a vector operator L as follows:

$$L(u,p;x,t) = 0 \quad \text{(Eq.7)}$$

where vector functions u and p are the unknown state variables and parameters defined as

$$u = (\psi, c)^T$$
$$p = (s_s, K_{ij}, k_{rw}, \theta, \alpha_L, \alpha_T, R)^T \quad \text{(Eq.8)}$$

where superscript T denotes the transpose of a vector or matrix, with initial conditions

$$u = f_0, \text{ when } t = t_0 \quad \text{(Eq.9.1)}$$

and boundary conditions

$$u = f_1 \text{ on } (\Gamma_1) \quad \text{(Eq.9.2)}$$
$$L_B = (u,p;x,t) = f_2, \text{ on } (\Gamma_2) \quad \text{(Eq.9.3)}$$

where L_B is a vector operator representing flux boundary conditions.

ADJOINT STATES

Consider a general performance criterion

$$J = \int_{t_0}^{t_f} \int_{(\Omega)} f(u,p,x,t)\, d\Omega dt \quad \text{(Eq. 10)}$$

where f(u,p,x,t) is a user-chosen function. The first-order variation of J is

$$\delta J = \int_{t_0}^{t_f} \int_{(\Omega)} \left(\frac{\partial f}{\partial u}\delta u + \frac{\partial f}{\partial p}\delta p\right) d\Omega dt \quad \text{(Eq. 11)}$$

The integration of the second term may be interpreted as the "direct effect" term accounting for those changes δp that produce explicit changes in the response, while the integration of the first term as the "indirect effect" term accounting for the indirect change in J due to those changes δp that produce changes in u.

In principle, the solution of the derivative of Eqs.(1) through (3) gives sufficient information to calculate δJ for arbitrary δp. However, if a large number of parameter changes in δp are to be analyzed, it becomes prohibitively expensive. An alternative approach is to eliminate the unknown term associated with δu in Eq.(11).

Define the scaler product of any two vector functions u and v on space region (Ω) and time integral (T) as

$$(u,v)_{\Omega,T} = \int_{t_0}^{t_f} \int_{(\Omega)} u_i v_i d\Omega dt \quad \text{(Eq. 12)}$$

The double index implies the summation for components. Let vector function $\phi, = (\phi_1, \phi_2)^T$ be arbitrary; it will be chosen below.

Taking the first variation of Eqs.(7) through (9), multiplying them by, ϕ, and using Green's second identity, the following is obtained.

$$(\delta u, \nabla_u^+ L\phi)_{\Omega,T} + (\delta p, \nabla_p^+ L\phi)_{\Omega,T} + BIT = 0 \quad \text{(Eq. 13)}$$

The BIT denoting all boundary integral terms is

$$BIT = (\delta p, \nabla_p^+ L_B \phi)_{\Gamma,T} + (\delta u, \nabla_u^+ L_B \phi)_{\Gamma,T} - (\phi, \nabla_u L_B \delta u + \nabla_p L_B \delta p)_{\Gamma,T} + (\delta u, \phi)_{\Omega,t_f} - (\phi, \delta u)_{\Omega,t_0} \quad \text{(Eq. 14)}$$

$\nabla_u + L$ and $\nabla_p + L$ are the transposed adjoint operators of $\nabla_u L$ and $\nabla_p L$, respectively. The method by which $\nabla_u + L$ and $\nabla_p + L$ can be found from $\nabla_u L$ and $\nabla_p L$ will be discussed later.

We already have the initial and boundary conditions [Eqs.(9.1) through (9.3)] for δu, if we define the final and boundary conditions for φ such that

$$\phi = 0, \quad when\ t = t_f \qquad \text{(Eq.15.1)}$$

$$\phi = 0, \quad on\ (\Gamma_1) \qquad \text{(Eq.15.2)}$$

$$\nabla_u\ {}^{+}L_B\phi = 0, \quad on\ (\Gamma_2) \qquad \text{(Eq.15.3)}$$

then all terms on the right side of Eq.(14), except the first one, will vanish. And if no unknown boundary parameter is assumed, the first term vanishes also. Therefore, BIT = 0.

Rewrite Eq.(11) as

$$\delta J = (\delta u, \frac{\partial f}{\partial u})_{\Omega,T} + (\delta p, \frac{\partial f}{\partial p})_{\Omega,T} \qquad \text{(Eq. 16)}$$

Adding Eq.(13) to Eq.(16), we obtain:

$$\delta J = (\delta u, \nabla_u^{+} L\phi + \frac{\partial f}{\partial u})_{\Omega,T} \qquad \text{(Eq. 17)}$$

$$+ (\delta p, \nabla_p^{+} L\phi + \frac{\partial f}{\partial p})_{\Omega,T}$$

The first scaler product on the right side of Eq.(17) can be eliminated, if we select ϕ, to satisfy:

$$\nabla_u^{+} L\phi + \frac{\partial f}{\partial u} = 0 \qquad \text{(Eq. 18)}$$

Equation (18) with the conditions of Eq.(15) forms the (vector) adjoint problem of the original coupled problem Eq.(7) through Eq.(9). Its solution ϕ, is namedthe adjoint state (vector) of the original vector u. With the adjoint state ϕ, the partial functional derivative of Eq.(17) for any parameter p_j can be written as:

$$\frac{\delta J}{\delta p_j} = \int_{t_0}^{t_f} \int_{(\Omega)} \left(\nabla_p^{+} L\phi + \frac{\partial f}{\partial p}\right)_j d\Omega dt \qquad \text{(Eq. 19)}$$

ADJOINT EQUATIONS

For any operator matrix R, we define $R^{+} = (R^{*})^{T}$, where * denotes the adjoint operation and superscript T represents the transpose operator. Adjoint operation rules can be derived from Green's formula. Adjoint operation rules for the elements of operation, ∇L and ∇L_B, derived by Sun and Yeh (11) are listed in Table I. In Table I, f and g are scaler functions and v is a vector function. K is a symmetrical tensor and n is the normal direction of boundary (Γ).

TABLE I
Adjoint Operation Rules for Elements of Operation ∇L, and ∇L_B

Element of ∇L	Element of $\nabla^{*} L$	Element of ∇L_B	Element of $\nabla^{*} L_B$
fa	fa		
$f\frac{\partial}{\partial t}a$	$-\frac{\partial}{\partial t}(fa)$		
$\frac{\partial}{\partial t}(fa)$	$-f\frac{\partial}{\partial t}a$		
$\nabla(f\nabla a)$	$\nabla(f\nabla a)$	$(f\nabla a)n$	$(f\nabla a)n$
$\nabla(k\nabla a)$	$\nabla(K\nabla a)$	$(K\nabla a)n$	$(K\nabla a)n$
$v(\nabla a)$	$-v(\nabla a)$	$(Va)n$	0
$\nabla(f\nabla ga)$	$-f\nabla g\nabla a$	$(f\nabla ga)n$	0
$\nabla(k\nabla ga)$	$-K\nabla g\nabla a$	$(K\nabla ga)n$	0
$\nabla[K\nabla(fa)]$	$f\nabla(K\nabla a)$	$[K\nabla(fa)]n$	$(fK\nabla a)n$

a Represents δu in element of ∇L; ϕ in element of $\nabla^{*} L$.

The steps of deriving the adjoint problem for a coupled problem were summarized by Sun and Yeh (11) as follows:

Step 1. Find gradient operator matrices $\nabla_u L$, and $\nabla_u L_B$ by differentiation.

Step 2. Find $\nabla_u{}^{*} L$ and $\nabla_u{}^{*} L_B$ using derived adjoint operation rules, and then obtain $\nabla_u + L$, and $\nabla_u + L_B$ by transposition.

Step 3. Form the vector adjoint equation using Eq.(18).

Step 4. Form the final and boundary conditions of the adjoint problem using Eq.(15).

Step 5. Find gradient operator matrices $\nabla_p L$ and $\nabla_p L_B$ by differentiation. Find $\nabla_p{}^{*} L$ and $\nabla_p{}^{*} L_B$ using derived adjoint operation rules, and then obtain $\nabla_p + L$ and $\nabla_p + L_B$ by transposition.

Step 6. Obtain all partial functional derivatives of performance J with respect to unknown parameters using Eq.(19).

Using the steps in Eq.(1) through Eq.(4), the adjoint equations are obtained

$$\begin{aligned}
&\frac{\partial f}{\partial \psi} - \frac{\partial}{\partial t}[(s_w s_s + \theta\frac{ds_w}{d\psi})\phi_1] \\
&+ [(s_s\frac{ds_w}{d\psi} + \theta\frac{d^2 s_w}{d\psi^2})\frac{\partial \psi}{\partial t}]\phi_1 \\
&+ K_{ij}\frac{\partial}{\partial x_j}(\psi + z)\frac{\partial k_{rw}}{\partial \psi}\frac{\partial}{\partial x_i}\phi_1 \\
&- \frac{\partial}{\partial x_i}(K_{ij}k_{rw}\frac{\partial}{\partial x_j}\phi_1) \\
&+ R\theta\frac{\partial s_w}{\partial \psi}(\frac{\partial c}{\partial t} + \lambda c)\phi_2 \qquad \text{(Eq. 20)} \\
&- E_{im}K_{mj}\frac{\partial}{\partial x_j}(\psi + z)\frac{\partial k_{rw}}{\partial \psi}\frac{\partial \phi_2}{\partial x_i} \\
&+ \frac{\partial}{\partial x_i}(E_{im}K_{mj}k_{rw}\frac{\partial \phi_2}{\partial x_j}) \\
&- \left[K_{ij}\frac{\partial}{\partial x_j}(\psi + z)\frac{\partial k_{rw}}{\partial \psi}c\right]\frac{\partial}{\partial x_i}\phi_2 \\
&- \frac{\partial}{\partial x_i}(K_{ij}k_{rw}c\frac{\partial}{\partial x_j}\phi_2) - \theta c\frac{\partial s_w}{\partial \psi}\frac{\partial}{\partial t}\phi_2 = 0 \\
&\frac{\partial f}{\partial c} + (\theta s_w R\lambda\phi_2) - \frac{\partial}{\partial t}(\theta s_w R\phi_2) \\
&- \frac{\partial}{\partial x_i}(D_{ij}\frac{\partial}{\partial x_j}\phi_2) \qquad \text{(Eq. 21)} \\
&- v_i\frac{\partial}{\partial x_i}\phi_2 + \theta\frac{\partial s_w}{\partial t}\phi_2 = 0
\end{aligned}$$

where E_{ij} in Eq.(20) is

$$E_{ij} = \frac{\partial D_{i1}}{\partial v_j}\frac{\partial c}{\partial x_1} \qquad \text{(Eq. 22)}$$

The initial and boundary conditions are as follows:

$$\phi_1 = 0, \quad \phi_2 = 0 \quad when\ t = t_f \qquad \text{(Eq. 23.1)}$$

$$\phi_1 = 0, \quad \phi_2 = 0 \quad on\ \Gamma_1$$

$$(K_{ij}k_{rw}\frac{\partial}{\partial x_j}\phi_1 - E_{im}K_{mj}k_{rw}\frac{\partial}{\partial x_j}\phi_2 \qquad \text{(Eq. 23.2)}$$

$$+ K_{ij}k_{rw}c\frac{\partial}{\partial x_j}\phi_2)n_i = 0$$

$$(D_{ij}\frac{\partial}{\partial x_j}\phi_2)n_i = 0 \text{ on } \Gamma_2' \qquad \text{(Eq. 23.3)}$$

SENSITIVITY COEFFICIENTS

To obtain the sensitivity coefficient of state u_i at point x_l and time t_m with respect to parameter p_j defined on zone Ωn, let $t_f = t_m$ and the function f in Eq.(10) be

$$f = u_i(x,t)\,\delta(x-x_l) \qquad \text{(Eq.24)}$$

where $\delta(\bullet)$ is the Dirac-δ function. The performance criterion J now becomes

$$J = \int_{t_0}^{t_m}\int_{\Omega} u_i(x,t)\,\delta(x-x_1)d\Omega dt = \int_{t_0}^{t_m} u_i(x_1,t)dt \qquad \text{(Eq. 25)}$$

Using Eq.(19) and noting $\partial f/\partial p = 0$, we have

$$\frac{\delta J}{\delta p_j} = \int_{t_0}^{t_m}\int_{\Omega_n}(\nabla_p^+ L\phi)_j d\Omega dt \qquad \text{(Eq. 26)}$$

where ϕ is the adjoint state, which depends upon x, t, t_m. By introducing translation) $\tau = t_m - t$ into the adjoint state, we can show that $\phi(x, t_m\text{-}t) = \phi(x,0) = 0$ when $t = t_m$. Substituting Eq.(25) into Eq.(26) and differentiating it with respect to t_m, we obtain

$$\frac{\delta u_i(x_1,t_m)}{\delta p_j}$$

$$\int_{t_0}^{t_m}\int_{\Omega_n}[\nabla_p^+ L\frac{d}{dt_m}\phi(x,t_m-t)]_j d\Omega dt \qquad \text{(Eq. 27)}$$

Choosing the function f as in Eq.(24) and Eq.(27), steps 5 and 6 lead to the following sensitivity coefficients

$$\frac{\partial u_i}{\partial s_s} = \int_{t_0}^{t_m}\int_{\Omega_n} s_w(\frac{\partial\psi}{\partial t}\phi_1')\,d\Omega dt \qquad \text{(Eq. 28.1)}$$

$$\frac{\partial u_i}{\partial k_{rw}} = \int_{t_0}^{t_m}\int_{\Omega_n}\{K_{ij}\frac{\partial}{\partial x_j}(\psi+z)\frac{\partial}{\partial x_i}\phi_1'$$

$$- E_{i1}K_{1j}\frac{\partial}{\partial x_j}(\psi+z)\frac{\partial}{\partial x_i}\phi_2' \qquad \text{(Eq. 28.2)}$$

$$+\left[K_{ij}\frac{\partial}{\partial x_j}(\psi+z)c\right]\frac{\partial}{\partial x_i}\phi_2'\}d\Omega dt$$

$$\frac{\partial u_i}{\partial K_{ij}} =$$

$$\int_{t_0}^{t_m}\int_{\Omega_n}\{\frac{\partial K}{\partial K_{ij}}k_{rw}\frac{\partial}{\partial x_j}(\psi+z)\frac{\partial}{\partial x_i}\phi_1' \qquad \text{(Eq. 28.3)}$$

$$-E_{i1}\frac{\partial K}{\partial K_{1j}}k_{rw}\frac{\partial}{\partial x_j}(\psi+z)\frac{\partial}{\partial x_i}\phi_2' +$$

$$\left[\frac{\partial K}{\partial K_{ij}}k_{rw}\frac{\partial}{\partial x_j}(\psi+z)c\right]\frac{\partial}{\partial x_i}\phi_2'\}d\Omega dt$$

$$\frac{\partial u_i}{\partial\theta} = \int_{t_0}^{t_m}\int_{\Omega_n}[\frac{ds_w}{d\psi}\frac{\partial\psi}{\partial t}\phi_1' + \qquad \text{(Eq. 28.4)}$$

$$S_w R(\frac{\partial c}{\partial t}\lambda c)\,\partial_2' + c\frac{\partial s_w}{\partial t}\phi_2']\,d\Omega dt$$

$$\frac{\partial u_i}{\partial\alpha_L} = \int_{t_0}^{t_m}\int_{\Omega_n}\left(\frac{\partial D_{ij}}{\partial\alpha_L}\frac{\partial c}{\partial x_j}\frac{\partial}{\partial x_i}\phi_2'\right)d\Omega dt \qquad \text{(Eq. 28.5)}$$

$$\frac{\partial u_i}{\partial\alpha_T} = \int_{t_0}^{t_m}\int_{\Omega_n}\left(\frac{\partial D_{ij}}{\partial\alpha_T}\frac{\partial c}{\partial x_j}\frac{\partial}{\partial x_i}\phi_2'\right)d\Omega dt \qquad \text{(Eq. 28.6)}$$

$$\frac{\partial u_i}{\partial R} = \int_{t_0}^{t_m}\int_{\Omega_n}\left[s_w\theta(\frac{\partial c}{\partial t}+\lambda c)\phi_2'\right]d\Omega dt \qquad \text{(Eq. 28.7)}$$

where

$$\phi_1' = \frac{d}{dt_m}\phi_1(x,t_m-t)$$

$$\phi_2' = \frac{d}{dt_m}\phi_1(x,t_m-t) \qquad \text{(Eq. 28.8)}$$

respectively, and u is $\psi(x,t)$ and c(x,t), respectively. Although the sensitivity coefficients of ψ and c have the same integral forms as indicated in Eq.s(28.1) through (28.8), the adjoint state ψ will be different because of the terms $\partial f/\partial\psi$ and $\partial f/\partial c$ which represent one unit source term at location x_l either in Eq.(20) or in Eq.(22).

Numerical Solution of Original and Adjoint Problems

The original problem and the adjoint problem are given by Eqs.(1) through (3) and Eqs.(20) through (23). For a groundwater problem, these equations can be solved sequentially by the following procedure.

Step 1. Solve Eq.(1) and (3) to obtain the pressure distribution $\psi(x,t)$, saturation distribution $s_w(x,t)$, and velocity distribution V(x,t).

Step 2. Solve Eq.(2) and (3) to obtain the concentration distribution c(x,t).

Step 3. Solve Eq.(21) and (23) to obtain the adjoint state $\phi_2(x,t)$.

Step 4. Compute the source/sink term (including terms containing ϕ_2) of Eq.(20) by using the calculated $\psi(x,t)$, c(x,t), and $\phi_2(x,t)$.

Step 5. Solve Eq.(20) to obtain the adjoint state $\phi_1(x,t)$.

CONCLUSIONS

The adjoint method is applied to groundwater flow-mass transport coupled equations in variably saturated media. The method is especially suitable fora limited number of performance measures and an unlimited number of parameters. Applicability of the method to the variably saturated media will be assessed.

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SOILD: A COMPUTER MODEL FOR CALCULATING THE EFFECTIVE DOSE EQUIVALENT FROM EXTERNAL EXPOSURE TO DISTRIBUTED GAMMA SOURCES IN SOIL

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ABSTRACT

The SOILD computer model was developed for calculating the effective dose equivalent from external exposure to distributed gamma sources in soil. It is designed to assess external doses under various exposure scenarios that may be encountered in environmental restoration programs. The model's four major functional features address (1) dose versus source depth in soil, (2) shielding of clean cover soil, (3) area of contamination, and (4) nonuniform distribution of sources. The model is also capable of adjusting doses when there are variations in soil densities for both source and cover soils. It can also be used to assess doses for various building scenarios. The model is supported by a data base of approximately 500 radionuclides (1).

DOSE VERSUS SOURCE DEPTH

Effective dose equivalent responses from distributed gamma sources in soil have been derived by Chen (2) on the basis of the recommendations of the International Commission on Radiological Protection's (ICRP's) Publication 51 (3) on external exposures. The Monte Carlo method was used to obtain the responses. The results were expressed in the following empirical formula that correlates the effective dose equivalent (H) to the source photon energy (E), source slab thickness (T), and soil density (ρ):

$$H(\rho,T,E) = \frac{H_o}{\rho}\left\{1-Exp\left[-\alpha\mu T-\beta(\mu T)^{1.5}\right]\right\} \quad \text{(Eq. 1)}$$

where H_o is the effective dose equivalent for the infinitely thick source layer, μ is the photon attenuation coefficient of the soil, and α and β are the fitted coefficients. The dose response from a gamma-emitting radionuclide was calculated as follows:

$$H_R(\rho,T) = \sum_i^N f_i H(\rho,T,E_i) \quad \text{(Eq. 2)}$$

where f_i is the gamma yield for photon energy E_i of the ith photon emitted by the nuclide.

SHIELDING FACTOR OF CLEAN COVER SOIL

Covering a contaminated area with clean soil has been used as a means of reducing external exposure. The required thickness of the clean soil layer depends on its ability to shield against gamma radiation. The point-kernel method is used to calculate the soil shielding factor. The calculation is based on the latest buildup factors derived by Trubey (4). Assuming the concrete buildup factors for soil, the shielding factor for cover soil can be expressed as follows:

$$F_s = \frac{I_s(\mu_a T_a + \mu_s T_s)}{I_a(\mu_a T_a)} \quad \text{(Eq. 3)}$$

where

$$I_m(x) = \int_x^\infty \frac{e^{-z}}{z} B_m(z)\,dz, m = a \text{ or } s \quad \text{(Eq. 4)}$$

where μ is the photon attenuation coefficient; B is the buildup factor; T is the medium thickness; and a and s are designations for air and soil, respectively. In this equation, T_a is assumed to be 100 cm for the human receptor above the ground.

AREA FACTOR

Area factors are used when soil contamination is confined to a limited rather than an infinite area. The point-kernel method and air buildup factors are used to calculate area factors. Area factors in SOILD are calculated on the basis of the dose contributions from the area bounded by the concentric circles on the contaminated soil surface. The area factor for a particular area can be estimated as follows:

$$F_a = \frac{[I_a(\mu_a r_i) - I_a(\mu_a r_{i+1})]}{I_a(\mu_a T_a)} \quad \text{(Eq. 5)}$$

where I_a is the integral defined in Eq. (4), and r_i and r_{i+1} are the outer and inner radii of the concentric circles bounding the area of interest. The derived area factor is energy-dependent and, therefore, varies from one radionuclide to the other.

NONUNIFORM SOURCE DISTRIBUTION

Two methods are used in SOILD to address nonuniform source distributions. One method models on the assumption that there are stratified source layers, and that each layer has a uniform source distribution. The other method models on the basis of the following source distribution:

$$S(x) = S_o e^{-\alpha x} \quad \text{(Eq. 6)}$$

where S_o is the source density at the top layer, x is the source depth measured from the surface, and α is the coefficient that characterizes the source distribution. The SOILD model has capabilities for calculating doses for a given distribution of the source characterized by the parameter.

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** Work supported by the U.S. Department of Energy, Office of Environmental Restoration and Waste Management, under Contract W-31-109-ENG-38.

OTHER FEATURES

The SOILD model also has the capability to trace the decay chains of the parent nuclide and to add the contributions from the daughter nuclides to that of the parent. In the current version of SOILD, this capability is based on the assumption that equilibrium has been established among the radionuclides in a chain. Approximately 500 radionuclides are built into the data base of SOILD. In addition, the model has three types of dose equivalent data based on different exposure orientations: rotational (ROT), anteroposterior (AP), and isotopic (ISO). The ROT data are used to estimate exposure from contaminated ground, the AP data are used to estimate the exposure of cleanup workers from contaminated walls, and the ISO data are used to estimate the exposure of a resident in a uniformly contaminated building. A set of organ dose data is also provided to facilitate the calculation of dose equivalents for specific organs. These dose equivalent data are also based on the recommendations of ICRP Publication 51 (3).

CODE APPLICABILITY

The SOILD model has been developed for application in environmental restoration programs. It can (1) determine the effective dose equivalent from external exposures from various contamination scenarios (2) establish guidelines for external exposures from gamma-emitting radionuclides, and (3) be used to design remedial actions (such as level of cleanup or clean soil coverage). The SOILD model was designed in an IBM/PC environment and is equipped with menu-driven, user-friendly features, including graphic output capabilities.

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REMEDIAL INVESTIGATION FOR THE 200-BP-1 OPERABLE UNIT HANFORD SITE RICHLAND, WASHINGTON

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ABSTRACT

The Hanford Site, Richland, Washington, contains over 1500 identified waste sites that will be characterized and remediated over the next 30 years. In support of the Hanford Federal Facility Agreement and Consent Order, the U.S. Department of Energy has initiated a remedial investigation/feasibility study (RI/FS) at the 200-BP-1 operable unit. The 200-BP-1 RI is the first Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) investigation on the Hanford Site that involves drilling into highly radioactive and chemically contaminated soils. The initial phase of the site characterization is oriented toward determining the nature and extent of any contamination present in the vicinity of the 200-BP-1 operable unit. The major focus of the phase I RI is the drilling and sampling of 10 inactive waste disposal units which received low level radioactive liquid waste.

INTRODUCTION

The Hanford Site which comprises approximately 1450 km^2 of semiarid land is located in south-central Washington state (Fig. 1). The Site is owned by the U.S. Department of Energy and is currently operated by the Westinghouse Hanford Company (WHC). Since 1943, the Hanford Site has been used in part, for reactor operations, reprocessing of spent fuel, and management of radioactive waste. In recent years the mission has switched from production of special nuclear materials to primarily waste management and environmental restoration.

Hanford Site facilities are generally centralized into four numerically designated areas (100, 200, 300, and 1100 Areas) which the U.S. Environmental Protection Agency has placed on the National Priority List under the CERCLA (1). Within the 200 Area, the site is divided into 8 waste area groups largely corresponding to the major processing plants. The waste area groups include: liquid waste disposal sites (ie., cribs, ponds, and ditches), solid waste burial grounds, underground storage tanks, and unplanned releases. The contamination is in the form of nonhazardous, hazardous, radioactive, and mixed wastes. Each waste area group is further divided into operable units on the basis of waste disposal practices, geology, hydrogeology, and pertinent site characteristics. To date, a total of 44 operable units have been identified within the 200 Areas.

Site characterization and remedial activities at each operable unit are being addressed through the Hanford Federal Facility Agreement and Consent Order (2), which was negotiated and approved in May 1989 by the U.S. Department of Energy (DOE), U.S. Environmental Protection Agency (EPA), and the Washington State Department of Ecology (Ecology).

200-BP-1 OPERABLE UNIT DESCRIPTION

The 200-BP-1 operable unit is located in the north-central portion of the 200 East Area. The operable unit includes 13 waste management units (10 inactive cribs and 3 unplanned releases) and encompasses approximately 10 ha with the majority of the waste management units concentrated in a 1.6 ha region at the eastern end (Fig. 2). The 200-BP-1 waste disposal activities were associated with management of waste from U-Plant uranium reclamation, using the tributyl phosphate (TBP) and 241-BY Tank Farm operations.

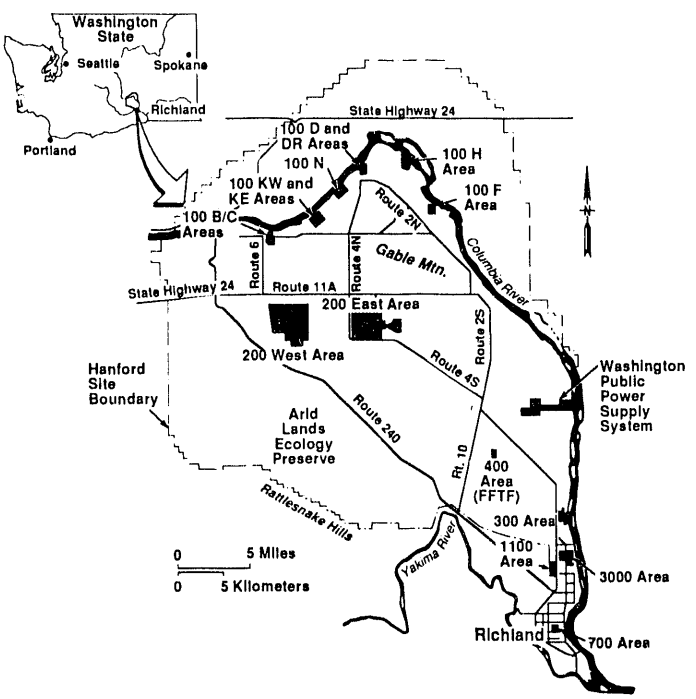


Fig. 1. The Hanford Site, Washington.

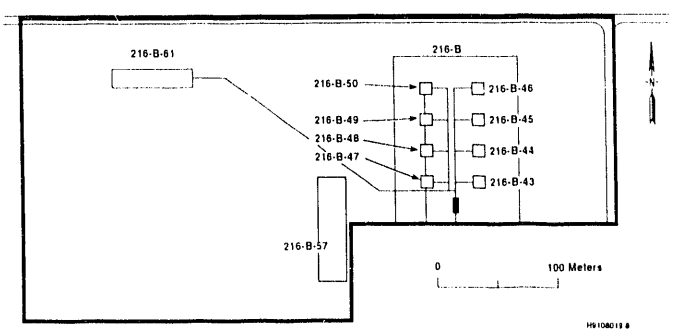


Fig. 2. 200-BP-1 operable unit.

The TBP process at the 221-U Building was used to recover uranium metal from waste generated by the bismuth phosphate ($BiPO_4$) process in B-Plant. Before implementing the TBP process, the waste had been stored in the 241-BY Tank Farm. From 1952 to 1958, stored waste in the 241-BY tanks was transferred to the U-Plant for uranium recovery. The stored waste sludge was dissolved in nitric acid, and then the uranium was extracted using TBP in a normal paraffin diluent. The TBP process wastes contained fission products, sulfate, and phosphate ions in aqueous nitric acid solution. The acid solution was made alkaline for transfer and storage in the 241-BY Tank Farm. The stored TBP wastes were then treated with potassium ferrocyanide [$K_4Fe(CN)_6$] as a cesium scavenger. The supernatant was cribbed after the activity of Cs-137 dropped below 0.1 uCi/ml (3).

During the period in which TBP supernatant was discharged to the cribs, the concept of specific retention disposal was employed. This practice limited discharge volumes to the specific retention volumes of the soils, based on their moisture retention capacity. It is apparent that this concept was not fully implemented and the calculated specific retention volumes of the soil columns were exceeded (4).

From 1965 to 1974, 241-BY storage tank condensate was cribbed in the 200-BP-1 operable unit. The condensate was a result of in-tank solidification (ITS) process which was accomplished by in-tank heating. Evaporates were collected, condensed and subsequently discharged to the cribs.

The exact concentration and quantity of radionuclides and contaminates of concern remaining within 200-BP-1 is uncertain. Historical records indicate that seven cribs received an estimated 33,840,00 L of TBP supernatant waste, 2 cribs received an estimated 139,200,000 L of ITS condensate, and one crib was constructed but has no documented history of past disposal operations. The primary known contaminates are radionuclides (hydrogen-3, technetium-99, strontium-90, cesium-137, cobalt-60, plutonium-238/239/240, total uranium, and ruthenium-106) and nonmetallic ions (nitrate, phosphate, total cyanide, ferrocyanide, and free cyanide).

200-BP-1 REMEDIAL INVESTIGATION

In March of 1990, the EPA approved the Remedial Investigation/Feasibility Study Work Plan for the 200-BP-1 Operable Unit Hanford Site, Richland Washington, DOE-RL, 88-32, Rev. 1 (5). The 200-BP-1 work plan is the first CERCLA investigation on the Hanford site that involves drilling into highly radioactive and chemically contaminated soils. The purpose of this document is to guide the DOE and WHC in the implementation of all RI/FS activities conducted at this operable unit. The initial phase of the RI is oriented toward determining the nature and extent of any contamination present in the vicinity of the 200-BP-1 operable unit. Primary objectives of the RI/FS are to collect data on site and waste characteristics, contamination pathways, transport mechanisms, and to conduct treatability testing as necessary to support the evaluation of proposed remedies.

Nonintrusive characterization activities were initiated in the summer of 1989. Activities included topographic mapping, ground penetrating radar (GPR), and biota and surface scintillation surveys. A topographic map was prepared at a 0.5 m contour interval extending approximately 100 m beyond the operable unit boundary. The map included all surface features and anomalies found during the scintillation and GPR surveys. The GPR survey identified one unidentified underground pipeline within the operable unit. The biota survey consisted of a site inspection which resulted in no visible signs of endangered plant or animal species. Approximately 4 ha were hand surveyed for dose rates and contamination levels using alpha and beta/gamma radiation detection equipment. The survey resulted in finding wide spread surface contamination with general contamination of 400 counts per minute and localized spots up to 10 mRem/hr. The contamination is thought to be wind blown contamination from the crib and/or adjacent Tank Farm areas.

As a result of the migrating radioactive contamination, surface stabilization activities were initiated in the spring of 1991. Approximately 0.1-0.3 m of surface soil was removed from the eastern half of the operable unit and consolidated on the crib areas. The contaminated soil was then stabilized with approximately 0.5 m of clean top soil. Revegitation with natural grasses will be completed in the fall of 1991.

A recently identified groundwater cyanide plume to the north of the 200 East Area is believed to be attributed to past crib operations at the 200-BP-1 operable unit. After reviewing existing groundwater data, work plan actions determined that additional hydrogeologic characterization was required. In order to determine the nature and extent of the contamination, sampling of a 44 groundwater well monitoring network was initiated in January 1991. The groundwater network consists of 35 existing and 9 new wells constructed to support 200-BP-1. Figure 3 illustrates a preliminary cyanide plume map based on the first 2 quarters of 1991 groundwater analysis. The total list of contaminates of concern being evaluated in the groundwater were discussed earlier.

Source and Vadose Zone Characterization

The primary task associated with the 200-BP-1 RI is the drilling and sampling of ten inactive cribs within the operable unit. The objectives of this task are to determine the physical environment and distribution and concentration of waste constituents in the subsurface. Extensive planning and preparation was required prior to commencing characterization activities. Some of the extensive planning activities included: completion of a hazard classification, identification of drilling and sampling methodology, and procurement of an interim storage facilities to accommodate mixed waste.

A hazard classification (6) was completed to evaluate potential exposures and/or releases of contaminates in the soil beneath the cribs. Some of the hazards considered in this safety assessment included: estimates of radiological soil concentration, calculated dose rates, potential for an explosive reaction of ferrocyanide within the crib soils, and criticality.

The estimate of radioactive contaminate soil concentrations assumed that the activity discharged to the cribs was uniformly distributed over some volume of soil under each crib. The volume of soil was varied to provide a range of possible contamination levels. Dose rates were then calculated from these estimates for three simple geometries (split-tube sampler, 250 ml sample bottle, and 208 l drum). A time and motion study for split-tube sampling operations was completed for the purpose of determining approximate exposure rates to the worker.

Laboratory tests and analyses conducted to date indicate a potential for deflagration/detonation if large quantities of ferrocyanide compounds were to reach temperatures in

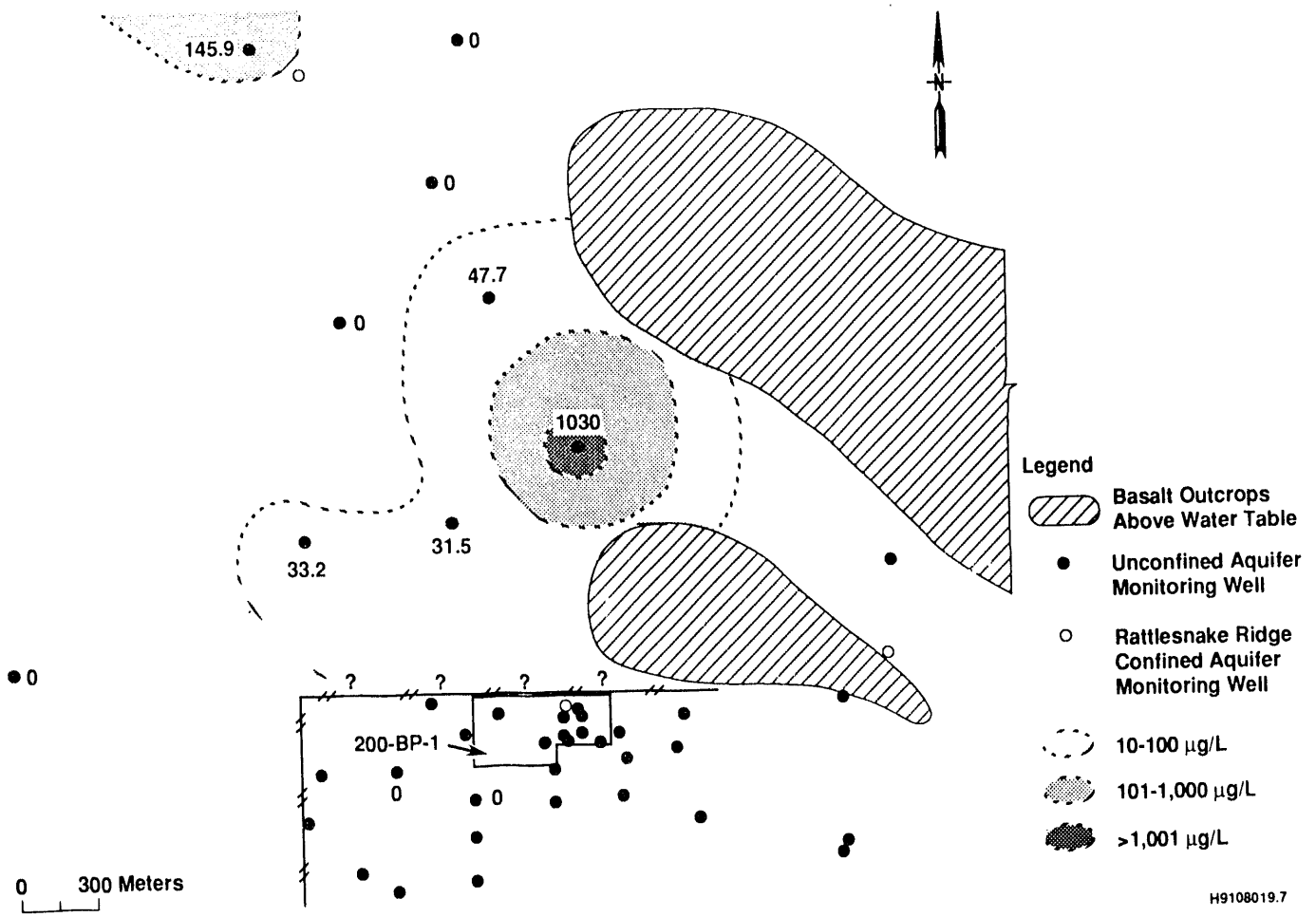


Fig. 3. Preliminary Plume Map-total cyanide.

excess of 200°C. These temperatures can not be reached with cable-tool drilling method. The examination of existing data and flow sheets indicated that only a small amount of nickel ferrocyanide was discharged to the cribs and has been further diluted by the soil matrix. The range of reactive compositions and general soil characteristics were also evaluated and it was concluded that no credible hazard exists for generating an ignition or explosive reaction as a result of the drilling operation.

Potential criticality events were evaluated and found not to be a hazard due to the insufficient inventory of fissionable material in the cribs.

An evaluation of drilling and sampling methodology was completed to assure data quality objectives were accomplished. A detailed guidance document was prepared to assist field personnel and identify acceptable drilling and sampling methodologies for each borehole.

Drilling and sampling consists of two phases: vadose zone and source sampling. The initial vadose drilling phase includes the drilling of three deep (approximately 70 m) boreholes through separate cribs. The boreholes will be continuously sampled for physical properties and at selected intervals for radiological and chemical analyses. The second source sampling phase is to drill three borings through each crib to a depth of approximately 10 m. Chemical samples are collected at designated intervals. The data quality objectives of these boreholes are the following:

- Identify all waste constituents remaining in the cribs.
- Obtain detailed geologic stratigraphic information to assess the possibility of infiltrating effluent waste becoming perched and migrating laterally.
- Obtain concentration profiles of waste constituents to evaluate vertical migration and assess the future impact to the groundwater.
- Obtain representative vadose zone samples for physical laboratory testing including: column leach tests, physical properties, and potential bench-scale treatment tests.

The drilling technique used on all boreholes is the cable-tool method. This technique was chosen primarily for radiological contamination control. Temporary casings are telescoped through intervals of contamination to limit the driving of contaminants deeper into the vadose zone.

Soil samples are extracted from each borehole via split-tube sampler. Radiological sample handling procedures have been developed to be consistent with the as low as reasonably achievable (ALARA) policy. The procedures were initially implemented during a nonradioactive "hands on" training session. The session allowed field personnel the opportunity to become acclimated to handling highly radioactive samples and illuminate any potential problems prior to drilling through the radiologically contaminated cribs. When handling radioactive soils, lead blankets and shielded waste drums are used when ever possible to reduce radiation exposures to the worker. A glovebox is also employed to reduce

radiation exposure and is located within a sample preparation trailer. The glovebox is used to transfer material from the split-tube sampler to sample bottles for shipment to an appropriate physical or analytical laboratory.

An interim storage facility for mixed waste compliant with EPA and Ecology policies and regulations was required prior to initiating drilling activities. The interim storage building has a storage capacity of 27, 208-l containers. The building interior has a chemical resistant coating, a grated floor covering and a chemical resistant containment sump. Waste drums are initially segregated according to suspected radioactive or mixed, nonradioactive, or unknown waste. When field instruments indicate the potential of a mixed waste, the drill cuttings are placed in a lined drum and transferred to the interim storage facility. The drums are held pending evaluation of analytical results.

CONCLUSION

Site characterization activities at the 200-BP-1 operable unit have resulted in the development of many new drilling and sampling strategies. The extensive planning and preparation activities have paid off with the start up and continued drilling and sampling efforts at the 200-BP-1 operable unit. As of the writing of this paper, 4 boreholes have been completed or in the process of being drilled. One borehole in crib 216-B-61 and 2 boreholes in crib 216-B-57 have been completed. Crib 216-B-49 is currently being characterized. Drilling and sampling efforts will continue for approximately 6 months.

The Hanford Site presents unique challenges for RI activities. The successful implementation of site characterization activities at the 200-BP-1 inactive radioactive cribs will benefit subsequent operable units and lead the way to the ultimate cleanup of the Hanford Site.

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ENVIRONMENTAL SOIL SAMPLING UNDER STORAGE TANKS UTILIZING ANGLED AUGER BORINGS

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ABSTRACT

At the Department of Energy's Fernald Environmental Management Project (FEMP) radium bearing waste is being stored in concrete structures known as the K-65 Silos. As part of the Remedial Investigation/Feasibility Study (RI/FS) at the FEMP the soils surrounding the K-65 silos are being evaluated to determine the presence and extent of radiological and Hazardous Substance List constituents that may have leaked from the silos.

Five auger borings at angles of 4 to 12 degrees below horizontal were found to be the only feasible method for collecting the samples from beneath the silos and an associated steel tank. Conventional auger drilling equipment was found to be inadequate for the project in that torque requirements for low-angle borings are much greater than those needed for vertical borings; therefore a horizontal boring machine was used to complete the five borings.

Accurate vertical tracking of the location of the advancing boreholes was necessary in order to ensure that the silos were not breached and that the boreholes would not fully penetrate the glacial till beneath the silos, which overlies the Great Miami Aquifer. A Horizontal Digitilt Uniaxial Inclinometer was used to track the boreholes.

Continuous soil sampling within the boreholes was accomplished with a Bearing Head Continuous Sample Tube System. The scope of the project changed to include the sampling of perched groundwater when water was encountered in the borings.

Although four out of the five originally proposed boring lengths were not achieved, the project was a success in that it showed that the drilling, sampling, and borehole-tracking methods used for the low-angle borings all worked well.

INTRODUCTION

At the Department of Energy's Fernald Environmental Management Project (FEMP) near Cincinnati, Ohio, radium-bearing waste is being stored in reinforced concrete structures known as the K-65 Silos. The radium-bearing residues were formed as byproducts of uranium ore processing. The silos received residues from 1952 to 1958. As part of the FEMP site-wide Remedial Investigation/Feasibility Study (RI/FS), the soils surrounding the K-65 silos are being evaluated in order to determine the presence and extent of radiological and Hazardous Substance List constituents that may have leaked from the silos and the associated decant tank. Limited geotechnical analysis is also being performed on selected samples to determine how the soil might be expected to behave during various remedial actions, as well as to provide general geological and descriptive geotechnical parameters.

Five auger borings at angles of 4 to 12 degrees below horizontal were found to be the only feasible method for collecting the samples from beneath the silos and an associated steel tank. The Sampling and Analysis Plan called for a total of five borings to be completed beneath the two silos and the associated decant tank. Continuous soil sample collection was accomplished with a Central Mining Equipment (CME) Bearing-Head Continuous Sample Tube System assembly within 4.25-inch I.D. by 8.25-inch O.D. extra-heavy-duty hollow-stem augers. This sampling system collected a three-inch-diameter core along the length of the borings in five foot increments.

Accurate vertical tracking of the location of the advancing boreholes was necessary in order to ensure that the silos were not breached and so that the boreholes would not fully penetrate the clay-rich glacial till beneath the silos, overlying the regional Great Miami Aquifer. The technology used to accomplish the borehole tracking was found in a device known as a Horizontal Digitilt Uniaxial Inclinometer (1).

During drilling of the low-angle borings, significant changes to the scope of the approved Work Plan were implemented due to the occurrence of perched groundwater in the glacial overburden that underlies the K-65 silo area. The length of three of the borings was reduced due to encountering perched groundwater. One boring was abandoned approximately 20 feet short of the target length due to encountering soils that were too hard to sample; in order to compensate, another boring was extended an additional 20 feet.

TECHNOLOGIES UTILIZED TO ACCOMPLISH THE LOW-ANGLE BORINGS

Drilling Method

During low-angle auger drilling, gravity causes much greater frictional resistance than that encountered during conventional vertical drilling since gravitational forces are active along the length of the augers rather than at a single point. A survey of conventional auger drilling equipment specifications revealed that their available torque was likely to be inadequate to achieve the boring lengths of up to 170 feet that were necessary to characterize the soils underlying

the K-65 silos. A horizontal boring machine (2), commonly used to install pipelines and culverts beneath roadways, was chosen for the project because 1) it was found to possess sufficient torque to meet the project requirements, and 2) use of conventional auger drilling equipment would have necessitated excavation of pits in order to achieve the required drilling angles and position the machine near the initial boring points. Due to the possibility of encountering contaminants in the soils, excavations larger than one cubic yard were not permitted.

Only slight modifications to the drive head of the machine were necessary to prepare it to use hollow-stem augers. An adjustable auger guide was also constructed to ensure that the prescribed angle was maintained between the boring machine and the initial boring point. The drive-head modifications and the fabrication of the auger guide were completed by the RI/FS drilling contractor, Pennsylvania Drilling Company.

Due to the unconventional nature of low-angle borings and sensitivities concerning the tracking of the boreholes, practice boring was completed in an area where no subsurface or radiological hazards were present. This allowed the crews to become familiar with the drilling, sampling, and borehole-tracking phases of the project before working in the less favorable conditions surrounding the K-65 silos. The practice location was underlain by glacial deposits similar to those expected in the K-65 silo area.

After the initial boring point was established at each boring site, a licensed surveyor calculated the drilling angles needed to clear critical structures by at least three feet and have a minimum of three feet of relatively impermeable glacial overburden below the final sampling point. Figure 1 is a depiction of the parameters and the associated equations used to calculate the minimum and maximum drilling angles. After the above-specified angles were calculated, the drilling angle was set by constructing a compacted gravel pad at an angle between the minimum and maximum required angles calculated by the surveyor. A four-inch-thick precast concrete pad was placed over the gravel for additional support. The boring machine was moved into place with a crane and anchored by augering 5 six-inch-diameter by six-feet-long helix eye-bolts into the ground and chaining the boring machine to the anchors. Placement of the anchors was such that two anchors secured the front of the machine while three anchors held the rear of the machine in place. At Location 1616, due to the requirement to push casing along with the augers, additional anchoring was necessary. The supplemental anchoring consisted of 7 six-inch-diameter steel posts set in concrete to a depth of six feet. Four posts were set in front of the machine and three were set to the rear.

Three of the five borings required for the task did not achieve their targeted length due to the occurrence of the perched groundwater. Figure 2 depicts the targeted boring lengths, actual boring lengths, and boring locations.

After groundwater was found in a boring, continued soil sampling for chemical and radiological analysis was found to be pointless as seepage of potentially contaminated water into the augers and soil sampling equipment could cross-contaminate the soil samples. Continued soil sampling through the perched water zone was completed in two borings in order to collect samples for geotechnical analysis, field screening, and to better define the geology beneath the silos.

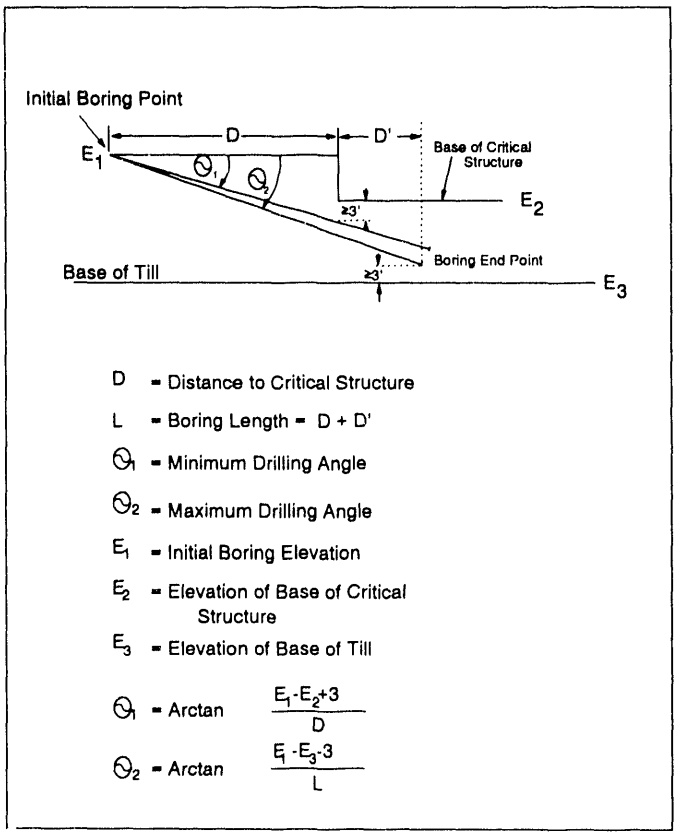


Fig. 1. Boring angle calculation paramaters.

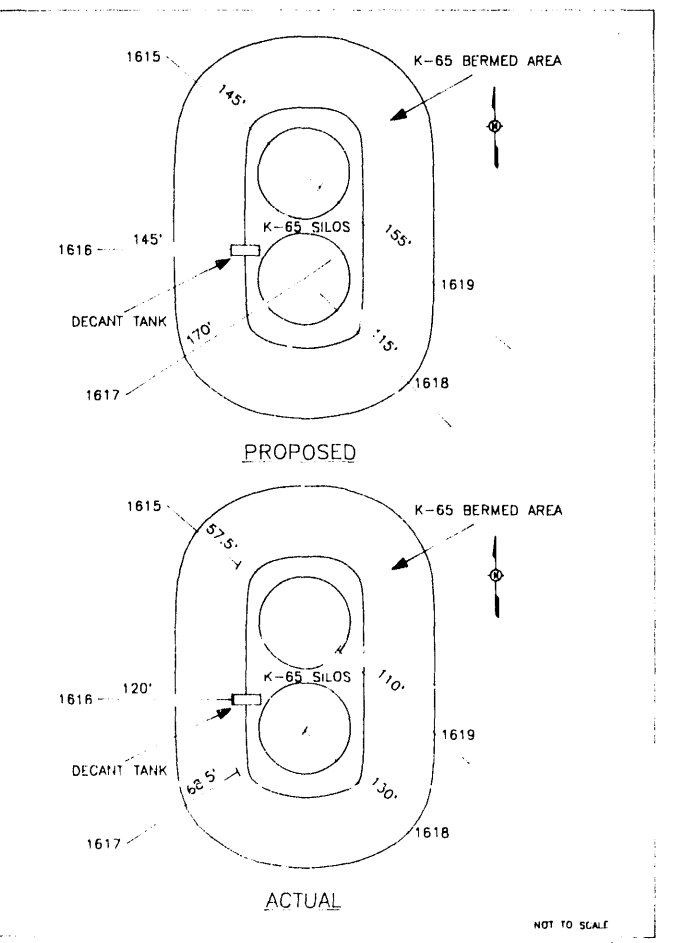


Fig. 2. Plan views of proposed and actual boring lengths.

In order to overcome the effects of the water seepage into the augers, one boring was temporarily cased as it was advanced. Boring 1616 was found to be the most critical boring of the project as it was targeted for sampling soils beneath a 9000-gallon steel tank. Historically the tank was used to hold liquids that were decanted off the silos as they were filled with the slurried waste. The tank's integrity was highly suspect since there was no secondary containment around the tank and it is more than 35 years old. Furthermore, Borings 1615 and 1617 and stratigraphic information from area monitoring wells indicated the tank was emplaced within a perched water horizon.

Boring 1616 was temporarily cased with 10.75-inch O.D. by 10-inch I.D., threaded, schedule 40 carbon-steel casing. The casing was added in five-foot lengths and was pushed behind the augers after each five-foot section of the boring was drilled and sampled. When the boring had penetrated the perched water-bearing horizon, it was temporarily halted so that a sample of the water could be collected. Drilling and casing advancement then continued through the perched zone and into the underlying clay. As previously described, soil samples were collected through the perched zone for geological, geotechnical, and screening purposes. When the casing was seated in the clay below the perched water horizon, the borehole was pumped dry and drilling, sampling, and casing advance continued. The borehole remained dry so soil samples were useable for chemical and radiological analysis.

When Boring 1616 reached a length of 112.5 feet, a hardpan consisting of a calcareous claystone was encountered within the glacial till. Augering continued through the hardpan but the casing could not be pushed past the point where the hardpan was encountered nor could soil samples be collected from the hardpan. After the hardpan was partially penetrated, soil sampling continued from 118 to 120 feet where the boring was abandoned due to the inability of the sampling equipment to function in the claystone.

Sampling

Continuous soil sampling of the borings was accomplished using a nonrotating, bearing-head sampler which collected samples in five-foot increments. The cutting shoe of the sampler was placed slightly ahead of the augers and the sample was pushed into the sampler as the augers were advanced. This technique is similar to drive sampling using a Shelby tube in that it provides a sample that can be classified as relatively undisturbed. The sampler was lined with two 30-inch clear tubes composed of Tenite TM.

Soils underlying the FEMP that were penetrated by the low-angle borings are classified as glacial overburden (3). Subunits within the glacial overburden include loess, lacustrine deposits, till, and glaciofluvial sediments. Soil samples collected from the low-angle borings were classified by the Unified Soil Classification System (USCS). The USCS classification was used so that consistency would be maintained with other RI/FS subsurface soil sampling programs where the system has been used since the initiation of RI/FS sampling.

Four USCS soil types were encountered in the slant borings: 1) **CL**-Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays; 2) **ML**-Inorganic silts and very fine sands, rock flour, silty or clayey fine sands or clayey silts with slight plasticity; 3) **SC**-Clayey sands, sand-clay mixtures; and 4) **GC**-Clayey gravels, gravel-sand-clay mixtures.

Table I shows a summary of the footage attempted, the footage recovered, and the percent recovery for each soil type and for the total low-angle boring project. Classification of soils not recovered was approximated by noting what was recovered on either side of the missing interval.

In addition to providing samples for the above-mentioned descriptions and chemical, radiological, and geotechnical analyses, continuous sampling of borings at low angles provides much more detailed information on the stratigraphic variability of a sequence of soils than vertical borings through the same sequence of soils.

Samples of perched groundwater were also collected from each of the five borings in order to supplement the soil sample analysis. Analytical parameters for the water samples included all of the chemical and radiological analyses that were specified for the soil samples as well as general groundwater quality parameters.

While the groundwater samples collected from within the augers were not equivalent to those that could be collected from a properly constructed monitor well, they were considered to be extremely valuable in determining the nature and extent of possible contamination in the soils beneath the K-65 silo area.

The original sampling and analysis plan called for submitting 28 soil samples for chemical, radiological, and geotechni-

TABLE I

Soil Sample Classification, Footage, And Recoveries

Soil Classification		Feet Attempted	Feet Recovered	Percent Recovery
CL-	Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays	320.1	275.0	86
ML-	Inorganic silts and very fine sands, rock flour, silty or clayey fine sands or clayey silts with slight plasticity	51.9	50.7	98
SC-	Clayey sands, sand-clay mixtures	90.3	77.6	86
GC-	Clayey gravels, gravel-sand-clay mixtures	16.3	15.7	96
Totals		478.6	419.0	88

* Soil classifications are per the Unified Soil Classification System (USCS). Soil types were determined in the field.

cal analysis. Due to the occurrence of groundwater in the borings the samples actually collected as of August 10, 1991 were: for soil - 13 chemical, 15 radiological, and 15 for geotechnical analyses; and for groundwater - six chemical, six radiological, and six general groundwater parameter analyses.

Borehole Tracking

Construction drawings of the K-65 silos were evaluated to determine locations and elevations of foundations, piping systems, and an underground storage tank to be avoided during drilling. The thickness of the till beneath the K-65 silos was defined with isopachous maps based on logs from monitor wells installed in the area. The integration and evaluation of this information provided a safe "window" within which sampling had to occur.

The technology needed to provide the detailed vertical borehole tracking was found in a device normally used to measure settlement or heave in embankments, dams, and foundations. The device is known as a Horizontal Digitilt Uniaxial Inclinometer and is manufactured by the Slope Indicator Company. The technology is accurate to within 0.025 feet per 100 feet of casing, according to the manufacturer.

Borehole surveys using this technology were conducted at specified intervals in order to insure that the boring was maintained within the safe "window." The frequency of the angle checks was initially proposed to be every five feet as the borehole was advanced. Test borings and the first three borings conducted in the K-65 silo area showed that the five-foot frequency was more often than was necessary, so the frequency of the borehole surveys was reduced to one survey when a boring reached the halfway point to its respective critical structure; additional surveys were conducted at 20-foot intervals for the remainder of the boring.

The Inclinometer surveys collected data from points at two-foot intervals along the length of the borings, allowing the angle of the boring to be calculated at each data point. The data was reduced using a Lotus 1-2-3 spreadsheet where the input parameters are the elevation of the initial boring point, instrument readings, and the lengths along the boring corresponding to the individual readings. The output from the spreadsheet was 1) the angle at each data point, 2) the average borehole angle to each data point, 3) the depth of each data point below the initial boring point, 4) the elevation of each data point, and 5) the horizontal distance of each data point from the initial boring point.

These data were then used in the construction of a cross-sectional view of the boring with respect to the critical structure(s) it was to pass. Figure 3 is an example of the final output of the inclinometer-derived data integrated with area survey data and geologic information.

SUMMARY AND DISCUSSION

Although four of the five originally proposed boring lengths were not achieved, the project was a success in that it showed that the drilling, sampling, and borehole-tracking methods used for the low-angle borings all worked well. The torque output limit of the boring machine was not even approached nor was the limit strength of the augers, even in the longest boring. When borings reached a length of approximately 100 feet, the machine had to be shifted from fourth to

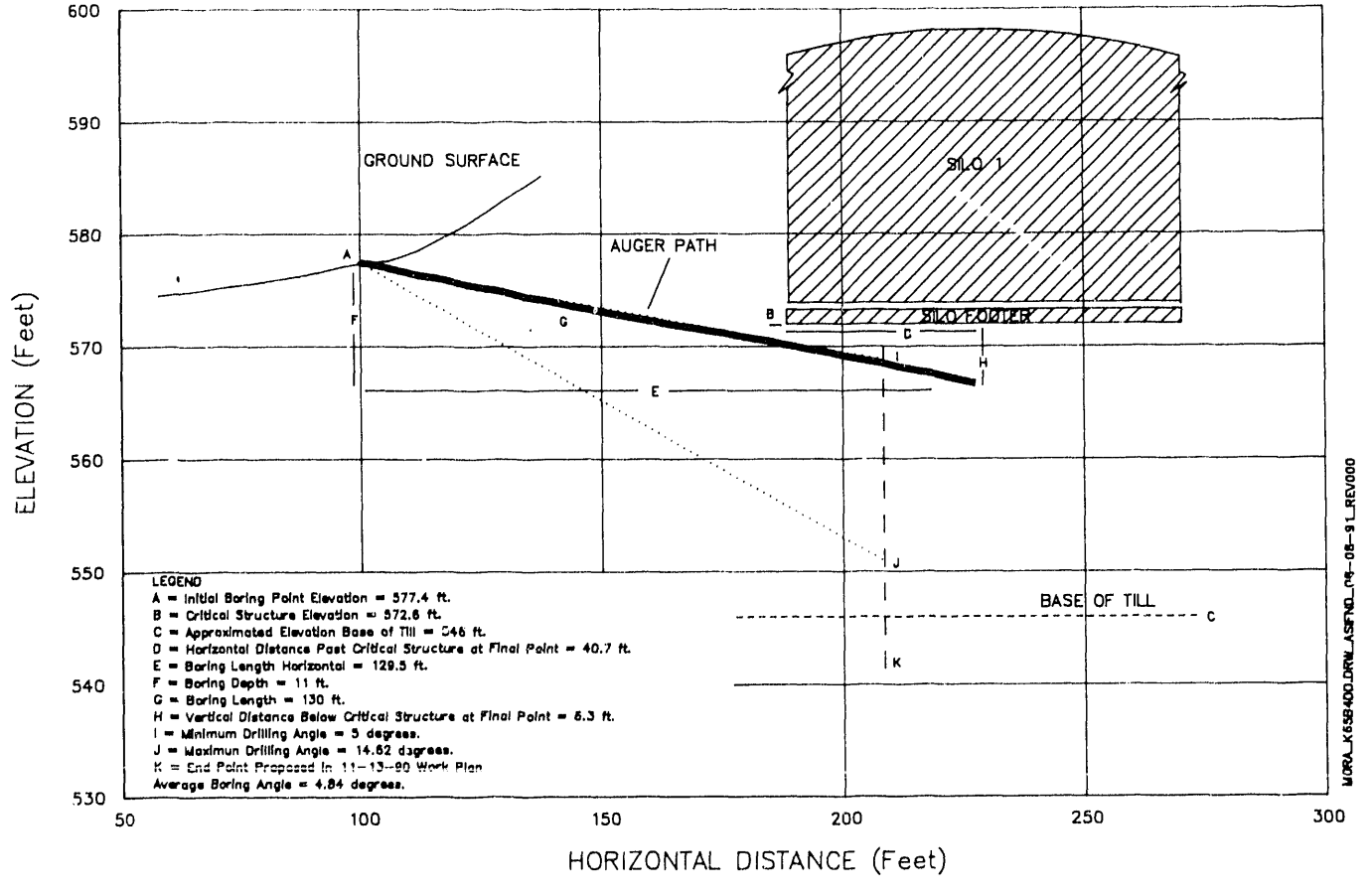


Fig. 3. Slant boring 1618 (No. 4) at K-65 silos.

third gear. For the boring machine used in this project, torque-per-gear in foot-pounds is as follows: 4th - 4782, 3rd - 8082, 2nd - 14778, 1st - 30225.

The torque available from conventional auger drilling equipment surveyed fell considerably below the 8082 foot-pounds that was available in third gear. The augers used in the project were designed to withstand up to 30,000 foot-pounds of torque. Based on this information it is a conservative estimate that this drilling and sampling technique can achieve borehole lengths in excess of 200 feet. Conversations with drillers experienced in auger drilling related that about 100 vertical feet is the maximum depth that could be attained with conventional drilling equipment, using the same size augers as were employed in the low-angle borings, in soil types found at the FEMP.

The presence of perched groundwater in the K-65 area soils prevented the attainment of the proposed boring lengths in three of the five borings, but the borings provided an opportunity to sample vadose zone soils and the groundwater in proximity to the structures that were suspected to be leaking. The groundwater samples are expected to be very valuable in defining the extent of contamination. Also, since contaminant detection limits are much greater in water than in soils, better definition of contaminant levels is possible.

The feasibility of installing monitor wells in the low-angle borings was investigated. The results indicated that it is possible to install monitoring wells in low-angle borings. Placing a conventional sandpack around the well screen was determined to be a major difficulty as the sand would not pour down such low-angle borings. This difficulty can be overcome by using a commercially available dual screen system where the sandpack is installed between two screens as part of the manufacturing process. A second difficulty in installing monitor wells at such low angles is how to prevent the grout from flowing over the screened interval. This can be accomplished by using a cement basket attached to the riser pipe just above the screened interval. The basket expands to create a seal of the annular space as the augers are withdrawn. Calls to distributors of well supply equipment related that these baskets are composed of either metal or rubber and are not presently available in stainless steel or teflon. If materials other than stainless steel or teflon are to be used in monitor well construction, it is prudent to obtain regulatory concurrence prior to use.

While the use of temporary casing to seal off water-bearing zones was successful, pushing the casing as well as removing the auger cuttings from the casing was difficult and time-consuming. Difficulties in pushing casing could likely be lessened if the boring machine could be placed in a shallow pit where the force could be distributed across the rear of the pit rather than at specific points around the machine. According to the boring machine manufacturer, a reduced annular space between the augers and the casing would provide for more efficient removal of cuttings.

At present the K-65 low-angle boring project is on hold pending analytical results of groundwater samples collected from the borings. When the results become available they will be evaluated in order to determine if the project objectives have been met or additional sampling is needed.

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METHODS FOR DRILLING AND WELL INSTALLATION IN RADIOLOGICALLY CONTAMINATED SOILS

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ABSTRACT

Methods and procedures are described for drilling and well installation in radiologically contaminated soils. This investigation was conducted at a facility located in the Town of Ashford, New York, that was formerly used for nuclear fuel reprocessing. The fuel reprocessing plant and related facilities are underlain by a surficial water-bearing glaciofluvial sand and gravel deposit averaging 7.6 meters or more in thickness. Beneath this deposit is a dense glacial till, composed primarily of clay and silt, exhibiting low permeability (i.e., 10^{-8} cm/sec range).

As part of a well installation and monitoring program initiated at the site, two augered soil borings had been drilled in separate areas in the vicinity of the main plant. Radiological contamination (primarily beta activity) was encountered in both borings at an average depth of 8.2 meters below ground surface, within the surficial sand and gravel layer. Based upon radiochemical analyses, it was apparent that most of the contamination resided in an insoluble state (adsorbed onto soil particles). However, significant activity (10^{-5} μCi/ml) still existed in a soluble form within the groundwater.

The investigation that followed was concerned with two operations: 1) drilling and completion of monitoring wells within the two contaminated boreholes; and 2) characterizing surrounding areas using an alternate exploratory approach.

The first operation involved the development and implementation of procedures for handling and control of radiologically contaminated soil and groundwater during drilling, sampling, and well installation. The intent was to define the thickness of the sand and gravel layer at both locales as well as provide long-term monitoring points that would satisfy recommended monitoring well design criteria.

The second operation involved the installation of eight exploratory well points within surrounding areas to further define the extent of subsurface contamination. While exact stratigraphic information was not acquired at these locales, the well point installation method minimized waste generation and equipment contamination, maximized worker safety, was relatively fast and cost-effective (as compared to other methods), and provided valuable data regarding the nature and extent of subsurface contamination.

INTRODUCTION

The drilling and well installation methods discussed within this paper were utilized during a Groundwater Monitoring Well Installation Program which was implemented at the West Valley Demonstration Project (WVDP) between October 1989 and September 1990. The primary purposes of the program were to fulfill the requirements of Department of Energy (DOE) Order 5400.1 relating to a general environmental protection program for the WVDP. This program included the necessity of implementing an on-site groundwater monitoring program and meeting the criteria of RCRA (Resource Conservation and Recovery Act) standards for existing solid waste management units. The program involved drilling and installation of wells to monitor known permeable zones within the overburden deposits on site.

Secondary objectives of the program were intended to support ongoing site characterization activities which included refining the knowledge of the site glacial stratigraphy as well as groundwater geochemistry and flow paths within the glacial sediments.

BACKGROUND INFORMATION

The WVDP is a federal and state government cleanup and radioactive waste management project directed by the U.S. Department of Energy (DOE). The project is located on approximately 81 hectares of a 1,336 hectare reservation developed as a nuclear energy center by the State of New York in the early 1960's. The reservation is located in Cattaraugus County, New York, approximately 48 kilometers south of the city of Buffalo and 32 kilometers inland of Lake Erie (refer to Fig. 1). The initial tenant of the reservation constructed and operated a nuclear fuel reprocessing plant and radioactive waste disposal area. During 1966-72, the plant received spent fuel assemblies from nuclear reactors and processed the fuel elements to recover uranium and plutonium. During this time, approximately 640 metric tons of irradiated fuel were reprocessed at the plant resulting in the generation of 2.5×10^6 liters of liquid high-level radioactive waste. This waste is stored in one carbon steel tank contained in an underground concrete vault.

Currently, the site contains spent fuel assemblies that have not been reprocessed, high-level radioactive liquid wastes generated by the recovery process, a variety of low-level radioactive solid wastes generated by the reprocessing facility and received from off-site commercial installations (contained in two closed radioactive waste disposal areas), an above-ground cell for storage of drums of cement-stabilized radioactive waste resulting from WVDP activities, and a number of other waste storage facilities (refer to Fig. 2). The mission of the WVDP, which commenced in 1982, is to solidify the liquid high-level waste, develop containers to encase this waste, transport the waste to a federal repository, dispose of the low-level and transuranic wastes produced from site

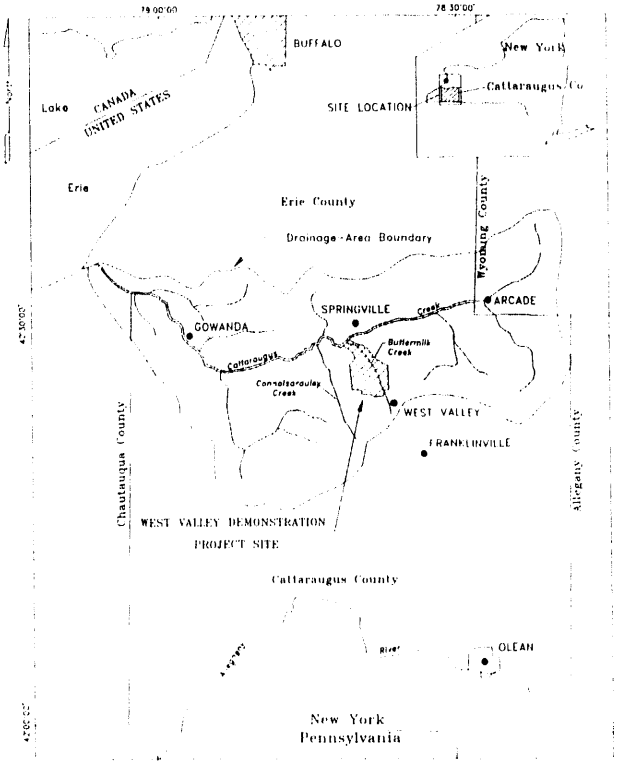


Fig. 1. West Valley Demonstration Project-location of site.

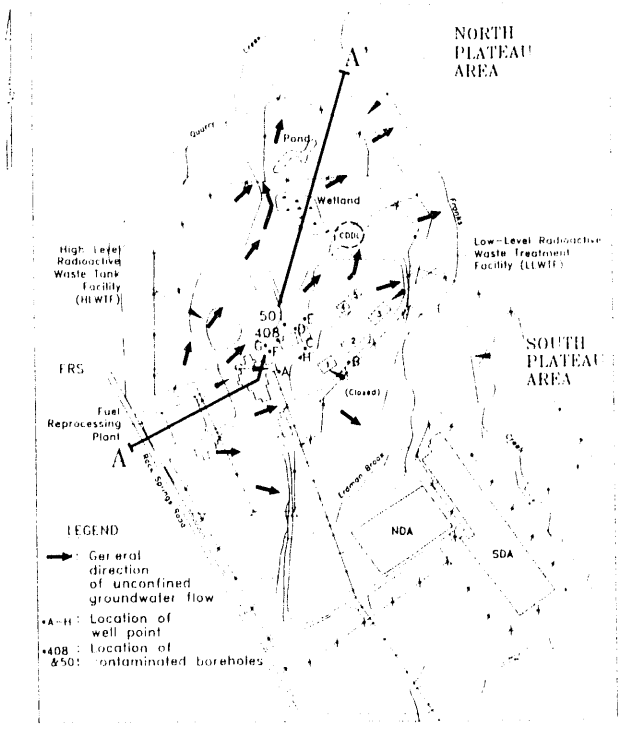


Fig. 2. West Valley Demonstratioin Project-site features.

cleanup activities, and decontaminate and decommission the facilities used to accomplish the Project mission.

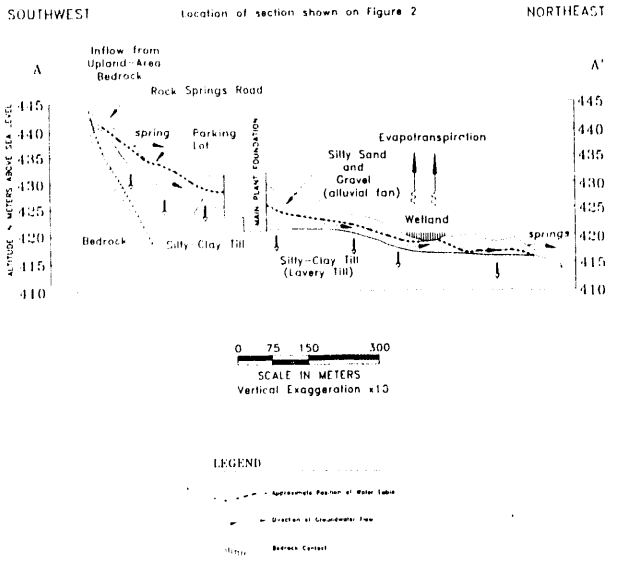


Fig. 3. West Valley Demonstration Project-North Plateau generalized hydrogeologic cross section.

SUBSURFACE CONDITIONS

The fuel-reprocessing plant (i.e. main plant) and related facilities are built on an elevated plateau, referred to as the North Plateau. (A generalized geologic cross-section showing the stratigraphic relationships beneath this area is given in Fig. 3.) The North Plateau is blanketed by a surficial silty sand and gravel layer which ranges from slightly more than 12 meters just northeast of the main plant to less than 0.9 meters feet along adjacent stream channels (refer to figure 2.). The surficial sand and gravel varies in composition but averages 55 percent gravel, 20 percent sand, 15 percent silt, and 10 percent clay. It has a moderate hydraulic conductivity in the 10^{-6} to 10^{-4} cm/sec range and averages approximately 6.0 x 10^{-5} cm/sec. Glacial till, composed mainly of silt and clay, resides beneath the surficial sand and gravel. Although largely saturated, the dense till does not transmit significant quantities of groundwater because of its low hydraulic conductivity (i.e., 10^{-8} cm/sec range).

Unconfined groundwater saturates the lower part of the surficial sand and gravel where it immediately overlies the till. Groundwater within this layer flows radially away from the main plant and northeastward toward stream channels bordering the plateau. Groundwater flow through the surficial sand and gravel is predominantly horizontal, and vertical leakage into the underlying till is inconsequential. Discharge from the sand and gravel occurs by evapotranspiration, by seepage to intermittent-stream channels that drain the plateau, and by seepage to springs above the contact between the surficial sand and gravel layer and till along the periphery of the plateau (reference 1). The directions of groundwater flow through the sand and gravel are shown in Fig. 2.

DRILLING AND WELL INSTALLATION

The field operations phase of the subject program began on October 26, 1989, and was completed on June 25, 1990. A total of 96 monitoring wells were installed on-site. Depths of wells ranged from 1.8 to 41.5 meters below ground surface. The total drilling footage for the program was 1,182 meters, which included 13 exploratory boreholes that later were grouted up to ground surface and abandoned. Drilling was

performed with two truck-mounted rigs using 10.8 cm I.D. hollow stem augers. Geologic samples from individual borings were taken continuously with 61 cm split-spoon samplers.

All monitoring wells were constructed of Johnson 5.1 cm I.D. flush joint, Schedule 5S, Type 304 stainless steel riser pipe. The screens used were Johnson stainless steel "Channel Packs"^{TM} incorporating 10-slot (0.025 cm) wire-wound inner and outer screens with intervening fine-grained sand as a filter pack. An additional filter pack was incorporated into each well installation in order to fill the annular space between the well screen and the borehole wall.

DISCOVERY AND ASSESSMENT OF SUBSURFACE CONTAMINATION

During December 1989, radiological contamination (primarily beta activity) was encountered while drilling at well location #0408 (refer to Fig. 2) at a depth of 8.5 meters below ground surface (within the surficial sand and gravel layer). A day later, a second rig encountered radiological contamination while drilling at well location #0501 at a depth of 7.9 meters below the surface. In both instances, at the first sign of contamination, drilling operations were halted in order to further characterize the subsurface conditions. Augers were left in place and the drill rigs were moved off from each site.

Based upon radiochemical screening of both silty and filtered groundwater samples obtained from each borehole, it appeared that the majority of the contamination resided in an insoluble state (adsorbed onto soil particles). Significant activity (10^{-5} μCi/mL), however, still existed in a soluble form within the groundwater.

Given the depths at which contamination was first encountered in borings #0408 and #0501, it was thought that a deep source might be the cause for such occurrences. Groundwater flow, as depicted on Fig. 2, suggests that borings #0408 and #0501 are downgradient from the main plant and fuel receiving and storage building (FRS). The FRS, which occupies the east part of the main plant, was the point of entry for fuel assemblies received at the site. The structure houses two concrete pools which contain over 3.0×10^6 liters of water. The geologic cross section (Fig. 3) shows the approximate foundation details of the FRS (furthest east) and main plant with respect to the surrounding geologic strata.

The subsequent investigative efforts which followed were concerned with two operations: 1) drilling and completing monitoring wells within the two contaminated boreholes, #0408 and #0501; and 2) characterizing surrounding areas through the use of driven well points.

PROCEDURES FOR DRILLING AND COMPLETION OF MONITORING WELLS

Procedures (outlined below) were developed for handling and control of radiologically contaminated soil and groundwater during drilling, sampling, and well installation. The intent was to define the thickness of the surficial sand and gravel layer at both locales as well as to provide long-term monitoring points that would satisfy suggested (i.e., EPA/RCRA) monitoring well design criteria (2). Prior to startup of operations at the contaminated borings, the procedures were tested in a "dry run" mode at a clean locale. Two borings were drilled and sampled, having wells subsequently installed in each to familiarize the field crew with the procedures and resolve any problems.

General procedures which were implemented included:

- Work would not occur during heavy rain, snow, or freezing conditions.
- Drill sites were roped off to assure limited access.
- All necessary equipment was mobilized to the drilling sites before initiating further work.
- All activities associated with drilling and well installation (ie. inside the roped-off area) occurred in anti-contamination clothing. Drilling crews wore vinyl anti-C's and splash shields on their hard hats.
- Radiation monitoring was performed on a continual basis.

A portable "slush" tank was fabricated out of steel plating to contain the potentially contaminated soils and water generated during drilling and well installation (refer to Fig. 4). A 30 cm diameter hole was cut into the base of the tank near one end and a similar diameter steel pipe, approximately 38 cm in length, was welded to the underside of the tank around the perimeter of the hole.

Prior to tank placement, Herculite sheeting was laid down across the entire operations area to reduce the possibility of contaminating the ground surface. An oversized hole was cut into the Herculite to fit around the auger stem. A mound of bentonite pellets was compacted around the augers (at grade) and hydrated with water. The slush tank was then lifted with a winch, positioning the extended pipe over the top of the augers. After the tank was lowered over the augers, the pipe was then pushed into the ground around them which ultimately resulted in having the bottom of the tank (around the pipe extension) resting on the mound of bentonite pellets. The mound of bentonite minimized any water from migrating upwards along the outside of the pipe and also slightly angled the tank to drain water away from the soil cuttings during drilling and well installation.

Final site preparation prior to drilling included:

- Laying down plywood boards in areas over the Herculite to secure footing during operations.
- Placing poly-lined 208 liter drums in close proximity to the slush tank.
- Setting up metal "horses" in the operations area behind the drill rig which were used for holding augers and drill rods.
- Taping plastic to back portions of the drill rig and mast to prevent surfaces from becoming contaminated.

During drilling operations, soil cuttings were collected and segregated in the slush tank and subsequently shoveled into the lined 208 liter drums. Water that collected in the slush tank was transferred to separate lined drums using a centrifugal pump.

As drill rods were being retracted through the hollow-stem augers during split-spoon sampling intervals, a compressed ball of durable paper towels was wrapped around them allowing excess water to drain back into the borehole. The rods were thoroughly cleaned of mud and wiped dry at the top opening of the augers which continued as the rods were being retracted. Used paper towels, gloves, and associated materials were disposed of into yellow plastic bags. Since the drill rods could be positioned through the rig's mast, it was not necessary for them to be broken down during sampling

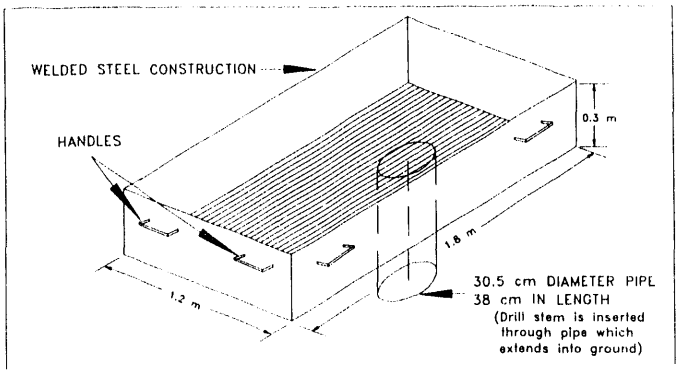


Fig. 4. Portable slush tank.

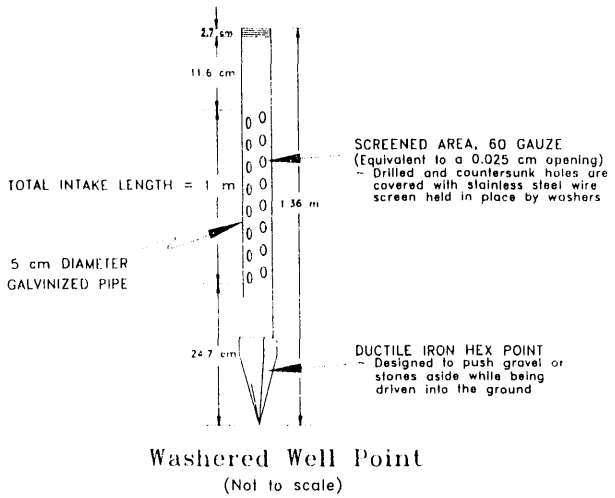


Fig. 5. Washered well point.

runs unless they would ever exceed 12 meters in length (which did not occur). Additionally, to alleviate the potential for water build-up within the rods, a small weep hole was placed into the lowest rod prior to advancing each borehole.

During sampling runs, both the bottom drill plug and split-spoon sampler were removed inside a lined 208 liter drum (positioned near the rig) to guard against potential splashing. When detached from the rods, samplers were first drained into the drum to minimize the spread of any loose material and were then opened on a sheet of yellow Herculite. Samplers were cleaned before re-entering the borehole, typically with water, a scrub brush, and a final water rinse. Upon completion of sampling at each locale (i.e., when top of till was reached), the drill rods were retracted from the borehole, broken down into their shortest lengths, placed on a layer of yellow Herculite, and covered with another layer to await transport to a designated decontamination area.

Methods for monitoring well installation were for the most part, in accordance with suggested practices. However, to compensate for downhole contamination, the sand pack around the well screen was eliminated to minimize the potential for water displacement and the time spent at each locale. It was believed that the omission of the filter pack would not affect the well design since the screens were already "channel-packed" with a thin layer of sand. Thus, the surrounding formation material was allowed to collapse around each of the well screens (prior to placement of a bentonite seal and grout) which in turn, greatly reduced the amount of time spent at each locale. Cement-bentonite grout was also pumped downhole at the slowest rate possible during well completion to control the discharge of water from the borehole. All discharge water was collected in the slush tank and subsequently transferred to lined 208 liter drums.

As augers were being retracted from the borehole, attempts were made to gently spin them in a counterclockwise direction in order to minimize the amount of cuttings coming to ground surface. All soil cuttings were shoveled into lined 208 liter drums. Augers were broken down into their shortest lengths, placed in an accessible area on a layer of yellow Herculite, and then covered with another layer to await transport to a designated decontamination area. Table I outlines

TABLE I

Monitoring Well Installation Data

Well No.	Boring Depth (meters)	Well Depth (meters)	Screened Interval (meters)	Date of Installation
0408	12.19	11.58	8.53 - 11.53	6/25/90
0501	10.06	10.06	7.01 - 10.06	6/19/90

*Bottom of well is at top of till.
**Unit screened is surficial sand and gravel.

the well installation details pertaining to final depths and screened intervals.

Later attempts were made to decontaminate the augers and drill rods utilized at each locale but proved to be too time consuming and was not cost effective. Thus, all contaminated and potentially contaminated equipment was placed into metal boxes (designed for storage of radiologic waste) which remained on-site. All soil cuttings were treated as radiologic waste and were likewise transferred into metal boxes. A composite water sample was collected from each 208 liter drum and characterized for both radiological and various chemical constituents. Since the water did not contain hazardous chemical constituents nor abnormally high radiological activity, it was subsequently transferred to the on-site low-level waste treatment facility.

PLACEMENT OF DRIVEN WELL POINTS

The discovery of contamination in borings #0408 and #0501 left questions concerning its lateral extent within the subsurface. Based on the low permeability of the underlying glacial till, it was believed that the majority of contamination would be confined to the surficial sand and gravel layer. Conventional drilling with augers was ruled out as a potential method for further investigating this concern due to a number of reasons, including cost effectiveness. Other methods (i.e., driven sampling instruments and cone penetrometers) were also ruled out primarily due to equipment costs and the possibility of such equipment becoming contaminated during the course of operations. Driven well points were ultimately chosen for the investigation since the method is relatively fast, requires minimal labor, and utilizes inexpensive materials. Additionally, this method, as employed, would minimize

equipment contamination and waste generation and thus, maximize worker safety.

Eight exploratory well points were installed to varying depths below ground surface in an effort to further define the extent of subsurface contamination. Since the main plant and FRS were considered potential sources contributing to the observed contamination levels in #0408 and #0501, the majority of the well points were placed in areas northeast of the structures (downgradient to the direction of groundwater flow). Three well points (i.e., WP-B, C, and H) were placed in the vicinity of ex-Lagoon 1 which was a confirmed site of contamination.

Each well point consisted of 5.1 cm I.D. galvanized steel riser pipe attached to a 1.2 meter bottom section of perforated pipe (refer to Fig. 5). The perforations were covered with pieces of stainless steel, No. 60 wire mesh (equivalent to a 0.025 cm opening), held in place by threaded washers. An iron hex-shaped point was attached to the bottom of each perforated section. The points had widened shoulders designed to push gravel or stones aside to reduce the danger of ripping the wire mesh as the pipes were being driven into the ground. A 63.5 kg hammer was used for driving each installation. Since this technique did not incorporate actual drilling and geologic sampling, the final depths and horizons penetrated for each installation were estimated (via triangulation methods) based upon nearby subsurface information obtained during this and previous investigative programs. All final depths were assumed to be top of till. Table II outlines the well point installation details. Well locations are depicted on Fig. 2.

One to three days after installation, groundwater was extracted from the well points via dedicated bailers and analyzed in an on-site laboratory for gross alpha, gross beta, and tritium. The well points offered flexibility in sampling since in several instances, they were either driven deeper or pulled up to higher elevations in an attempt to observe changes in water quality with depth.

TABLE II

Well Point Installation Data

Well Point ID	Depth (meters)	Screened Interval (meters)	Date Driven
WP-A	8.53 m	7.31-8.53	3/30/90
" "	10.06 m	8.84-10.06	5/03/90
WP-B	3.65 m	2.44-3.65	3/30/90
WP-C	7.01 m	5.79-7.01	4/02/90
WP-D	9.45 m	8.23-9.45	4/03/90
" "	7.92 m	6.70-7.92	5/09/90
WP-E	6.70 m	5.49-6.70	4/03/90
WP-F	10.07 m	9.75-10.97	5/04/90
WP-G	10.36 m	9.14-10.36	5/04/90
WP-H	2.13 m	0.91-2.13	5/03/90
" "	5.18 m	3.96-5.18	6/14/90

* Note: WP-D was retracted 1.52 meters at a later date.
* All depths assumed to be top of till.
* Unit screened assumed to be sand and gravel.

SUMMARY

Radiologically contaminated soil and groundwater exist in certain areas within the subsurface at the WVDP as verified through actual drilling. When contamination is encountered, operations are slowed, time is lost, and expensive materials become contaminated to the point that they cannot be cleaned cost effectively. Additionally, since the vertical and horizontal extent of contamination is not known precisely, the uncertainty forces conventional drilling operations to proceed with extreme caution and, therefore, at much greater cost than comparable efforts in uncontaminated media.

The procedures which were developed for the handling and control of radiologically contaminated soil and groundwater proved to be quite effective during the drilling, sampling, and well installation operations. Surface contamination to the ground, drill rigs, and drilling crews was kept to a minimum while a high degree of occupational safety and health was maintained for all parties involved. The combined drilling and well installation efforts resulted in the expenditure of approximately 21 meters of augers and drill rods along with miscellaneous equipment (i.e., drill plugs, cutters, split-spoon samplers, slush tank, pump) which was ultimately dispositioned as radiologic waste. (The estimated cost to replace this equipment was approximately $7,500.00. However, the primary goal was accomplished which was to define the thickness of the sand and gravel layer at both locales as well as provide long-term monitoring points that would satisfy recommended monitoring well design criteria. Additionally, use of the Johnson "Channel Pack" well screens eliminated the time and labor needed to emplace a sand pack between the screen and the borehole wall in wells #0408 and #0501.

The well point installation technique utilized inexpensive, expendable materials and was relatively simple to implement. (The materials required for each installation averaged $270.00). Compared to conventional drilling methods, this technique greatly reduced the time and labor needed to acquire useful information regarding the nature and extent of subsurface contamination. It is noted, that the time and labor costs for each well point installation averaged 2 percent of the time and labor costs associated with drilling and completion of monitoring wells in each of the two contaminated boreholes. In addition, this method minimized waste generation and equipment contamination, and maximized worker safety.

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ELECTRICAL RESISTANCE TOMOGRAPHY TO MONITOR VADOSE WATER MOVEMENT

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ABSTRACT

We report results of one test in which Electrical Resistance Tomography (ERT) was used to map the changes in electrical resistivity in the vadose zone as a function of time while water infiltration occurred. The ERT images were used to infer shape and movement of the infiltration plume in the unsaturated soil. We supplied a continuous water source at a point about 10 feet below the surface (at the end of a shallow screened hole) for only a short time--2.5 hours. This pulsed source introduced a 'slug' of water whose infiltration was followed to about 60 foot depth during a 23 hour period. The ERT images show resistivity decreases as the water content of the vadose zone increased while water was added to the soil; the resistivity of the soil later increased after the supply of water was cut-off and the induced soil moisture began to subside.

INTRODUCTION

In recent years, considerable attention has been given to the role of the unsaturated zone in contaminant transport and storage. This interest results from the fact that most often, contaminants reach the ground water aquifers after first moving through the vadose zone, which is, of course, thereby contaminated. Also, release rates to an aquifer are influenced by vadose transport processes. The difficulty is that movement, distribution and storage of contaminants in the unsaturated zone are influenced by complex underground properties such as hydraulic heterogeneity and little understood processes such as sorption.

Transport processes in the unsaturated zone are often complex and poorly understood. It is becoming increasingly clear that understanding spatial variability of hydraulic properties is essential to predicting water velocity (both speed and direction) in a system as heterogeneous as most soils. Laboratory or scaled experiments can help our understanding of the role of heterogeneity but a combination of laboratory and field experimentation will provide the most convincing validation of conceptual and numerical models. For example, realistic high permeability paths and layering as they exist naturally are difficult to model either numerically or with scaled experiments. Therefore, carefully designed field experiments are need.

Infiltration is the entry of water into the soil from the ground surface and the associated flow away from the surface within the unsaturated zone. When the supply at the surface is large (e.g., heavy rain) infiltration will follow a limiting case, called the infiltration capacity of the soil (1). This capacity decreases with time as the upper regions become saturated and the infiltration capacity asymptotically approaches a constant rate. This decline occurs as the soil pores fill with water. Of course, the initial decrease and ultimate steady state infiltration rates depend on the hydraulic properties of the soil.

ELECTRICAL RESISTIVITY TOMOGRAPHY--

To image the resistivity distribution between two boreholes, a number of electrodes were placed in each hole; each electrode in electrical contact with the formation . Two electrodes were driven by a known current and the resulting voltage difference was measured between other pairs of electrodes. (Each ratio of measured voltage and current we will call a transfer resistance.) Then, the known current was applied between two other electrodes and voltage differences again measured using electrode pairs not being used for the source current. This process is repeated until all the linearly independent combinations are measured. The measurements which we have described for a cross borehole survey are similar to those used in the conventional surface dipole-dipole resistivity survey.

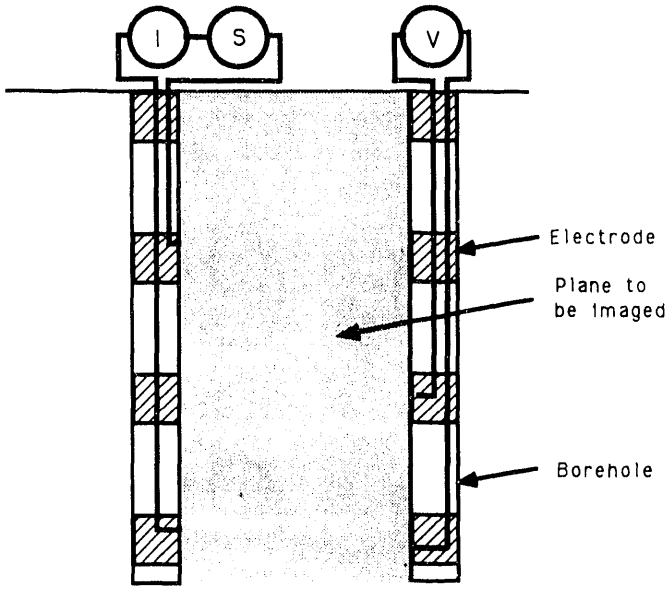


Fig. 1. Schematic of resistivity measurements made between two boreholes. Electrodes in each borehole make electrical contact with the formation. Current is driven through the formation from two electrodes and the potential difference is measured between other electrode pairs. The procedure is repeated for many combinations of source and receiver electrode positions in the same hole or in different holes. The number of electrodes per borehole used for the work described herein was 8 rather than the 4 shown by this figure.

The goal was then to calculate the distribution of resistivity in the vicinity of the boreholes given the measured transfer resistances. This problem is highly non linear because the

current paths are dependent on the resistivity distribution but this type of inversion has been studied by several researchers in medical and geophysical research. Subsequent to this earlier work many have tried other approaches with varying degrees of success (e.g., 2, 3, 4, 5, 6, 7, and 8). Recent work (9) shows that variational constraints can be used to stabilize such inversions.

EXPERIMENTAL PROCEDURE

The site is located within the boundaries of Lawrence Livermore National Laboratory, Livermore, California. The entire vicinity is underlain by late Tertiary and Quaternary continental fluvial and lacustrine sediments. These sediments are complexly interbedded, unconsolidated alluvial clay, silt, sand and gravel. Depth to ground water is about 70 feet.

Data Acquisition and Reconstruction

Two boreholes were drilled about 20 feet apart in which 8 electrodes were grouted at equally spaced intervals between the surface and 60 foot depth. Boreholes were assumed to be straight and vertical.

Infiltration of water was from a third 12 foot deep injection hole, screened over the lower few feet, and located midway between the other holes. We began the experiment by taking cross borehole ERT data before water was added to the injection hole. This data was used as background to compare with subsequent data which was taken during the 2.5 hours water was added to the injection well. This comparison was to separate the static resistivity distribution from the changes caused by water infiltration. The comparisons were made by reconstructing the ratio of each transfer resistance measured before and during infiltration, multiplied by the corresponding transfer resistance calculated for a homogeneous resistivity distribution.

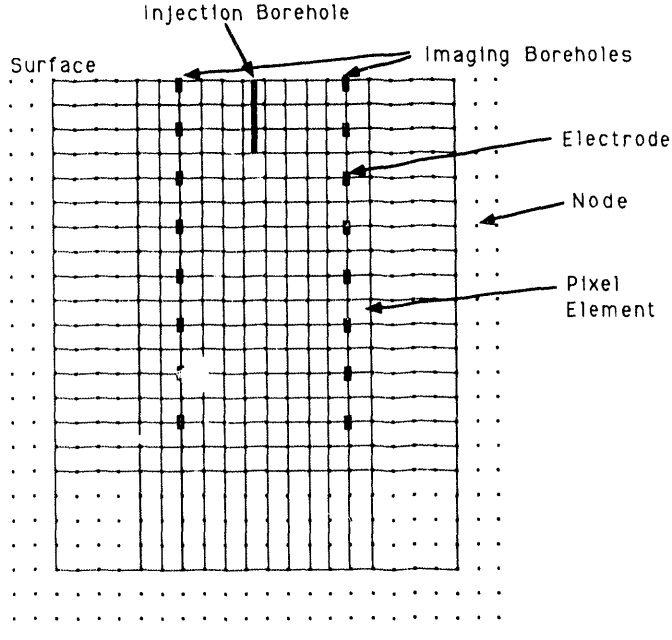


Fig. 2. The reconstruction plane was modeled by a finite element mesh 7 elements wide (between the boreholes) and 14 elements long (along the boreholes). Additional elements were used to model the resistivity external to the region between the boreholes.

RESULTS AND DISCUSSION

Figure 3a shows the tomograph before infiltration. Reconstructed resistivity values range from 8 to 320 ohm-m and indicate something of the formation structure. The more resistive region is near the surface between about 1.5 m (5 ft.) and 7.6 m (25 ft.)depth.

This corresponds to a gravel zone between 2.4 m and 8.5 m (8 and 28 ft.) recorded in the driller's log for one of the holes. High resistivity would be expected in such a layer that is far from the water table because this material can hold little water by capillarity. The other resistive layer at about 15.2 m (50 ft.) depth is much thinner. This feature may correspond to a sandy layer found during drilling between 14.3 and 15.8 m (47 and 52 ft.) The electrically conductive region between about 7.6 and 14.3 m (25 and 47 ft.) depth is likely the thick zone of clayey silt and silty clay between 8.5 and 14.3 m (28 and 47 ft.) in the driller's log.

Figure 3b-3e shows a time sequence of tomographs which are comparisons with the background. This sequence shows the results obtained as water was added to the soil. Increased water content will result in decreased resistivity (decreased resistivity corresponds to lighter shades in Fig. 3, no change is indicated by black shade). Therefore, these images are displayed showing decreasing resistivity relative to the pre-infiltration condition.

Figure 3b, taken only 6 minutes after infiltration began, shows little change in resistivity. In fact, at this point it is likely that so little water has actually entered the formation that this image provides a good test of the precision to which changes can be imaged. If the formation resistivity is constant, the data error free and the reconstruction algorithm perfect, the comparison image should be uniform throughout the plane. Deviation from this ideal is a measure of the goodness of these assumptions. For this experiment we believe that the anomalies in Fig. 3b are a reasonable measure of the data errors and algorithm performance in the presence of these errors. In other words, for subsequent comparison images, changes of the magnitude seen in Fig. 3b cannot be expected to reflect actual changes in the soil.

Thirty nine minutes after infiltration began, a distinct and significant anomaly appears near the bottom and to the left of the injection hole (Figure 3c). After 70 minutes, this anomaly has grown in size and the resistivity has continued to decrease. Between 70 and 102 minutes the water appears to begin movement downward along what may be a fairly narrow channel. The image is consistent with a very narrow channel which is barely resolvable. Another possibility is that some part of the flow is out of the image plane. The delayed formation of this channel for at least 70 minutes is consistent with the presence of a barrier at about 3.0 m (10 ft.). Shallower than 13.0 m the fine grained soil (predominantly clays in the driller's logs between 2.1 and 3.3 m (7 and 11 ft.)) absorbed water until saturated, then water moved across the capillary barrier, into the courser gravels (shown below 3.3 m in the driller's logs).

After 150 minutes (after Figure 3e) the water source was shut off. Figure 4 shows the results obtained after the water was shut off. From 222 and 287 minutes (Figure 4a and 4b) the resistivity continues to decrease and the anomaly grows deeper (i.e.,anomalies shown in a lighter shade), even with a significant part at 55 feet along the right borehole. The rapid

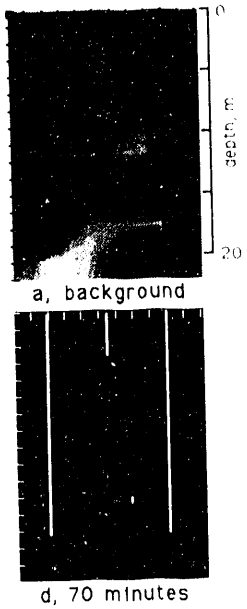


Fig. 3. Absolute and comparison images showing resistivity changes while water was added to the formation. Borehole location and mesh size is indicated on the overlay for each image. (a) Absolute image of resistivity distribution before infiltration. For this image the color scale is logarithmic from about 0.9 to 2.5 (8 to 320 ohm-m; shade scale shows minimum value in white and maximum value in black). Images (b) through (e) are comparison images of changes in resistivity distribution during infiltration. Times are measured from beginning of infiltration. For these images the shade scale is relative with zero resistivity change shown in black and maximum resistivity change shown in white.

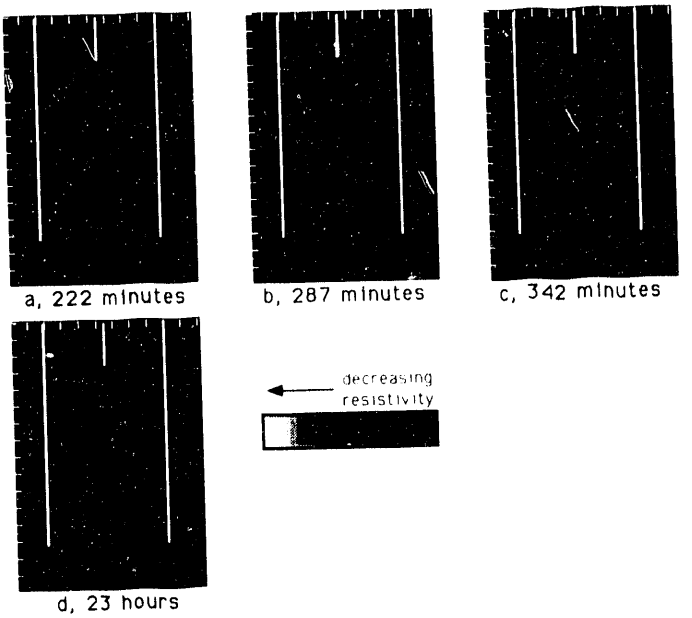


Fig. 4. Comparison images showing resistivity changes after the water source was shut off. Borehole location and mesh size is indicated on the overlay for each image. (a) through (d) are comparison images of changes in resistivity distribution during infiltration. Times are measured from beginning of infiltration. For these images the shade scale is relative with zero resistivity change shown in black and maximum resistivity change shown in white.

movement of the anomaly from 3.0 to 16.8 m (10 to 55 ft.) implies a highly permeable formation as might be expected from sandy gravels. A broad zone of such material shows in the drillers log between about 3.0 and 9.1 m (10 and 30 ft.) in borehole on the right and between 1.8 and 8.2 m (6 and 27 ft.) in the borehole on the left. Heterogeneity of the formation is indicated here also. The anomaly near the bottom of the hole on the right appears nearly isolated. At least two possibilities might explain why this anomaly appears disconnected from the source of flow. First, water movement may be through a very narrow channel which is not resolvable or which is just resolvable. Second, there may be flow out of the image plane.

After 342 (Figure 4c) minutes the magnitude of the resistivity decreases become smaller. This implies that the plume of moisture content is declining as the excess water moves by capillarity down concentration gradient into the surrounding formation or by gravity down permeable paths to the water table. As we have pointed out above, our picture of the spatial and temporal formation of this infiltration plume, as deduced from the tomographs, is consistent with the known geology at the site: heterogeneity of the soil leads to a rather complex plume shape. However, we were somewhat surprised at the speed at which the plume developed. If the water moved from 3.7 m to 18.3 m depth (12 feet to 60 ft.) by 102 minutes (Figure 3e), as suggested by the fourth comparison image, the average speed was almost a half a foot per minute. That suggests a high average hydraulic conductivity. But in fact, Figure 3d suggests that development of the plume below about 3.7 m (12 ft.) didn't begin until at least 70 minutes into the test. Therefore, a more reasonable transit time is less than 32 minutes. This implies an average wetting front speed of more than 0.5 m per minute(1.5 ft. per minute) and of course an even higher hydraulic conductivity.

ACKNOWLEDGEMENTS

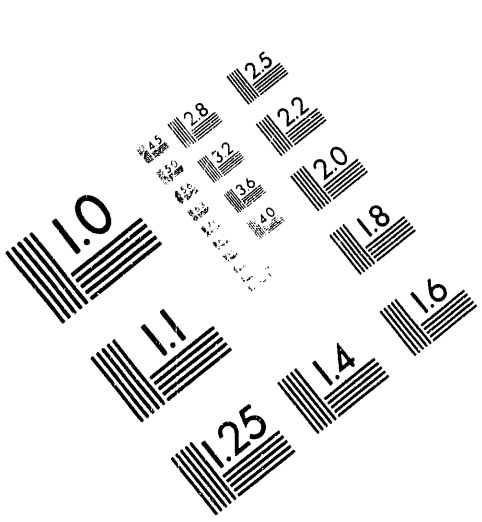
The authors are grateful for helpful discussions with J. Berryman and M. Wilt. J. Beatty provided programming support. J. Carbino provided field technical support. R. Thorpe coordinated site access and borehole drilling.

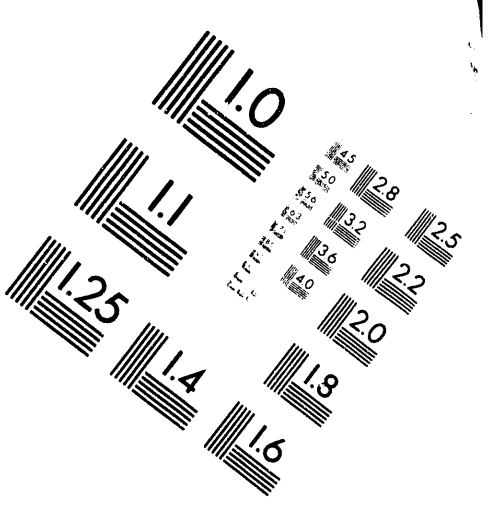
This work was supported by the Institutional Research and Development program at Lawrence Livermore National Laboratory and by the Office of Basic Energy Sciences of the U.S. Department of Energy. This work was performed under the auspices of the U.S. Department of Energy by the Lawrence Livermore National Laboratory under contract W-7405-ENG-48.

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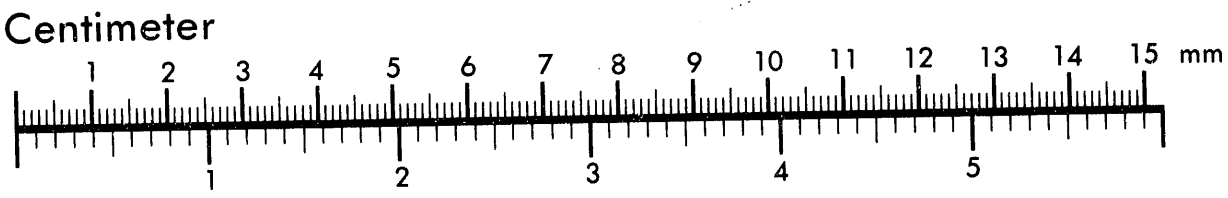
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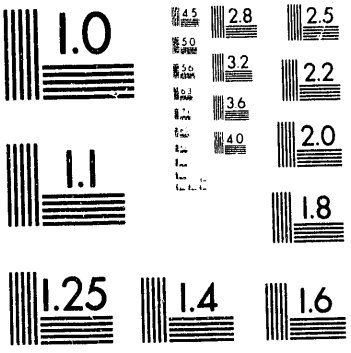


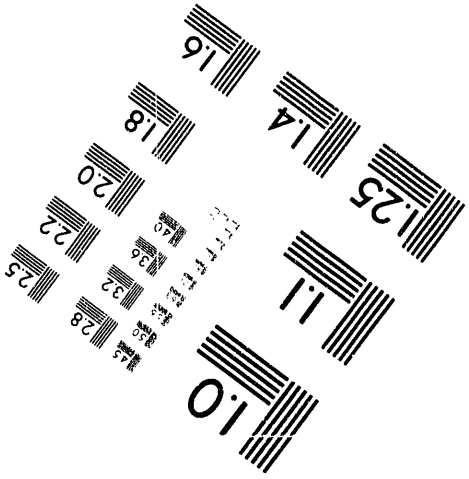


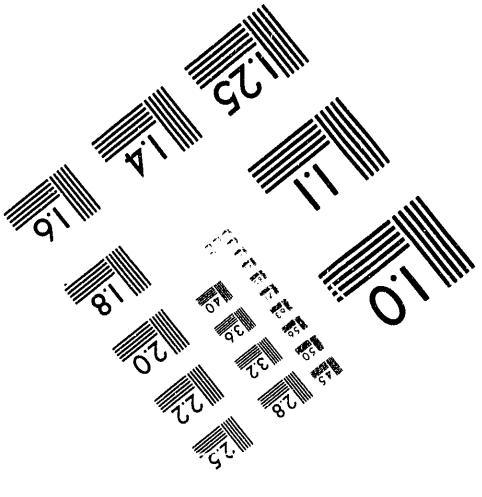


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GRAPHICAL PRESENTATION OF FERROCYANIDE TANK COMPOSITIONS

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ABSTRACT

This paper illustrates the composition of the Hanford Site ferrocyanide tanks using three-component diagrams. The diagrams show the thermodynamic and physical relationships between reactants and diluents as a function of concentration. They have been especially useful for clarifying safety work and chemistry issues.

The three-component diagrams act as a way to aid in the understanding of both possible and probable tank layer compositions. Most overall tank compositions appear to be nonreactive and indicate that the fraction of material that might react in tank is only a small part of the total. The result has been a focus of effort on compositions that can actually propagate and a deemphasis on the many combinations that are endothermic. As sampling data becomes available actual tank compositions will be plotted on the diagrams.

INTRODUCTION

Ferrocyanide or citrate may react with sodium nitrate at temperatures greater than 500 K; thus, releasing heat and gases. Diluents (i.e. water) or excess reactants (i.e. sodium nitrate) quench the reaction, which can render Hanford Site's tanks and cribs less reactive at a given temperature.

For a reaction to proceed by itself, it has to be exothermic and it must be able to heat the reactants from a base temperature to the minimum temperature where reaction can occur. Any excess energy can be used to raise the reaction products to higher temperatures. If any excess reactant, either fuel or oxidizer, is added the maximum temperature is less because some reaction energy is required to heat the excess material up.

UNCERTAINTIES AND LIMITATIONS

Little measured data exists on the actual tank compositions or on the reactive behavior of the ferrocyanide and citrate. In the absence of reaction data, the three-component diagrams are based on theoretical thermodynamic calculations using handbook values. The calculations assume an "ideal system" that is isothermal, isobaric, and adiabatic. These simplifying assumptions are conservative and the actual tanks are likely to be less reactive than what the diagrams portray.

The actual tank compositions are not known and efforts are underway to sample and analyze the tanks. The tank data shown in this presentation is from historical records (with computer enhancement) which are neither precise nor complete.

FINDINGS

Ferrocyanide Containing Tanks

Twenty-four of Hanford Site's single-shell tanks have been identified as containing ferrocyanide. Eight of these tanks contain a total of 100 tons of ferrocyanide. Concern exists that at elevated temperatures, the ferrocyanide and the sodium nitrate in the tanks will react; thus, releasing heat and gases.

The three-component diagrams define the compositions that can sustain a ferrocyanide reaction, depict how reaction temperature changes with varying compositions, and estimate the location of Hanford Site's tank compositions on the diagrams.

Figure 1 depicts the thermodynamic relationship between two reactants, $Na_2NiFe(CN)_6$ and $NaNO_3$, and diluents. The diluents are calculated in terms of water equivalents because water has the largest affect on diluting the reaction. The other diluents are entered at the same equivalent thermal value as water.

The hatch area on the diagram indicates where a reaction will not propagate because of dilution. Correspondingly, the white area in the diagram indicates where a reaction may propagate, under ideal conditions. The graph shows that large excesses in diluents or excesses in either reactant quench the reaction.

The line separating both areas represents where the heat released from the reaction is equal to the heat absorbed by diluents and excess reactant. Thus, the diagram defines the compositions that can sustain a ferrocyanide reaction.

Figure 2 is similar to Fig. 1 except the affect of tank composition upon reaction temperature is portrayed. Laboratory experiments measured the minimum temperature to be 500 K for a reaction to initiate. As the composition reaches optimum stoichiometry, the reaction temperature increases. Figure 2 shows optimum stoichiometry at 40% ferrocyanide, 60% sodium nitrate, and 0% diluents. At this point, the reaction will proceed at its highest possible temperature and presumably will propagate at its highest rate.

The energy used for phase changes and compound decompositions produces isothermal lines that diverge and converge on the diagram. Also, the diagram only includes changes for reactants, products, and water. At higher temperatures, energy changes in the other diluents found in the waste would decrease the reaction temperatures from that shown on Fig. 2. Also shown on Fig. 2 are Chemist Mixes #1 and #2. A panel of senior chemists postulated two conservative, but probable, energetic compositions that are within the reactive envelope depicted on the diagrams. The two compositions are based on past tank and process operations and the characteristics of the tank constituents. The two compositions are not intended to completely represent the actual tank compositions, but only the most energetic mixture likely to exist.

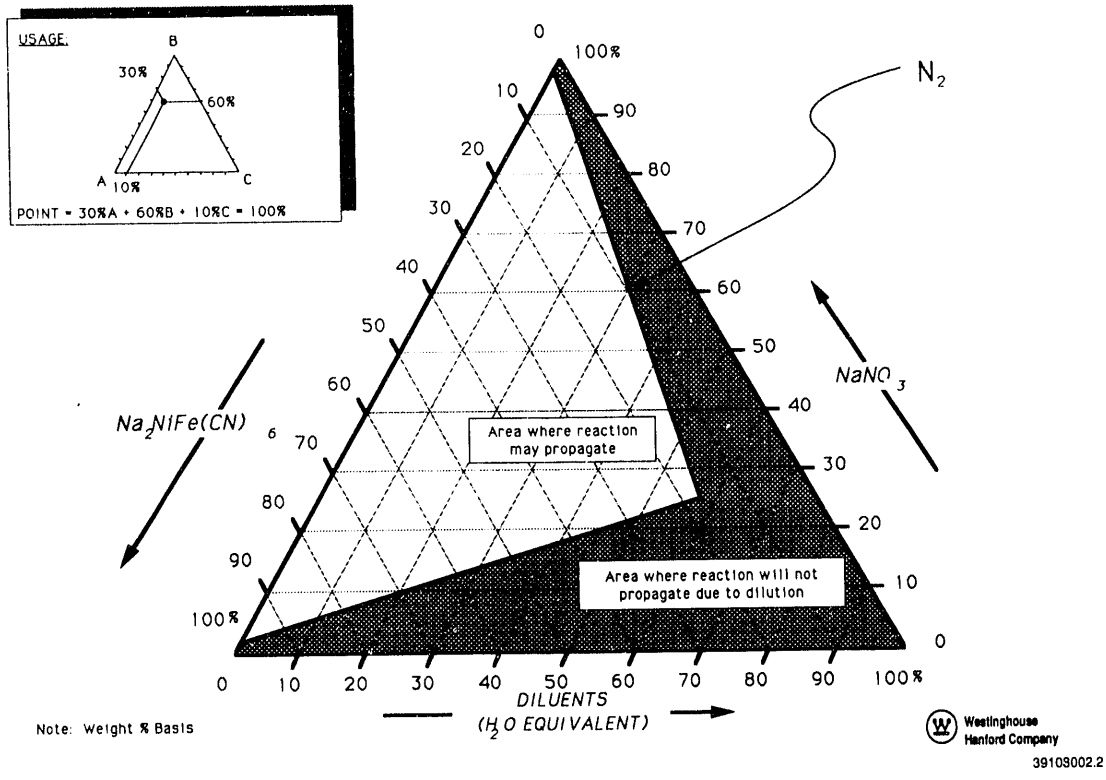


Fig. 1. Ferrocyanide tank 3-component diagram. Reaction propagation vs. concentration.

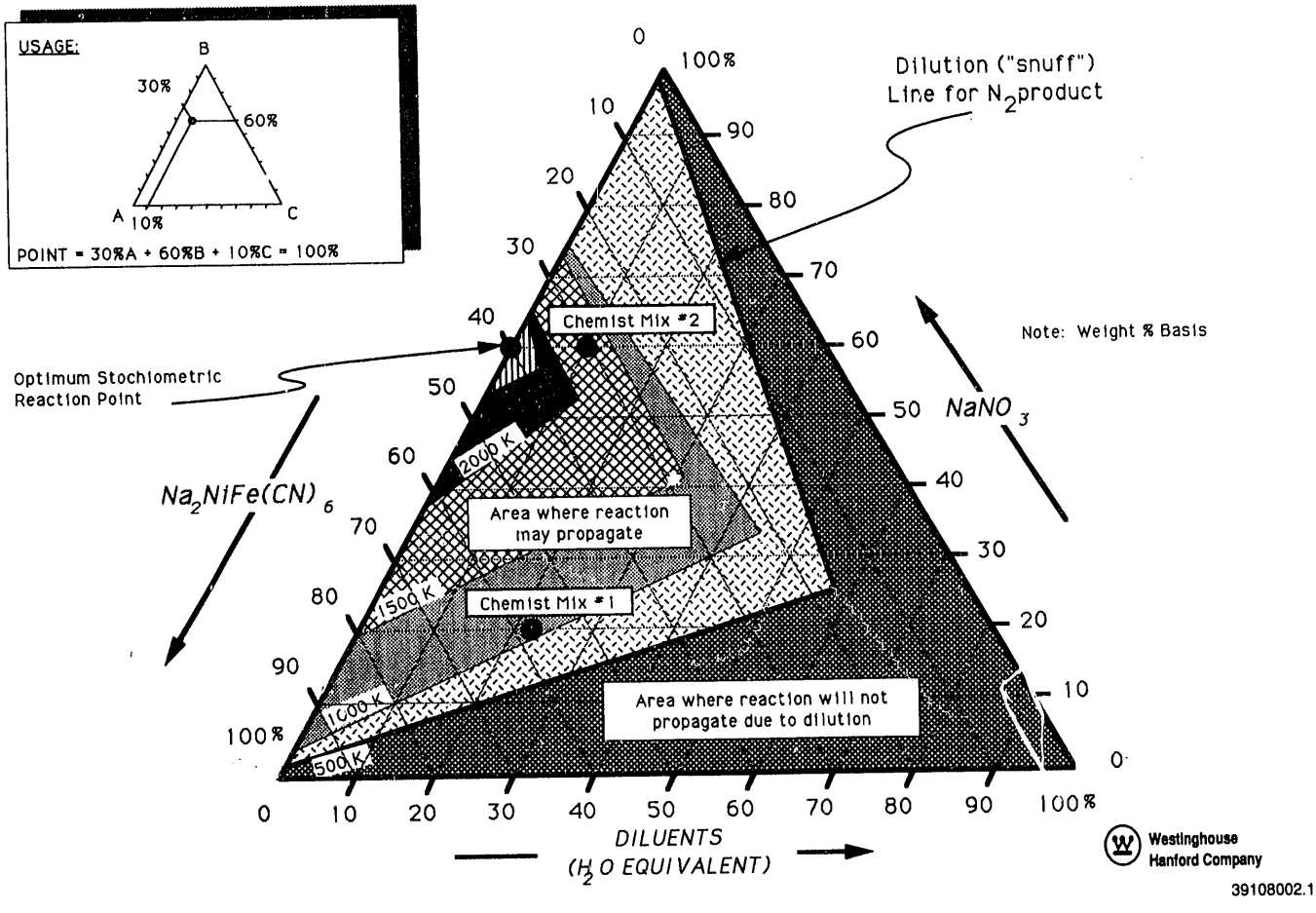


Fig. 2. Ferrocyanide tank 3-component diagram. Reaction propagation vs. concentration.

$Na_4NiFe(CN)_6 + 54NaNO_3 + 22H_2O \longrightarrow 6Na_2CO_3 + FeO + NiO + \boxed{60NO_2} + 44NaOH$
$\Delta H_r = +6234$ KJ

$Na_4NiFe(CN)_6 + 14NaNO_3 + 2H_2O \longrightarrow 6Na_2CO_3 + FeO + NiO + \boxed{20NO} + 4NaOH$
$\Delta H_r = -226$ KJ

$Na_4NiFe(CN)_6 + 9NaNO_3 \longrightarrow 5.5Na_2CO_3 + FeO + NiO + \boxed{7.5N_2O} + .5CO_2$
$\Delta H_r = -2152$ KJ

$Na_4NiFe(CN)_6 + 10NaNO_3 \longrightarrow 6Na_2CO_3 + FeO + NiO + \boxed{6N_2O + 4NO}$
$\Delta H_r = -1820$ KJ

$Na_4NiFe(CN)_6 + 6NaNO_3 \longrightarrow 4Na_2CO_3 + FeO + NiO + \boxed{6N_2} + 2CO_2$
$\Delta H_r = -3050$ KJ

Fig. 3. Possible Ferrocyanide reactions. 39104091.2

Figure 3 lists several ferrocyanide reactions that can occur. The key difference in the reactions are the forms of nitrogen compounds produced. The most energetic case is ferrocyanide reacting to produce N_2, evolving 3050 kJ/mol ferrocyanide. The least energetic is ferrocyanide reacting to produce NO_2, absorbing 6200 kJ/mol ferrocyanide. For conservatism, the most energetic of these reactions, which produces pure N_2, was used unless otherwise noted.

Figure 4 depicts the thermodynamic properties for the various possible ferrocyanide reactions. The reaction envelope for ferrocyanide reacting to produce N_2 is as shown previously in Figs. 1 and 2. The other reactions have smaller reaction envelopes corresponding to their smaller energy evolution. The reaction to produce NO_2 can not be seen on Fig. 4 because it is an endothermic reaction.

In all probability, a combination of nitrogen compounds would be produced during a tank excursion, rendering the case of N_2 being produced as the bounding condition.

If the lower layer of sludge waste is assumed to be evenly mixed, Fig. 5 shows that the overall tank compositions appear nonreactive because of dilution. Because the tank contents are not proven to be homogeneous, the conclusion of nonreactivity is not assured.

Citrate Containing Tanks and Cribs

Composition diagrams were drawn for the cribs where some ferrocyanide solutions were discarded. While the reactivity potential is similar to the tanks there appears to be sufficient dilution from natural materials to preclude an exothermic reaction.

Similar data is presented as Fig. 6 for the case of sodium citrate and nitrates. It shows that relatively low concentrations of citrate are burnable in sodium nitrate and present a potentially large energy release because the potential inventory is larger. Water and other diluents have similar quenching effects on this system.

FUTURE WORK

Future work includes characterizing the tanks at which point the ferrocyanide tank issue will be much better defined. Also planned are burn propagation and kinetic tests.

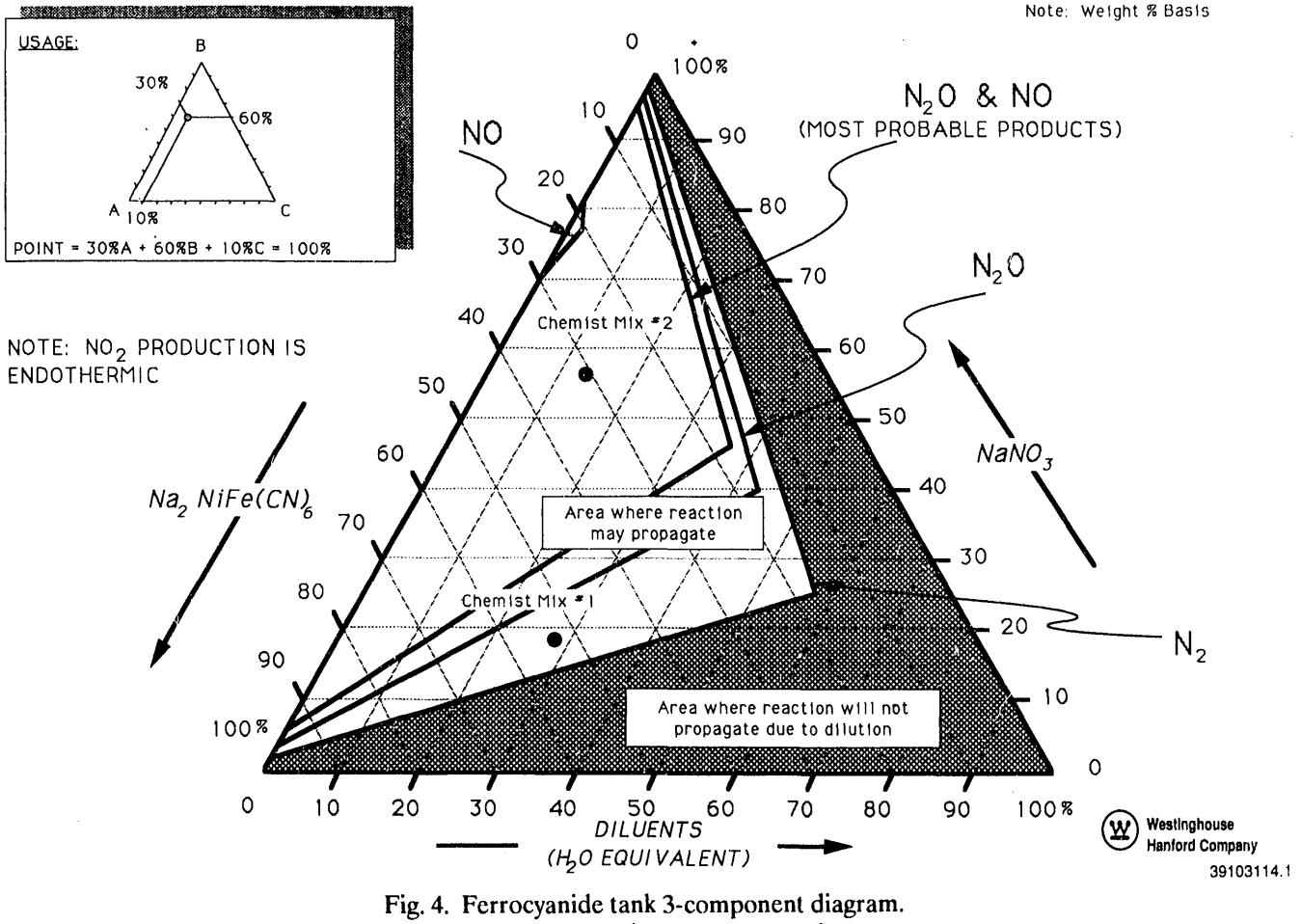


Fig. 4. Ferrocyanide tank 3-component diagram. Reaction propagation vs. concentration.

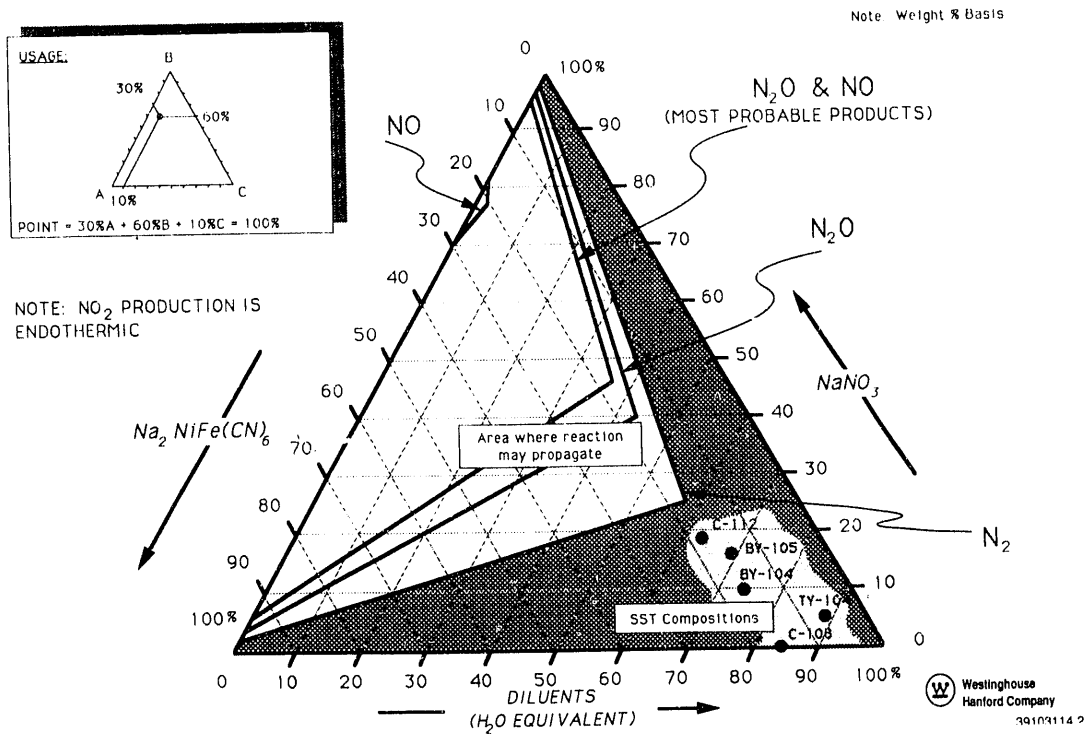


Fig. 5. Ferrocyanide tank 3-component diagram.
Reaction propagation vs. concentration.

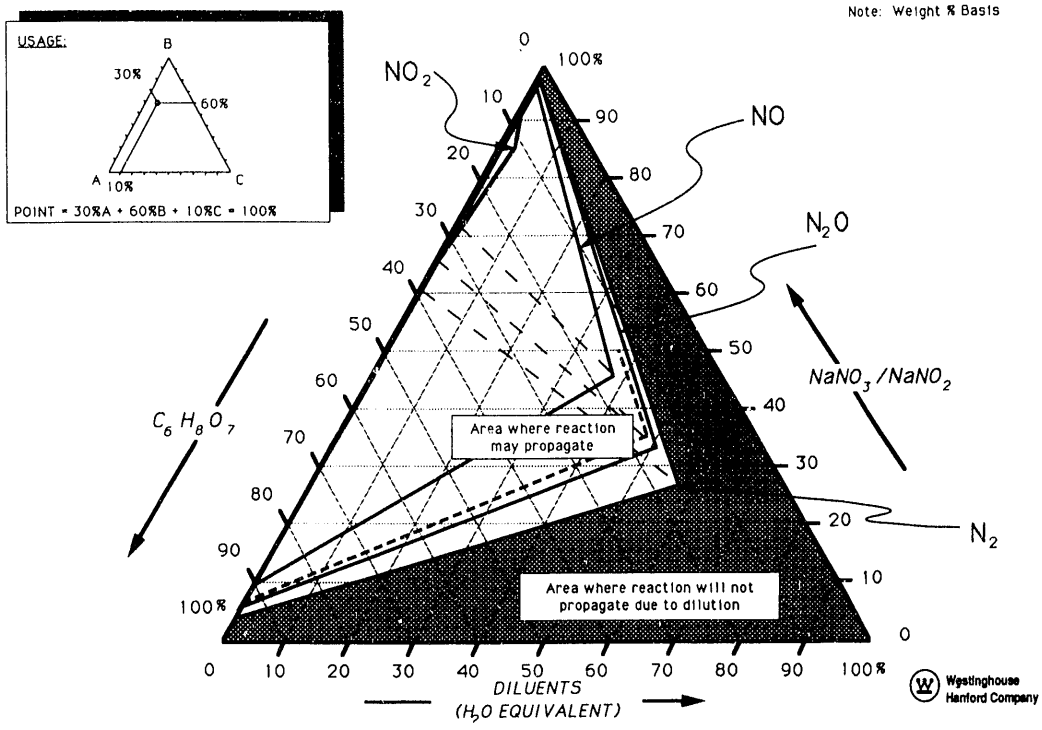


Fig. 6. Citrate 3-component diagram.
Reaction propagation vs. concentration.

CONCLUSIONS

The overall tank compositions appear nonreactive using the limited available data. However, current information is not adequate to close the safety concern of having a ferrocyanide-nitrate reaction in the single-shell tanks. To determine whether the ferrocyanide tanks pose a true safety problem, the tanks require sampling and analysis.

EFFICIENCY-BASED GROUNDWATER MONITORING DESIGN USING THE MONITORING EFFICIENCY MODEL (MEMO)

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ABSTRACT

An analytical Monitoring Efficiency Model (MEMO) has been developed to assist in the design of monitoring well networks at hazardous waste sites. The method simulates the migration of hypothetical contaminant plumes from a site and quantifies the efficiency of alternative well network designs in detecting the plumes. The computed efficiency provides a quantified basis for optimizing the design. Maps of the site showing areas where releases would or would not be detected by a given well network are produced, providing insight into the benefits of adding, deleting, or moving specific wells. MEMO is applied using a menu-driven computer program.

INTRODUCTION

Regulatory agencies require monitoring well networks at hazardous waste facilities to detect potential contaminant releases to underlying groundwater. Network design has often relied exclusively upon the judgement of the designers and regulators, and a clear approach for measuring the degree of protection offered by a monitoring network has not been well established.

The Monitoring Efficiency Model (MEMO) provides a method for quantifying and graphically displaying the efficiency of a given monitoring well network in detecting potential contaminant releases. Hypothetical contaminant plumes are used to determine the detection efficiency of the well network. Maps showing areas where releases would and would not be detected provide insight into the benefits of each well location and guide the optimization process.

MEMO is applied using a menu-driven computer program. The method is an extension of an approach suggested by Massmann, Freeze, and others (1,2) and Meyer and Brill (3). MEMO was developed at the request of Westinghouse Hanford Company, Richland, Washington, for the U.S. Department of Energy, and has been used as a tool for the design of RCRA monitoring networks at the Hanford Site.

GENERAL APPROACH

MEMO predicts whether a contaminant release to groundwater from a specific location within a hazardous waste site would be detected by a monitoring well network. This is accomplished by generating a contaminant plume using an analytical solution for contaminant transport, and determining whether the plume is intersected by a monitoring well before it migrates beyond a specified distance from the site. An illustration of this process is presented in Fig. 1. The process is repeated over a grid of locations across the site to develop a map of predicted locations where releases would or would not be detected. The 'monitoring efficiency' of the well network is then computed as the ratio of the area of detection to the total area of the site. For example, an efficiency of 90 percent predicts that releases occurring over 90 percent of the potential source area would be detected by the monitoring wells, and releases occurring over 10 percent of the potential source area would not be detected.

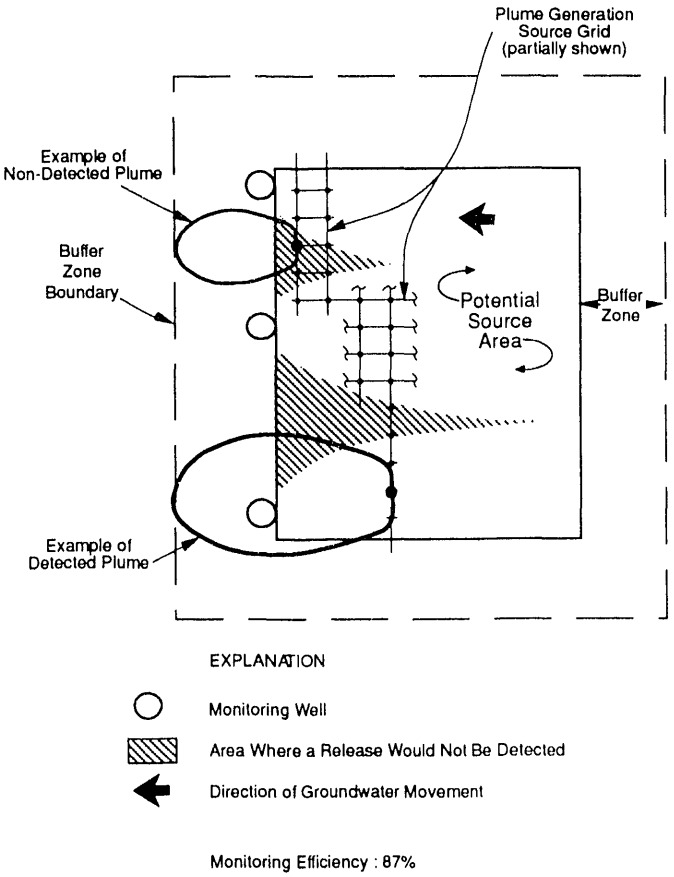


Fig. 1. Illustration of MEMO.

The model inputs consist of the source and transport parameters used to compute the shapes and sizes of the plumes, the direction(s) of groundwater movement, the average contaminant velocity, the analytical detection limits for water samples from the monitoring wells, and the extent to which the tip of a plume will be allowed to migrate beyond the potential source area boundary before it should be detected. The principal outputs are the monitoring efficiency and a site map showing predicted non-detection locations.

MEMO can be applied at most sites with available site-specific and literature-based information. Because the method is based upon a simulation of actual physical processes, evaluations of the adequacy of the network design are focused upon the physical parameters and processes governing contaminant migration, rather than upon qualitative judgements of how many wells are enough.

MEMO is presently configured with a two-dimensional, analytical plume generation routine based upon the analytical transport model of Domenico and Robbins (4). The transport model predicts the contaminant concentrations that would be observed at points downstream of the source. The Domenico & Robbins model assumes that solute is continuously released from a planar source that fully penetrates a saturated, uniform aquifer with a steady-state, horizontal flow system. The assumption of a uniform aquifer implies constant hydrologic and transport properties and a uniform hydraulic gradient over the length of the plume. This configuration of MEMO is best suited for low-concentration, aqueous-phase contaminants that remain at or near the top of the saturated zone, a horizontally stratified geologic medium with low vertical dispersivity, and negligible vertical groundwater flow. Other plume generation models could be incorporated into MEMO to meet site specific needs.

EXAMPLE APPLICATION

To illustrate the use of MEMO, a hypothetical example problem has been developed. Prior to determining the monitoring efficiency at a site, the user must define the region to be modeled (including the potential source area and a buffer zone boundary), the flow and transport parameters required for the plume generation routine, and a grid of source points that covers the entire potential source area. The buffer zone defines the limit to which the edge of a plume will be allowed to migrate beyond the potential source area boundary before it is detected. The flow and transport parameters required for the plume generation routine are the average contaminant velocity, the source width and concentration, and the longitudinal and transverse dispersivities. If significant, the first-order radioactive decay constant and the molecular diffusion coefficient should also be included. The source grid point spacing controls the accuracy of the solution.

Input parameter values for the example application are as follows:

Source Width	6 m
C_D/C_o	0.001
Buffer Zone Width	150 m
Longitudinal Dispersivity	10 m
Transverse Dispersivity	1.5 m
Average Contaminant Velocity	0.03 m/day

C_D is the detection limit for the contaminant of interest, and C_o is the concentration of that contaminant at the source. A target efficiency of 90% has been chosen for this example. Contaminant decay and molecular diffusion are not considered. The directions of groundwater movement are varied as described below.

The example application of MEMO is illustrated in the hypothetical site presented in Fig. 2. Five monitoring wells are located along the hydraulically downgradient boundary, at intervals of 150 to 300 m. The groundwater flow direction

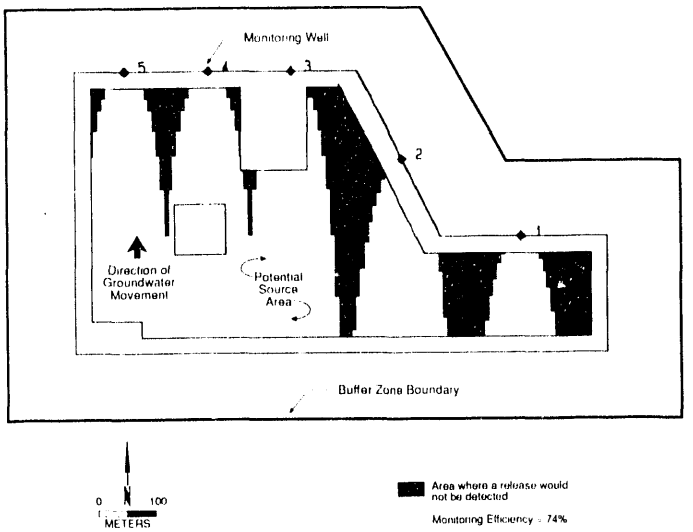


Fig. 2. Example application with five monitoring wells.

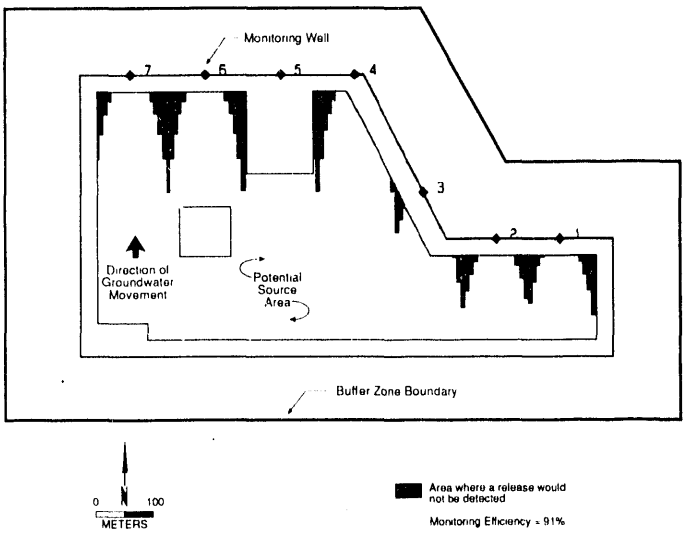


Fig. 3. Example application with eight monitoring wells.

is assumed to be to the north. The areas where releases would not be detected are shown in black. The monitoring efficiency is 74%, which is lower than the target minimum of 90%.

Figure 3 shows MEMO results for the same site when the number of monitoring wells is increased to seven. The well spacing has been reduced to 100 m intervals, and the efficiency has increased to 91%. This is slightly greater than the target efficiency of 90%. If confidence in the input parameters is sufficiently high, one or more of the wells could possibly be eliminated, and other well locations adjusted, while still meeting the target efficiency.

MEMO can be used to evaluate the sensitivity of the results to uncertainties in available data. An example is given in Fig. 4, where the groundwater flow direction is assumed to be 20 degrees west of due north. The determined efficiency has dropped to 84%. If such a flow direction is considered possible, one or more wells could be added to the west side of the site to improve the monitoring efficiency.

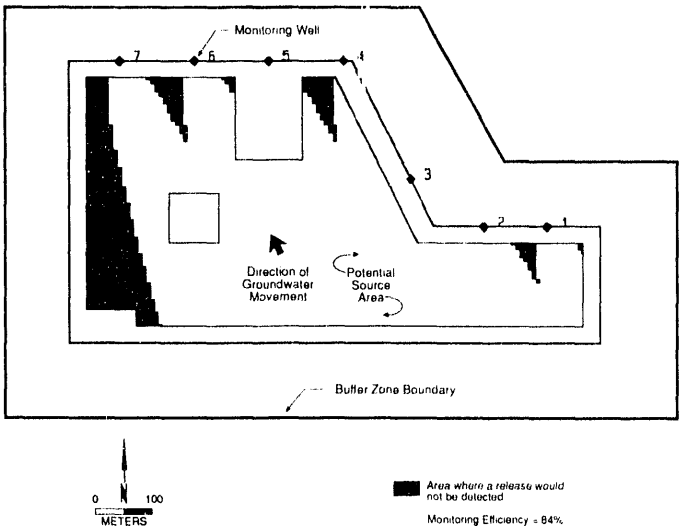


Fig. 4. Example application with alternative flow direction.

CONCLUSIONS

The Monitoring Efficiency Model (MEMO) incorporates an approach to monitoring well network design that is quantitative and produces an easily understood visual display. It provides a method for optimizing network design based upon actual physical processes. User judgement is an important element in the optimization process because of the expected need to estimate many of the input parameters. The benefits obtained from adding, deleting, or moving wells can be easily investigated using MEMO.

The example application presented here demonstrates the use of MEMO in evaluating sensitivity to well locations and flow directions. Similar studies can be made with any of the input parameters. Sensitivity analyses performed with MEMO provide well network designers and regulators insight into network design uncertainties. MEMO could be enhanced to include other plume generation routines that address such effects as three-dimensional dispersion. MEMO could also be developed on a probabilistic basis as an alternative to the deterministic approach presented here. The expanded use of MEMO and other similar design approaches is expected to reduce the uncertainties inherent in monitoring well network design.

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EVALUATION OF A RAPID HEADSPACE ANALYSIS METHOD FOR ANALYSIS OF VOLATILE CONSTITUENTS IN SOILS AND SEDIMENTS

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ABSTRACT

Contamination of the subsurface by volatile organic solvents is a common and significant environmental problem. A critical component of developing an accurate assessment of a site contaminated by these solvents is the acquisition of closely spaced, high quality contaminant concentration data. Many volatile organics are relatively mobile in the subsurface, requiring characterization of both horizontal and vertical contaminant migration. The volatile nature of these analytes, combined with the cost and effort typically required to perform quantitative analysis, has often compromised the number and quality of analyses used in characterization studies. A headspace analysis method was developed by Savannah River Laboratory to facilitate accurate and rapid delineation of the vertical and horizontal extent of volatile organic contamination in the subsurface. The method was designed to reduce sample handling, laboratory preparation, and analytical complexity. The headspace analysis method consists of four steps: 1) subsample the split spoon core immediately after opening the barrel using a small tube/plunger system, 2) place the subsample into a 22.5 mL headspace vial, 3) add 5 mL of distilled water and cap with a teflon lined septum, and 4) analyze on a gas chromatograph. This method was developed and modified as a result of multiple site investigations and has been applied to over 1500 samples.

To evaluate the headspace analysis method, we collected over 100 samples from four borings at depths ranging from 5 to 140 feet. Samples were analyzed using the headspace method and the results were compared to adjacent samples analyzed onsite using EPA methods that were modified to minimize losses of volatile constituents. The modified EPA method consisted of pentane extraction in a sealed vial after collection, weighing, and transfer in an onsite laboratory. The comparison analyses were performed by an independent organization. Despite the precautions incorporated into the modified EPA method, the analytical results indicate that sample transfers in the field and laboratory resulted in volatilization of most of the volatile solvents in the sediment samples. The headspace method appears to provide more representative data on the samples. One limitation of the headspace method is that the sample can not be diluted; thus, very high concentrations are truncated by an upper limit of detection. In most cases, this truncation may not be of practical significance because it occurs at relatively high concentrations (e.g., 100,000 ng/g). The results indicate that the headspace method minimized loss of volatiles associated with sample handling and provided large amounts of closely spaced data in a cost effective manner. The headspace results can be generated rapidly and transferred to the field such that informed decisions can be made during site characterization.

INTRODUCTION

Detection and delineation of volatile organic solvent contamination at a hazardous waste site can be a complex problem. The number and quality of analyses used in characterization studies has often been compromised by the difficulties and costs associated with quantitative analysis of these volatile analytes. A headspace analysis method was developed by the Westinghouse Savannah River Laboratory to facilitate the accurate and rapid delineation of the vertical and horizontal extent of volatile organic contamination in the subsurface, and to reduce the sample handling, laboratory preparation, and analytical complexity generally associated with the use of several United States Environmental Protection Agency Analysis Methods.

To evaluate the headspace method, over 100 subsurface sediment samples were collected from 4 sediment borings drilled at the Savannah River Site (Fig. 1). The sediment samples were analyzed using the headspace method and the results were compared to adjacent samples collected and analyzed by an independent subcontractor. The subcontractor used EPA methods that were modified to minimize losses of volatile constituents. A comparative study of the sample collection procedures, laboratory procedures, and analytical results of the headspace method and the subcontractor modified EPA method is presented in this paper.

SAMPLING AND ANALYTICAL METHODS

Sample Collection Procedure

The sediment borings were drilled at four sites adjacent to a solvent tank farm located west of a fuel and target tube manufacturing facility in M-Area at the Savannah River Site (Fig. 2). The boring locations were selected based on results

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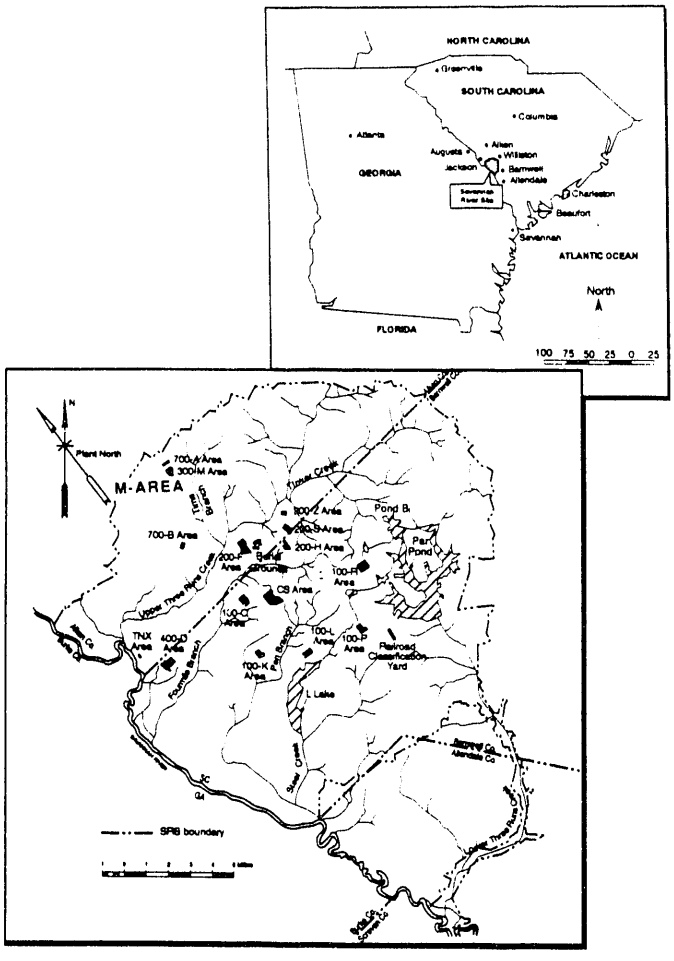


Fig. 1. Map showing the location of the solvent spill site at the Savannah River Site.

from a shallow soil gas survey and a documented solvent spill. In October 1975, over 1200 gallons of tetrachloroethylene (PCE) leaked from a cracked ceramic pump seal connected to one of the solvent tanks. The solvents were used during the late 1950's to the early 1980's to degrease the fuel and target tubes prior to shipment to the nuclear reactors.

The sediment borings were drilled with a Speedstar Quickdrill 275 utilizing 4-1/4-inch inside diameter hollow-stem augers. A standard 2-inch inside diameter split-spoon sampler was advanced vertically according to Standard Penetration Test procedures (ASTM D1586) at five foot intervals, beginning immediately below ground surface to a depth of approximately 140 feet or top of the water table. After each advance, the split spoon sampler was opened and two adjacent samples of sediment were collected. One sediment sample was collected for headspace analysis and the other collected by an independent subcontractor for analysis by a modified EPA Method. The remaining sediment left in the split-spoon was field screened with an HNu photoionization organic vapor meter and a Ludlum G.M. radiation detector and visually classified.

Headspace Sampling Procedure

The headspace sediment subsample (3-5 grams) was collected immediately from the open spilt-spoon using an open-ended plastic disposable syringe and extruded into a 22.5 mL borosilicate vial. Five mL of distilled water were added to the subsample using a pipet and the vial was sealed by crimping an aluminium cap around a teflon-lined butyl rubber septum. The sample vial was labeled and placed in an ice chest cooled to approximately 4°C for later analysis at an onsite laboratory. The subsample corer (syringe) was decontaminated between sampling events by brushing and rinsing with isopropanol followed by a distilled water wash.

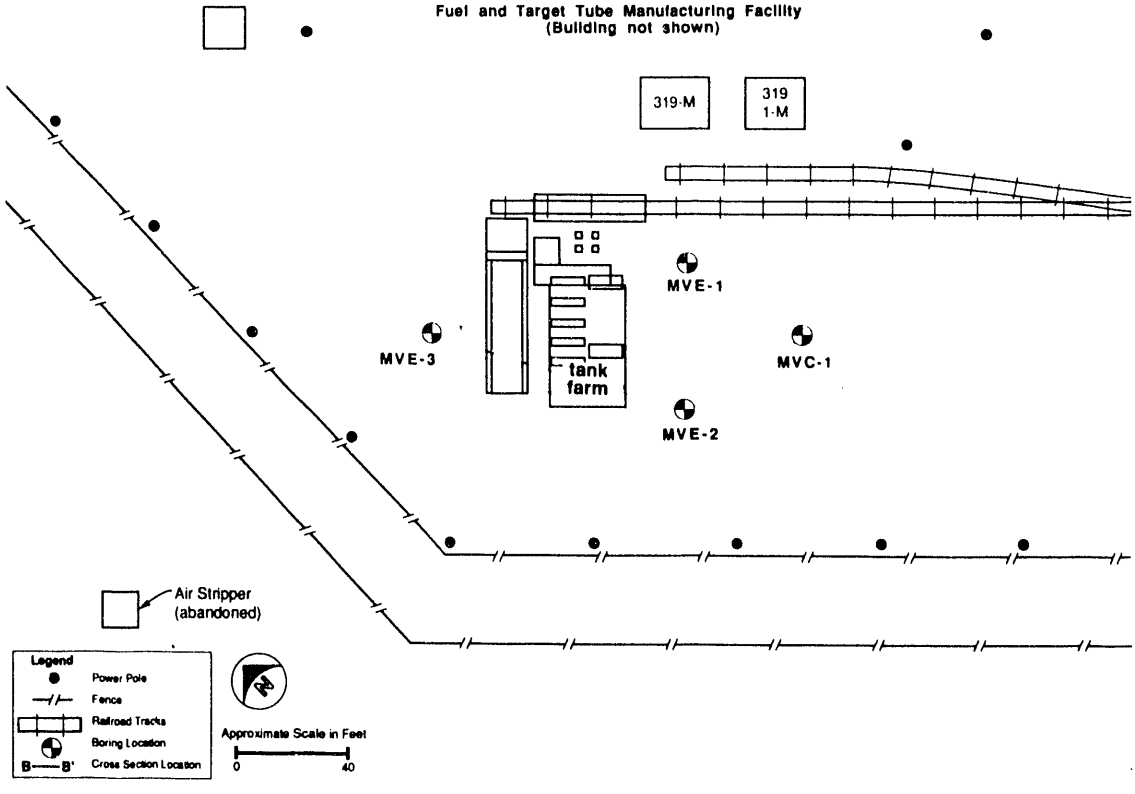


Fig. 2. Map showing the location of soil borings adjacent to the solvent tank farm.

Modified E.P.A. Sampling Procedure

Adjacent to the headspace subsample collection point, a subcontractor immediately collected an aliquot of sediment from the open split-spoon using a stainless steel spatula and packed it into a 2-ounce borosilicate jar with a teflon-lined screw cap. The jar was labeled and placed in an ice chest cooled to approximately 4° C for later analysis by the Close Support Laboratory (CSL). The stainless steel spatula was decontaminated between sampling events by wiping with a disposable moist Towelette.

Laboratory Analysis Procedure

The two separate laboratories utilized in the study to analyze the sediment subsamples were an onsite laboratory operated by Savannah River Laboratory personnel and a CSL operated by independent subcontract personnel. The onsite laboratory analyzed the headspace sediment subsamples and the CSL analyzed the sediment subsamples collected by the independent subcontractor. Both laboratories used standard Chain of Custody procedures and collected Quality Assurance/Quality Control (QA/QC) sediment subsamples to comply with the Savannah River Site Quality Assurance Requirements. These requirements included the analysis of duplicate samples, matrix spikes, and trip blanks at a minimum of ten percent of the total number of samples. All analyses were performed within the required holding time.

Headspace Analysis Procedure

The onsite laboratory consisted of a headspace analyzer connected to a Hewlett Packard 5890A Gas Chromatograph (GC). The headspace analysis procedure used is given below.

Step 1. Prior to field sampling, determine the average weight of a sealed headspace vial containing 5 mL of water. Upon receipt of the headspace sample vials from the field, weigh the capped vial containing the sediment sample. Subtract the weight of the vial without the sediment from the vial containing the sediment to determine the amount of sediment in the sample vial.

Step 2. Place vial with the sediment subsample in the headspace analyzer for analysis. Download the GC results from each sample analyzed into a computer for interpretation.

A previous study was conducted by Savannah River Laboratory personnel in order to evaluate the effects of adding a sodium sulfate/phosphoric acid solution instead of distilled water to the headspace sediment sample. The results of this study indicated that there was a significant statistical difference between the VOC analysis using distilled water versus the sodium sulfate/phosphoric acid solution. The use of distilled water in the headspace vial increased the volatilization and measured concentration of VOC. Additional work was conducted to determine whether sonication of the sample increased the measured VOC concentration. The results indicated that there was not a significant statistical difference between the samples that were sonicated for 15 minutes and the samples that were not sonicated.

Subcontractor Modified EPA 3550 Analysis Procedure

The CSL consisted of a travel camper outfitted with a Hewlett Packard 5890A gas chromatograph, electron capture detector, and an ultrasonic sonicator. Additional equipment included a balance, an oven for drying samples, a computer with printer and laboratory/safety supplies. The CSL was operated on a daily basis during the sediment boring investigation to provide analytical results on a real-time basis. The results were used to determine screen intervals for the vapor extraction wells installed as part of a vadose zone remediation program in M-Area.

The CSL analytical method used pentane in conjunction with sonication to extract the target constituents (predominantly PCE) from the sediment matrix. The method was based on EPA Method 3550, Sonication Extraction, found in EPA SW 846, "Test Methods for Evaluating Solid Wastes", 3rd ed., November 1986. The modified EPA Method 3550 procedure for sample preparation and extraction is included below.

Step 1. In a labeled VOA vial (40 mL), volumetrically pipet 5 mL of pentane and record the volume added. Place the vial on the top loading balance and record its tare weight. Add an aliquot of sediment from the 2-ounce jar subsample (approximately 5 to 10 grams) to the vial and accurately record the sample weight to the nearest 0.01 grams.

Step 2. If the sample is wet or highly consolidated (i.e. clay), add approximately 2 grams of sodium sulfate and mix.

Step 3. Tightly cap the VOA vial and sonicate at an output setting of 30 percent for approximately 5 minutes. The resulting sonicated sample should be dispersed throughout the pentane solvent and have a grain-like appearance. If not, then add an additional 1 gram of sodium sulfate and sonicate. Repetitions of this process may be needed to complete the extraction from some samples.

Step 4. After sonication, let the VOA vial stand until the solids have settled. Using a pasteur pipet, transfer a suitable aliquot of the pentane solvent (extract) from the vial in a labeled GC auto-sampler vial and cap immediately with septum crimp seals. Refrigerate the sample extracts until analyzed.

Step 5. After the sample was prepared, the extract was injected into a Hewlett Packard 5890A GC with an electron capture device for analysis.

DISCUSSION

The results of the laboratory analyses for the headspace method and the subcontractor modified EPA 3550 Method are presented in Tables I and II. A total of 92 sediment subsamples were analyzed for this study. In addition, 16 duplicate headspace sediment subsamples were collected to determine reproducibility of the analytical data. The concentrations of TCE and PCE in the headspace sediment subsamples ranged from less than 1 ng/g (presented as 1 on the Table I and II), up to 14,583 and 91,670 ng/g respectively. The concentrations of TCE and PCE in the sediment subsamples utilizing the subcontractor modified analytical method ranged from less than 1 ng/g up to 1,016 and 2,620,000 ng/g respectively. The duplicate samples, trip blanks, matrix spikes, and matrix spike duplicates performed for the methods indicated

TABLE I

Soil Boring MVE-1

Sample Collection Depth (ft)		Trichloroethylene (ng/g) Headspace Results	Trichloroethylene (ng/g) Modified EPA 3550 (EPA SW 846)	Headspace Greater Than Modified?	Tetrachloroethylene (ng/g) Headspace Results	Tetrachloroethylene (ng/g) Modified EPA 3550 (EPA SW 846)	Headspace Greater Than Modified?
6		1	1	SR	10331	216	Y
11		1	1	SR	14240	600	Y
16		4	1	Y	43765	84694	N
20		50	1	Y	28271	970000	N
21		8320	1	Y	91670	2620000	N
26		9318	1	Y	82874	75000	Y
31		706	1	Y	81126	420000	N
36		538	199	Y	19643	1300	Y
41		247	1	Y	8132	95	Y
46		754	17	Y	10339	323	Y
51		1135	11	Y	12036	11	Y
56	S	1	1	SR	4	1	Y
57	S	4	1	Y	7080	1	Y
61		607	1	Y	7804	1	Y
64		6	1	Y	4610	1	Y
66		2	1	Y	14	1	Y
71		1	1	SR	6	1	Y
76		2	1	Y	24	1	Y
81		7	1	Y	21	1	Y
86		2	1	Y	17	1	Y
91		3	1	Y	11	1	Y
96		1670	1	Y	7007	1	Y
100.5	S	3	1	Y	9	1	Y
101.5	S	16	1	Y	3135	1	Y
106		8	1	Y	14	1	Y
111.5		1	1	SR	2	1	Y
116		15	1	Y	29	1	Y
121		3	1	Y	7	1	Y
126		24	1	Y	59	40	Y
131		3	1	Y	9	1	Y
135.5	S	14583	1	Y	20638	1	Y
136	S	5	1	Y	8	1	Y
141		10119	4100	Y	14864	5700	Y

SOIL BORING MVE-3*

21	3	2	Y	3	1	Y
31	327	9	Y	7726	1	Y
36	204	7	Y	27	15	Y
46	444	3	Y	2684	10	Y
51	290	33	Y	2079	45	Y
56	2147	3	Y	3694	11	Y

Y = Yes
N = No
SR = Same Result
* = Soil Boring Partially Sampled
D = Average of Duplicate Headspace Analyses
S = Two Subsamples Collected From One Split-Spoon Core
1 = Result "Less than Detection"

TABLE II

Soil Boring MVC-1

Sample Collection Depth (ft)		Trichloroethylene (ng/g) Headspace Results	Trichloroethylene (ng/g) Modified EPA 3550 (EPA SW 846)	Headspace Greater Than Modified?	Tetrachloroethylene (ng/g) Headspace Results	Tetrachloroethylene (ng/g) Modified EPA 3550 (EPA SW 846)	Headspace Greater Than Modified?
6		1	1	SR	1	1	SR
11		1	1	SR	1	1	SR
16		1	1	SR	14	1	Y
21		1	1	SR	2	1	Y
26		1	1	SR	3	1	Y
36		10	1	Y	19	1	Y
41		149	1	Y	5376	1	Y
46		14	1	Y	31	1	Y
51		1	1	SR	1	1	SR
56		1	1	SR	1	1	SR
65	S	1	1	SR	1	1	SR
66	S	2	1	Y	5	1	Y
71		1	1	SR	2	1	Y
76		1	1	SR	1	1	SR
81		1	1	SR	3	1	Y
86		3	1	Y	8	1	Y
91		16	1	Y	62	1	Y
100		6621	33	Y	13892	35	Y
101		8	1	Y	17	1	Y
105	S	544	1	Y	5170	1	Y
106	S	1	1	SR	2	1	Y
111		1513	362	Y	8569	119	Y
116		4920	1	Y	8768	87	Y
121		4	1	Y	6	1	Y
126		13	1	Y	20	9	Y
131		15	1	Y	28	1	Y
SOIL BORING MVE-2							
6		2	1	Y	9	16	N
11		2	1	Y	9	9	SR
16		3	1	Y	30	1	Y
21	D	2	1	Y	2594	11	Y
26		80	3	Y	4667	31	Y
31	D	27	2	Y	3135	14	Y
36		32	5	Y	3312	33	Y
41	D	35	2	Y	3531	12	Y
46	D	68	5	Y	3332	36	Y
51		206	5	Y	4321	33	Y
56	D	5	7	N	5	34	N
61	D	266	5	Y	5189	27	Y
66		2	2	SR	4	10	N
71	D	10	1	Y	13	1	Y
76		1	1	SR	1	1	SR
81	D	1	2	N	1	12	N
86		1	1	SR	3	1	Y
91	D	1	1	SR	3	1	Y
96		4	558	N	3397	668	Y
101	D	7	2	Y	16	8	Y
106	D	21	3	Y	1711	17	Y
111	D	1	2	N	2	11	N
116	D	9	14	N	19	44	N
121		1	6	N	4	20	N
126	D	2	14	N	3	41	N
131	D	3	79	N	5	92	N
136	D	7551	1016	Y	9361	706	Y

Y = Yes
N = No
SR = Same Result
1 = Result "Less than Detection"
S = Two Subsamples Collected From One Split-Spoon Core
D = Average of Duplicate Headspace Analyses

that both methods could adequately measure the contaminants at concentrations down to the detection limit and that both methods generated reproducible results.

In general, the headspace analysis method resulted in a higher value for the measured concentration of both TCE and PCE (Table III). The primary exceptions to this general trend are: 1) samples with very high concentrations of contaminants, and 2) samples where both methods were below detection. For example, in soil boring MVE-1, there are five instances where the two methods are the same for TCE -- all of these instances result from below detection results from both methods. Similarly, in this core, the results from the modified EPA method are greater four out of thirty-three times -- all four instances result from truncation of very high concentrations inherent in the headspace method. These same trends may be observed in all of the other cores. The paired data used to generate Table III were ranked and ordered for statistical analysis. In this form, a Wilcoxon Signed Rank Test was applied to determine if the two methods yield statistically different results. This test is used when the shape of the underlying distribution is unknown to test the hypothesis that two population distributions are identical. At the 99% confidence interval, this hypothesis was rejected signifying that the two populations are different. Thus, the statistical test indicated that there is greater than a 99% probability that the two methods are statistically different (i.e., the headspace method generates higher values).

Table IV provides detailed information on depth, PCE concentrations, and lithology for MVE-1. Results from this core illustrate the relationship between concentration and lithology, and reinforce the general conclusions discussed above. The headspace method indicated the presence of contamination in each of the silty, clayey and poorly graded layers throughout the core. The modified EPA method generated below detection results for most of these zones. The headspace method truncated a series of very high concentrations in the upper part of the core. Figure 3 is a graphical representation of the data. The headspace method indicates low (but measurable) concentrations in the well graded sands, while the modified EPA method indicates below detection results in almost all of these layers.

From an analytical standpoint, there are several advantages of the headspace method over the subcontractor modified EPA Method. Some of these advantages include: 1) reduced sample handling effort and time in the field, 2) no solvent extraction required (the Henry's Law mass transfer in the headspace vial requires no operator effort), and 3) elimination of multiple sample transfers and minimization of the opportunities for volatilization of analyte. The headspace sediment sample is sealed in its final form ready for analysis within a few seconds of collection and is never directly han-

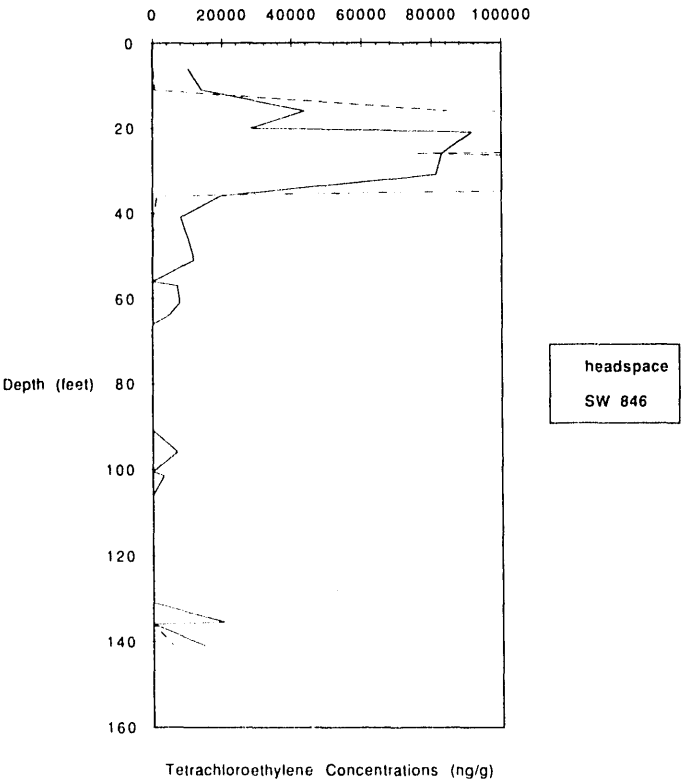


Fig. 3. Vertical profile of PCE concentrations from the two

TABLE III

Data Summary

Method Comparison From Tables I and II for Trichloroethylene and Tetrachloroethylene	Trichloroethylene					Tetrachloroethylene				
	Soil Boring MVE-1	Soil Boring MVE-2	Soil Boring MVE-3	Soil Boring MVC-1	**Total**	Soil Boring MVE-1	Soil Boring MVE-2	Soil Boring MVE-3	Soil Boring MVC-1	**Total**
Number of Headspace Analytical Results Greater than the Subcontractor Modified Method Analytical Results (Y)	28	15	6	14	**63**	29	16	6	20	**71**
Number of Subcontractor Modified Method Analytical Results Greater than the Analytical Results of the Headspace Method (N)	0	8	0	0	**8**	4	9	0	0	**13**
Number of Identical Results (SR)	5	4	0	12	**21**	0	2	0	6	**8**

TABLE IV

PCE Concentrations Versus Lithology in Soil Boring MvE-1

Sample Collection Depth (ft)		Tetrachloroethylene (ng/g) Headspace Results	Tetrachloroethylene (ng/g) Modified EPA 3550 (EPA SW 846)	Abbreviated Field Lithologic Description of the Split Spoon Core
6		10331	216	SANDY SILT (ML), dense, 5% clay
11		14240	600	SANDY SILT (ML), dense, 5% clay
16		43765	84694	SILTY SAND (SM), very dense,10-15% clay
20	S	28271	970000	SILTY SAND (SM), very dense,10-15% clay
21	S	91670	2620000	SILTY SAND (SM), very dense,10-15% clay
26		82874	75000	SILTY SAND (SM), very dense,10-15% clay, clayey lenses
31		81126	420000	CLAYEY SAND (SC)
36		19643	1300	POORLY GRADED SAND WITH SILT (SP-SM)
41		8132	95	POORLY GRADED SAND WITH SILT (SP-SM)
46		10339	323	SILTY SAND (SM)
51		12036	11	SILTY SAND (SM)
56	S	4	1	WELL GRADED SAND (SW)
57	S	7080	1	POORLY GRADED SAND (SP)
61		7804	1	POORLY GRADED SAND (SP), clay lenses
64	S	4610	1	SILTY SAND (SM), clay lenses
66	S	14	1	WELL GRADED SAND (SW)
71		6	1	WELL GRADED SAND (SW)
76		24	1	WELL GRADED SAND (SW)
81		21	1	WELL GRADED SAND (SW)
86		17	1	WELL GRADED SAND (SW)
91		11	1	WELL GRADED SAND (SW)
96		7007	1	WELL GRADED SAND WITH CLAY (SW-SC)
100.5	S	9	1	WELL GRADED SAND (SW)
101.5	S	3135	1	WELL GRADED SAND WITH CLAY (SW-SC)
106		14	1	WELL GRADED SAND (SW)
111.5		2	1	WELL GRADED SAND (SW), thin clay stringers (white)
116		29	1	WELL GRADED SAND (SW), thin clay stringers (white)
121		7	1	WELL GRADED SAND (SW)
126		59	40	WELL GRADED SAND (SW),some gravel
131		9	1	WELL GRADED SAND (SW),some gravel
135.5	S	20638	1	POORLY GRADED SAND WITH CLAY (SP-SC), 2 mm clay lns.
136	S	8	1	WELL GRADED SAND (SW)
141		14864	5700	WELL GRADED SAND (SW), Moist, Top of the Water Table

S = Two Subsamples Collected From One Split-Spoon Core

dled again during weighings or transfers. Once in the laboratory, approximately 50 samples can be analyzed in a normal working day on a single instrument. This allows data to be rapidly transmitted back to the field for incorporation into decisions about the drilling and characterization operations.

CONCLUSION

Despite the precautions incorporated into the modified EPA method, the analytical results indicate that sample transfers in the field and laboratory resulted in volatilization of most of the volatile solvents in the sediment samples. The headspace method appears to provide more representative data on the samples. One limitation of the headspace method is that the sample can not be diluted; thus, very high concentrations are truncated by an upper limit of detection. In most cases, this truncation may not be of practical significance because it occurs at relatively high concentrations (e.g., 100,000 ng/g). The results indicate that the headspace method minimized loss of volatiles associated with sample handling and provided large amounts of closely spaced data in a cost effective manner. The headspace results can be generated rapidly and transferred to the field such that informed decisions can be made during site characterization.

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ACKNOWLEDGEMENTS

The information contained in this article was developed during the course of work under Contract No. DE-AC09-89SR18035 with the U. S. Department of Energy.

AUTHOR INDEX

A

Aloysius, David L., 901
Anderson, D.B., 101
Andersen, P., 277
Ansted, John P., 115

B

Babad, Harry, 215, 227, 243
Baker, E.G., 511
Baker, Gary D., 633
Barr, Mary E., 543
Bascietto, J.J., 447
Bashor, Mark M., 627
Bauer, James D., 55
Beers, A.A., 47
Bench, Jean M., 21, 129
Benge, Mark M., 377
Bergman, Theresa, 43
Bernhardt, D.E., 147
Beskid, N.J., 479
Bhada, Ron K., 665
Bibler, J.P., 527
Bierley, Denise, 455
Bierman, George R., 615
Bilyard, Gordon R., 847
Bixby, Willis, 1
Blickwedehl, Robert R., 307
Blunt, D.A., 853
Boerman, P.A., 95
Boing, L.E., 345
Bonilla, R., 769
Borders, D.M., 589
Borsheim, G.L., 233
Bowers, Marvin H., 339
Bradbury, D., 527
Bramlitt, E.T., 531
Breckel, Jeff, 43
Brennecke, Daniel F., 745
Brettschneider, David, 551
Brouns, T.M., 101
Brown, M.C., 47
Brubaker, D. Mark, 27
Bryan, S.A., 233
Buck, J.W., 261
Buckmaster, Mark A., 891
Buelt, James L., 783
Burger, L.L., 233
Burks, B.L., 579
Butherus, Michael C., 795
Butler, David A., 871

C

Cady, H.H., 233
Caldwell, Jack A., 685
Cameron, R.J., 313
Carlson, Timothy J., 21
Carpenter, Clay E., 21
Carpenter, Donald J., 115
Carr, Dennis, J., 811
Cash, R.J., 233
Chapman, C.C., 703
Chatterjee, Samar, 301
Chen, S.Y., 889
Cheng, J.-J., 833
Chew, John R., 199
Clapp, R.B., 589
Coffman, R.T., 143
Cohen, Francine J., 901
Colby, S.A., 911
Cook, J., 277
Cote, R.F., 727
Cothron, Terry K., 85
Coyle, S.W., 605
Craig, J.R., 895
Crippen, M.D., 911
Crone, Jennifer T., 75
Crutcher, Judy W., 185
Cullen, James J., 415

D

Daily, William, 907
Dausin, L.R., 729
DeFigh-Price, C., 251, 257
Deichman, John L., 215
DePiero, F.W., 579
Devgun, J.S., 265, 479
Dietrich, A.J., 139
Donaldson, T.L., 95
Doty, Carolyn B., 403
Douglas, L.M., 817
Dove, F. Harvey, 295, 789
Dressen, A. Louise, 31
Droppo, Jr., J.G., 261
Duffy, Leo, 3
Duke, C.S., 447, 861
Dunn, M.J., 527
Dunster, D.G., 135
Durante, L.C., 135

E

Ebeling, L.J., 321
Eddy, C.A., 919
Edwards, C., 47
Egge, R.G., 361
Einberger, Carl M., 915
Eller, P.G., 543
Emerson, Jr., Robert J., 517
Emilia, David A., 661
Erickson, M.D., 479
Esparza-Baca, Charlene, 829
Evans, M.S., 567
Evans, R.B., 321

F

Fahy, Loretta B., 169
Farmer, G. Thomas, 475
Fekete, Leslie J., 517
Ferguson, R.D., 793
Ferguson, Richard D., 733
Ferrigno, Kenneth F., 677
Field, J.G., 697
Finger, Stanley M., 551
Fingleton, D.J., 853, 871
Fiore, James J., 59
Frain, J.M., 427
Francis, C.W., 107
Franklin, Brad, 165
Fredrickson, J.K., 101
Freeman, H.D., 511, 697

G

Galbraith, Robert M., 777
Gale, S.J., 143

Gerber, M.A., 511
Gerber, Michele S., 649
Gessner, R.F., 681
Gilbert, R.O., 271
Gimpel, Rod F., 283, 485
Glover, William, 829
Glum, S.R., 861
Goidell, L.C., 61
Gonzales, B. Louis, 685
Goodenough, J.D., 839
Gordon, J.W., 345
Gorman, M.J., 729
Grant, D.C., 139
Gray, S.I., 447
Green, D.J., 251
Gregoire, Christine, 11
Griffin, P.W., 179
Gross, Marvin, 551
Guimond, Richard, 5
Gustafson, F.W., 81

H

Hagood, M.C., 313, 421
Halford, Douglas K., 185
Hallen, Richard, 221
Hamp, Steven, 761
Hamrick, Doug, 247
Harmon, Thomas C., 401
Haroun, L.A., 853, 871
Harrison, Robert J., 661
Hassig, N.L., 271
Hayward, Gregory B., 671
Hayward, William M., 333
Heckendorn, Lisa A., 517
Hemmings, R.L., 527
Henckel, G.C., 191
Henley, D.R., 345
Herbes, S.E., 95
Hertel, W.A., 895
Hill, R.C. Philip, 243
Hodgson, K.M., 555
Hoffman, W. Dean, 621
Hopper, J.P., 199
Horvath, J.G., 327, 407, 469
Huff, D.D., 589
Hunt, Bill, 39
Hutterman, L.L., 135, 723

I

Imholz, Rebecca M., 27
Isherwood, William, 559

J

Jackson, Ronald L., 915
Jacobski, D.L., 579
Jacobson, Roger L., 415
Janke, D.S., 703
Janke, Randy C., 283
Janke, Robert J., 283
Jennings, H.L., 95
Jennrich, E., 277
Jensen, C.I., 433
Jin, D.J., 583
Johnson, Ben, 221
Johnson, G.D., 227
Johnson, N.R., 531
Johnson, R.T., 769
Johnson, W.L., 81, 191, 313
Jonas, Roberta J., 847
Jouve, A., 713

K

Kalinauskas, G.L., 527
Kam, J.T., 573
Kapustka, L.A., 443
King, Amy D., 91
Kinsel, William, 671
Kleinrath, Arthur W., 475
Kocher, Paula L., 627
Kostelnik, Kevin, 603
Kowalski, Teresa E., 199
Kozak, M.W., 151
Kroutch, Bryant, 789
Kuhlmeier, Paul D., 691

L

LaBrecque, Douglas, 907
Lahoda, E.J., 139
Langum, Remi B., 55
Lankford, Denton, 801
Leggett, W.D., 257
LePoire, D., 889
Levine, R.S., 479
Levitan, William M., 807
Lewis, C.J., 291
Lien, S.C.T., 479
Liikala, Stephen C., 119
Lindgren, E.R., 151
Lockhart, Frazer R., 51
Lojek, David A., 811
Longley, Susan W., 475
Longmire, P.A., 543
Looney, B.B., 919
Lu, Allen H., 883
Lucero, A.J., 95
Luttrell, S.P., 101
Lynn, Douglas, 801

M

MacDonell, M.M., 623, 793, 853, 871
Manion, W.J., 345
Mann, Paul, 455, 765
Marchetti, Steve, 247
Marino, Mark, 745
Marshall, G.E., 895
Marshall, Thomas C., 295
Marske, S.G., 357
Martin, C.J., 433
Martin, J. F., 447
Mattson, E.D., 151
Maubert, H., 713
McCracken, S.H., 623, 793
McKillip, S.T., 469
McMullin, S.R., 327
McNatt, F.G., 351
Mech, S.J., 257
Mehta, P., 889
Mellinger, George, 221
Mercer, Richard B., 915
Meyers-Schone, L., 861
Mihalic, M.A., 817
Mihalovich, Gary S., 633
Mills, J.G., 729
Millsap, W.J., 567
Moak, D.J., 143
Moberg, T.P., 555
Monaghan, Jim, 39
Montoya, Gilbert M., 367
Moore, E.B., 839

Moore, Herman H., 301
Mora, A., 895
Morgan, J. Derald, 665
Morrison, Sid, 19
Morrison, Stan J., 739
Murphie, William E., 59
Myers, David, 789
Myers, Jonathan, 841

N

Neiheisel, James, 439
Nichols, Eric, 559
Nickelson, Mark D., 413
Niles, Ken, 37
Nix, D., 277
Nixon, Philip, 707
Norrell, G., 527
Nuhfer, Kimberly R., 597

O

Ogg, Randy T., 75
Ohl, Phil, 247
Oliver, B.M., 265
Owen, D.H., 147
Özkaynak, Halûk, 871

P

Pack, Samantha Richter, 877
Paez-Restrepo, Antonio, 383
Palumbo, A.V., 95
Perry, Harry A., 755
Peterson, J.M., 623, 793, 853
Phelps, T.J., 95
Picel, M.H., 853
Pope, J.M., 61
Power, Max, 43
Prewett, S.V., 147
Price, John B., 475
Provencher, Richard B., 633
Pulsipher, B.A., 271

Q

Quaider, W., 861

R

Ramachandran, N. 769
Ramirez, Abelardo, 907
Ramos, Sharon J., 717
Rasmussen, Dana, 9
Rasmussen, Jim, 43
Redfearn, Andy, 91, 195
Reiser, Jane C., 801
Reith, Charles C., 685
Reynolds, D.A., 227
Rice, Jr., David, 559
Richardson, Debbie L., 755
Richardson, R.L., 123
Riemath, W.F., 511
Roberts, Paul V., 401
Roblyer, S.P., 291
Rohay, V.J., 313, 421
Rowe, J.C., 579
Rowland, T.J., 681
Rowlands, Robert D., 795
Ruberg, George E., 27
Russell, B.F., 433
Russell, Charles E., 415

S

Sanders, D.R., 573
Sanderson, William, 37
Schafetz, S., 889
Schassburger, R.J., 163
Scheele, R.D., 233
Schlotzhauer, David S., 465
Schulte, E., 713
Seiler, Fritz A., 295
Selleck, C.B., 579
Semprini, Lewis, 401
Serie, Patricia J., 31
Shimamoto, M.S., 567
Shirley, R.S., 605
Shuman, R., 277
Sibley, K.L., 469
Simpson, B.C., 233
Sims, W.R., 919
Sjoblom, Glen L., 55
Skeen, R.S., 101
Skiles, Joni, 195
Smith, David L., 333
Smith, D.C., 567
Smith, E.H., 823
Smith, Randy, 43
Sobocinski, Robert W., 841
Sontag, Steven, 159
Spain, E.H., 567
Spalding, B.P., 107
Spangler, Richie, 789
Spangler, Robert R., 739
Sprouse, Brian S., 173
St. Clair, Lynn, 707
Stepnewski, D.D., 227
Steude, John, 491
Stottlemyre, James A., 783
Stout, Daniel S., 655
Strachan, Denis, 221
Strandberg, G.W., 95
Street, G.H., 351
Strenge, D.L., 261
Subbaraman, G., 265
Surovchak, Scott, 407
Swanson, L.C., 143
Swindle, D.W., 69

T

Tardiff, M.F., 589
Teply, James, 751
Thiers, G.R., 573
Thompson, K. Michael, 773
Thomson, B.M., 543
Tingey, J.M., 233
Tomicich, M.J., 531
Townsend, John S., 665
Travis, Bryan, 533
Travis, Curtis C., 389
Treat, R.L., 697
Trent, Bruce, 533
Tucker, Brian, 491
Tuttle, R.J., 265

V

Valcich, P.J., 313
Valett, G.L., 623, 733
Varchol, B.D., 605
Vincent, Oba L., 643, 811
Virgon, J.E., 755
Vogel, R.A., 703
Vollmer, Arthur, 829

W

Wagoner, John, 15
Wallace, William A., 393

Wallo, III, A., 833, 847
Walsh, E.J., 321
Walzer, Ann E., 85
Warbritton, Kenyon R., 465
Watson, J.S., 69
Webster, S.L., 479
Weiss, Jr., Thomas G., 307
Wesely, Marjorie L., 685
Wheat, Beth, 707
White, D.C., 95
White, Michael K., 783
White, Robin K., 91, 195
Whitfield, Pat, 1
Wilder, J., 143
Williams, B.A., 443
Williams, J.L., 433
Williams, Monte, 475
Williams, W. Alexander, 655
Williamson, D.J., 433
Wilson, Charles R., 915
Wilson, Mary J., 185
Wodrich, Donald D., 215
Workman, D.J., 101
Wozniewicz, J.V., 433

X

Xue, Jianping, 871

Y

Yeazel, J.A., 681
Young, Charles D., 655
Yu, C., 833, 889

Z

Zelmer, Robert L., 459
Ziagos, John, 559

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