CONF-921137-PROC

Fourteenth Annual U.S. Department of Energy Low-Level Radioactive Waste Management Conference

Proceedings

March 1993

Idaho National Engineering Laboratory
EG&G Idaho, Inc.
National Low-Level Waste Management Program

Work performed under
DOE Contract No. DE-AC07-76ID01570

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

MASTER

This work was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assume any legal liability for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe on privately owned rights. 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.

Any conference papers not included in these proceedings were either not submitted for publication or were precluded from publication by technical problems such as disk incompatibility.

DISCLAIMER

Portions of this document may be illegible electronic image products. Images are produced from the best available original document.

ABSTRACT

This document contains many of the papers that were presented at the Fourteenth Annual U.S. Department of Energy Low-Level Radioactive Waste Management Conference, November 18–20, 1992, in Phoenix, Arizona. The papers address the following general topics: (a) Performance Management Track: risk assessment; waste characterization; site characterization; facility design; groundwater modeling; monitoring and modeling; and regulatory requirements; (b) Technical Track: waste minimization; new technologies; international perspectives; licensing issues; hot topics; commercial storage; DOE storage; treatment technologies; and mixed waste; and (c) Institutional Track: status report; changes in orders, regulations, and guidance; regulatory compliance issues; communicating risk; hot topics; and storage impacts.

CONTENTS

PERFORMANCE MANAGEMENT TRACK 1

Performance Management Overview Session

The Performance Assessment Process for DOE Low-Level Waste Disposal Facilities 3

Risk Assessment Session

Comparative Risk Assessment of Incineration vs. Compaction and Supercritical Water Oxidation for Low-Level and Mixed Wastes 7

Risk Assessment and Development of California's Ward Valley Low-Level Radioactive Waste Disposal Facility 21

In Pursuit of an Integrated Mixed Waste Risk Assessment Methodology 28

Waste Characterization Session

Radioactive Waste Characterization 38

Site Characterization Session

Intrusive and Nonintrusive Site Characterization Using Geophysics (Lecture Notes) 48

The Innovative Application of Surface Geophysical Techniques for Remedial Investigations 52

Contaminated Groundwater Characterization at the Chalk River Laboratories, Ontario, Canada 67

Lysimeter Data as Input to Performance Assessment Source Term Codes 84

Facility Design Session

Aboveground Roofed Design for the Disposal of Low-Level Radioactive Waste in Maine 94

Use of Engineered Soils Beneath Low-Level Radioactive Waste Disposal Facilities 105

Groundwater Modeling Session

Mechanisms of Contaminant Migration from Grouted Waste 118

Performance Assessment Techniques for Groundwater Recovery and Treatment Systems 127

Monitoring and Modeling Session

Discrete Source Computer Model for Radiation Exposure Outside a Low-Level Radioactive Waste Facility 142

The Effect of an Engineered Closure Cap on Radon Gas Transport from a Shallow Land Burial Site 151

Environmental Monitoring of Subsurface Low-Level Waste Disposal Facilities at Oak Ridge National Laboratory 170

Environmental Monitoring of the Tumulus Low-Level Waste Disposal Facilities at Oak Ridge National Laboratory 188

Panel on Performance Assessment Issues Session

Potential Impact of DOE's Performance Objective for Protection of Inadvertent Intruders on Low-level Radioactive Waste Disposal at Oak Ridge National Laboratory ... 204

Performance Assessment Closing Session

Integration and Interpretation of Results from Performance Assessments of Low-Level Radioactive Waste Disposal Facilities 215

TECHNICAL TRACK 221

Waste Minimization Session

Strategy for Upgrade of ORNL Treatment Facilities to Minimize Secondary Waste Generation 223

Pollution Prevention Program for New Projects—Lessons Learned 233

Low-Level Waste Minimization at the Y-12 Plant 236

New Technologies Session

IGRIS for Characterizing Low-Level Radioactive Waste 241

Electrokinetics for Removal of Low-Level Radioactivity from Soil 256

Application of Neural Networks to Waste Site Screening 279

International Perspectives Session

Russian Low-Level Waste Disposal Program 290

Status of Low-Level Radioactive Waste Management in Korea 303

Licensing Issues Session

Technical Issues in Licensing Low-Level Radioactive Waste Facilities 313

Issues in the Review of a License Application for an Above Grade Low-Level Radioactive Waste Disposal Facility 316

Technical Hot Topics Session

Low-Level Waste Management Alternatives and Analysis in DOE's Programmatic Environmental Impact Statement 322

DOE'S Integrated Low-Level Waste Management Program and Strategic Planning 329

Treatment of DOE and Commercial Mixed Waste by the Private Sector 341

Commercial Storage Session

Interim Onsite Storage of Low-Level Waste at Nuclear Power Plants 350

DOE Storage Session

An Update of a National Database of Low-Level Radioactive Waste in Canada 362

Radioactive Mixed Waste Storage 369

Disposal of Low-level Radioactive Waste at the Savannah River Site 378

Treatment Technologies Session

Contaminated Graphite Waste Incineration 387

Preliminary Design of a Biological Treatment Facility for Trench Water from a Low-Level Radioactive Waste Disposal Area at West Valley, New York 397

Bench-Scale Treatability Testing of Biological, UV Oxidation, Distillation, and Ion-Exchange Treatment of Trench Water from a Low-Level Radioactive Waste Disposal Area at West Valley, New York. 411

Mixed Waste Session

A Decision Methodology for the Evaluation of Mixed Low-Level Radioactive Waste Management Options for DOE Sites 428

Hazardous Waste Shipment Data Collection from DOE Sites 433

Solutions for Dioctyl Phthalate-Tested High-Energy Particulate Air Filters Destined for Disposal at Hanford, Washington 455

INSTITUTIONAL TRACK 459

State and Compact Region Status Report Session

The Texas Concurrent Characterization, Licensing, and Development Process 461

Developing a Low-Level Radioactive Waste Disposal Facility in Connecticut: Update on Progress and New Directions 471

Status of the North Carolina/Southeast Compact Low-level Radioactive Waste Disposal Project 477

Changes in Orders, Regulations, and Guidance Session

Requirements and Impacts of the Federal Facility Compliance Act on the Department of Energy 485

Planned Revision to DOE Order 5820.2A, "Radioactive Waste Management" 490

Integrating Total Quality Management Principles with the Requirements of DOE Order 5700.6C 497

Regulatory Compliance Issues Session

A Process for Ensuring Regulatory Compliance at the INEL's Buried Waste Integrated Demonstrations 501

DOE's Approach to Groundwater Compliance on the UMTRA Project 509

Nuclear Regulatory Commission's Technical Position on Concentration Averaging and Encapsulation for Waste Classification Purposes 523

The Constitution, Waste Facility Performance Standards, and Radioactive Waste Classification: Is Equal Protection Possible? 526

Public Involvement/Acceptance Session

The Social Basis of Public Policy Disputes 531

Communicating Risk Session

Verbal Risk in Communicating Risk 537

Is Low Level Radioactive Waste Different? Lessons Learned from Other Industries 543

When You Speak, Why Don't They Listen? 553

Institutional Hot Topics Session

DOE Acceptance of Commercial Mixed Waste—Studies Are Under Way 564

1993: Where is the Low-Level Waste Going? 566

Thoughts on the Siting Process 574

Perspectives on the Siting of Low-level Radioactive Waste Disposal Facilities in Illinois 598

Licensing and the North Carolina LLW Project 608

Impacts of Legal Challenges Session

Who Pays for the Costs of Delay? 613

Institutional Storage Impacts Session

Dealing with Radioactive Waste without Access to Disposal 618

Current and Future Economic Impacts of Onsite Storage A National Perspective 621

Defusing Hysteria: How Institutional Generators of LLW Can Make Allies, Not Adversaries, of Their Residential Neighbors 626

Storage and Public Acceptance 630

Interim Storage of Low-Level Radioactive Waste 635

ACRONYMS

CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	Code of Federal Regulations
DOE	U.S. Department of Energy
EPA	U.S. Environmental Protection Agency
GTCC	greater-than-Class C
HLW	high-level radioactive waste
LLW	low-level radioactive waste
MLLW	mixed low-level radioactive waste
NEPA	National Environmental Policy Act
NRC	U.S. Nuclear Regulatory Commission
RCRA	Resource Conservation and Recovery Act
RMW	radioactive mixed waste
PA	performance assessment

PERFORMANCE MANAGEMENT TRACK

The Performance Assessment Process for DOE Low-Level Waste Disposal Facilities

Elmer L. Wilhite
Savannah River Site
Westinghouse Savannah River Company
Savannah River Technology Center[a]
Interim Waste Technology Section
Aiken, SC 29802

INTRODUCTION

The United States Department of Energy manages several large sites in various locations. These sites are involved in nuclear material production and testing, nuclear reactor development and testing, and research and development. Low-level radioactive waste generated at these sites is disposed in near-surface disposal facilities located at six of the sites.

Safety of the low-level waste disposal facilities, as well as all U.S. DOE facilities, is a primary criterion in their design and operation. Safety of low-level waste disposal facilities is evaluated from two perspectives. Operational safety is evaluated based on the perceived level of hazard of the operation. The safety evaluations vary from simple safety assessments to very complex safety analysis reports, depending on the degree of hazard associated with the facility operation.

Operational requirements for the Department's low-level waste disposal facilities, including long-term safety are contained in DOE Order 5820.2A, "Radioactive Waste Management."[1]

This paper will focus on the process of conducting long-term performance analyses rather than on operational safety analysis.

PERFORMANCE OBJECTIVES FOR WASTE DISPOSAL

Requirements for management of radioactive waste are contained in DOE Order 5820.2A, "Radioactive Waste Management."[1] This order became effective on September 26, 1988. Chapter III of the order details policy and requirements for management of low-level waste.

Performance objectives for low-level waste management are summarized below:

1. Protect public health and safety in accordance with DOE orders
2. Assure that no member of the public receives more than 25 mrem per year, effective dose equivalent, from all pathways combined
3. Assure that the committed effective dose equivalents received by an inadvertent intruder will not exceed 100 mrem/yr for continuous exposure or 500 mrem for a single acute exposure
4. Protect ground water resources, consistent with federal, state and local requirements.

---

a. Operated by Westinghouse Savannah River Company under Contract No. DE-AC09-89SR18035 with the U.S. Department of Energy.

PERFORMANCE ASSESSMENT REQUIREMENT

The Radioactive Waste Management order also requires that low-level waste disposal facilities prepare and maintain a radiological performance assessment to demonstrate compliance with the performance objectives. The order further requires that an Oversight and Peer Review Panel be established to ensure consistency and technical quality within the DOE complex in the development and application of performance assessment models that include site specific climate, geohydrology and waste composition.

PERFORMANCE ASSESSMENT REVIEW PANEL

Peer Review Panel members were selected by the Department from nominees presented by each of the Field Offices. One member was appointed by the U.S. DOE Office of Environment, Safety and Health. In addition, the U.S. Nuclear Regulatory Commission and the U.S. Environmental Protection Agency were invited to appoint technical advisors to the Panel.

The review process, as determined by the Panel, consists of two parts. First, as a performance assessment is being developed, the Panel will conduct an informal review. The informal review consists of tours and discussions at the disposal facility relative to the planned performance assessment methodology followed by recommendations from the Panel to enhance the development of the assessment.

Second, when the performance assessment is finalized, the report is submitted to the Office of Waste Operations (EM-30) for review by the Panel. The final review consists of review and comment by individual Panel members, followed by a meeting of the Peer Review Panel to develop a consensus on the technical adequacy of the PA; the final review process typically requires at least three months. The Panel then advises EM-30 as to the technical adequacy of the assessment.

The Panel has developed and issued two documents:

- Recommended Format and Content for DOE Low-Level Waste Disposal Facility Radiological Performance Assessment Reports, DOE/LLW-81[2]
- Performance Assessment Review Guide for DOE Low-Level Radioactive Waste Disposal Facilities, DOE/LLW-93.[3]

These documents supplement guidance provided by DOE for the preparation of performance assessments[4] and will provide assistance to the Panel in conducting reviews. The Panel has also provided guidance to the Office of Waste Operations on points of compliance for the performance objectives.

PERFORMANCE ASSESSMENT DEVELOPMENT

The development of a performance assessment for a specific low-level waste disposal facility is a multi-step process. Performance assessment is, by nature, a multi-disciplinary process. Thus, the first step is to convene a working group representing the several disciplines involved. Key disciplines include: geology, geochemistry, hydrology, computer modeling, dose assessment, radiochemistry, and low-level waste disposal facility operations.

The working group must define the facility being assessed, including disposal unit design, waste generation processes, waste form and packaging (including waste treatment), waste emplacement and stabilization, technology for final closure, expected inventory of radionuclides, and inventory of chemicals potentially affecting migration of radionuclides. The disposal facility environs must also be characterized including climate, meteorology, geology, hydrology, ecology, and human population distribution (both current and projected). Use of natural resources (both current and projected) in the environs should be described as well as potentially disruptive natural phenomena such as seismicity and volcanism. Degradation of engineered

design features such as concrete vaults[5] and erosion or breaching of clay caps must also be considered, as appropriate.

The analysis of performance should begin by formulating conceptual models representing potential mechanisms for release of radionuclides from the waste, transport through the environment and exposure to humans.[6,7,8] Screening calculations should be employed to define the major radionuclides, pathways and exposure scenarios for more refined analysis.

For each of the scenarios and/or pathways selected for detailed analysis, the following steps should be followed:

- Present a clear and concise description of the system being analyzed
- Define the conceptual model developed to represent the system
- Select a computational model to analyze the conceptual model, and justify the selection
- Perform the necessary calculations, being careful to justify all assumptions.

Throughout this process, site-specific data should be used to the extent possible. When an assumption is made because of the lack of data, the assumption and justification for it must be documented.

Following the initial detailed analysis, analysis of the sensitivity of calculations to assumptions and selection of parameters should be performed. The propagation of uncertainty in parameters and scenarios should be assessed and the overall uncertainty in the results of analyses should be estimated.

INTEGRATION AND INTERPRETATION

The final step is to interpret the results of the analyses and integrate the interpretation into the overall assessment of long-term performance.

The integration and interpretation of results is commonly not given enough emphasis. Frequently, the PA preparer views the PA process as simply completing a number of calculations and reporting the results. Admittedly, these calculations can be very complex. However, just as important as completing the calculations is the process of "making sense" of the results in light of the assumptions that had to be made, the uncertainty in input data, etc. This is called integration and interpretation. Only through the process of integration and interpretation can the PA give an indication of whether the disposal facility is likely to meet the required performance objectives.

LESSONS LEARNED FROM REVIEWS

To date, the Panel has conducted six preliminary reviews at the Hanford site (Grout facility), at the Nevada Test Site (Area 5 burial ground), at the Idaho National Engineering Laboratory (Radioactive Waste Management Complex burial ground), at the Los Alamos National Laboratory (Area G burial ground), at the Oak Ridge National Laboratory (Solid Waste Storage Area 6 burial ground), and at the Savannah River Site (Saltstone facility). The Panel has also concluded the final review of the Hanford Grout facility assessment. The recommendations generated by the Panel from these reviews have been compiled and condensed into the following guidance.

- In the description of the facility and environs, sufficient detail must be presented to demonstrate adequate understanding of the facility and environmental processes potentially affecting contaminant migration. Most DOE Sites have a considerable history of environmental investigations/studies that should be factored into the performance assessment.

- Justification of each aspect of the assessment is critical. The review process is primarily that of validating the judgment of the assessor as pathways and scenarios are defined, computer codes are selected, etc. Thus, clearly stated and justified assumptions, selections of parameter values, choice of radionuclides for analysis, etc. are necessary.

- Disposal of low-level waste is evolving toward the reliance on engineered barriers to achieve performance objectives. Thus, the estimation of the lifetime of the barriers under disposal conditions is necessary for a credible performance assessment. Undue conservatism will result from taking no credit for engineered barriers.

- It may be helpful to present two overall analyses of performance, one health-conservative and the other a best engineering estimate. Such a presentation may point out critical uncertainties in the analysis and qualitatively indicate the degree of conservatism in the health-conservative analysis.

- Formulation of intruder scenarios should consider site-specific conditions (climate, environment, historical patterns of human activity, etc.) as well as "standard" scenarios.[5] Passive controls (markers, land use records, etc.) may be considered in the analysis of intrusion, however, the duration and effectiveness of the controls must be justified.

- The integration and interpretation of the results of the analyses required for a performance assessment is critical to the success of the assessment. This step involves interpreting the results of several analyses in light of the associated uncertainty and sensitivity, the extent of assumptions necessary to conduct the analyses, etc. Frequently, this step is neglected or not given sufficient emphasis, resulting in diminished credibility of the assessment.

- Sufficient detail must be documented to enable the review panel to undertake confirmatory calculations in order to judge the acceptability of the assessment.

REFERENCES

1. U.S. Department of Energy, "Radioactive Waste Management," DOE 5820.2A, September 26, 1988.

2. M. J. Case, et al., "Recommended Format and Content for DOE Low-Level Waste Disposal Facility Radiological Performance Assessment Reports," DOE/LLW-81, April 1989.

3. R. L. Dodge, et al., "Performance Assessment Review Guide for DOE Low-Level Radioactive Waste Disposal Facilities," DOE/LLW-93, October 1991.

4. M. J. Case and M. D. Otis, "Guidelines for Radiological Performance Assessment of DOE Low-Level Radioactive Waste Disposal Sites," DOE/LLW-62T, July 1988.

5. J. C. Walton, et al., "Models for Estimation of Service Life of Concrete Barriers in Low-Level Radioactive Waste Disposal," NUREG/CR-5542, September 1990.

6. M. W. Kozak, et al., "A Performance Assessment Methodology for Low-Level Waste Facilities," NUREG/CR-5532, July 1990.

7. M. M. Stevens, "Conceptual Model for Radiological Performance Assessment of Low-Level Radioactive Waste Disposal Facilities," ORNL/TM-11495, March 1990.

8. W. E. Kennedy, Jr. and R. A. Peloquin, "Intruder Scenarios for Site-Specific Low-Level Radioactive Waste Classification," DOE/LLW-71T, September 1988.

Comparative Risk Assessment of Incineration vs. Compaction and Supercritical Water Oxidation for Low-Level and Mixed Wastes[a]

Jean-Claude Dehmel
William Thurber
S. Cohen & Associates, Inc.

Robert Dyer
Madeleine Nawar
U.S. Environmental Protection Agency

ABSTRACT

The Department of Energy has initiated an Environmental Restoration Program involving the cleanup of currently operating facilities and facilities that were used in past weapons and civilian nuclear programs (DOE 1989a). The Environmental Restoration Program will involve a broad range of decontamination and decommissioning activities that will generate vast amounts of both low-level radioactive and mixed wastes. The DOE will be required to consider the merits of a number of treatment options to treat these wastes.

This paper discusses three treatment options: conventional compaction, incineration, and supercritical water oxidation (SCWO). Conventional compaction is assumed to be used for processing compressible low-level radioactive waste (i.e., dry-active waste). Incineration is assumed to be used for the treatment of both compressible dry-active waste and mixed waste, while SCWO is assumed to be used only for liquid mixed waste streams. For this evaluation, risk assessment analyses were performed to evaluate the relative merits of (a) compaction and incineration for the traditional types of low-level radioactive waste streams, and (b) incineration and supercritical water oxidation for the treatment of liquid mixed wastes.

APPROACH AND METHOD

The analyses were performed using "generic" waste streams and processing or treatment technologies. The information and data characterizing the radioactive waste streams were based on published DOE data (DOE 1990, DOE 1986, ADA 1990). The waste treatment systems (except for supercritical water oxidation) were assumed to be representative of DOE in general rather than a specific DOE facility. Since no full-scale supercritical water oxidation systems are operational, the necessary system parameters and operating characteristics were derived from the literature.

Compaction

Compaction is one of the simplest and most effective techniques for reducing the volume of dry active waste (DOE 1988). As such, it is particularly suitable for large volumes of slightly contaminated wastes. Conventional compactors accept only wastes that yield to relatively low pressures. Before compaction, all waste must be sorted to remove noncompressible components such as tools, pipes, valves, concrete, etc. Compactors are simple to operate and are available in various designs and sizes. Compactor designs range from the less expensive hand-operated systems to fully automated, electronically controlled hydraulic systems. Waste can be compacted inside a 55-gallon drum, wooden box, steel box, or other container, depending on the design of the compactor. A commonly used compactor for low-level radioactive waste consolidation is the 55-gallon drum unit. The compactor consists of an electrically driven pump, a hydraulic cylinder to which a platen is attached,

---

a. The work described in this paper was funded by the U.S. Environmental Protection Agency, Office of Radiation and Indoor Air under contract No. 68D90170. The contents, however, do not reflect the views of the Agency and no official endorsement should be inferred.

and a ventilation system comprising a prefilter, a high-efficiency particulate air filter, and an exhaust fan (SEC 1990). These compactor units supply compressive forces from 10 to 30 tons. Typically, noncompacted waste with a density of 8 lb/ft^3 can be compacted to a density of about 30 lb/ft^3 (DOE 1988, WAC 1991). With the use of antispring-back devices, the performance can be improved to achieve densities as high as 40 lb/ft^3 (DOW 1987). Accordingly, compaction ratios have been shown to range from an average of 2:1 to as high as 5:1 depending upon waste forms and operating practices.

Incineration

Incineration involves the introduction of wastes into a combustion chamber in a bulk form (e.g., boxes, bags, or drums), shredded, in a sludge form (e.g., slurry), or injected as liquid (IAE 1989, EG&G 1988, ASM 1988). The feed rate is governed by the combustible nature of the material and the design of the incinerator. Sometimes liquid wastes are introduced as a mixture of fuel and waste. Typical processing rates range from 23 to 382 kg/h for the currently operating or planned DOE incinerators (DOE 1989b, IAE 1989, EPA 1991). The waste/fuel ratio is determined by the combustion properties of the waste and incinerator capacity. The considerations noted above apply generally to all waste forms (mixed and low-level radioactive wastes). As combustion occurs, oxygen is consumed and the combustion gases are entrained in a secondary combustion chamber. The proper combustion conditions are maintained by controlling the amount of air, waste feed rate, and temperature. Special attention is given to the residence time to ensure that complete oxidation occurs and that the hazardous components are destroyed.

As the feed material is consumed, most of the ash is collected at the bottom of the combustion chamber or in ash bins. Some of the ash, however, is entrained with the offgas and settles or collects in various parts of the offgas treatment system. The deposition of ashes in various parts of the system is dependent upon waste feed, offgas velocity, particle size and density, combustion process, residence time, and type of air pollution system components.

Suspended particulates, fumes, and products of incomplete combustion, if any, are entrained in exhaust scrubbers and filtration devices before the combustion gases are released out of the stack. Offgas treatment typically involves passing the hot flue gases into a series of components to remove suspended particulates, gases, and radionuclides. Such components typically include heat-exchangers, filters and separators, high-efficiency particulate air filters, and adsorbers. Other forms of offgas cooling include quenching by water injection and dilution by introducing air at ambient temperature. Particulate emissions, depending on particle sizes and exhaust velocity, are trapped in heat-exchangers, filters, or electrostatic separators. The chemical and radioactive constituents of the offgas can vary significantly from those of the input waste.

Incineration has been shown to yield varying volume reduction factors, typically 4 to 40 for most types of compressible dry-active waste and combustible solids, and greater than 100 for liquids and most plastics (EG&G 1988, EG&G 1980, EG&G 1982, NRC 1983). As with compaction, incineration yields waste residues that are of much higher specific activity than the original waste stream. Consequently, it is expected that ash containers or bins will display higher external radiation exposure rates.

Supercritical Water Oxidation

Supercritical water oxidation relies on the principle that, above a certain temperature and pressure, the physical properties of water change to that of a solvent for organic substances (TES 1991, HON 1989, HON 1991, MOD 1990, STA 1987, SWA 1989, DOE 1989c, SWA 1990). The process takes place at high temperatures (above 370°C., 700°F.) and high pressures (above 3,200 psi, 225 kg/cm^2). At supercritical conditions, organic substances become extremely soluble in water while inorganic compounds do not. In this process, the organic substances are oxidized and nearly or totally destroyed in the presence of oxygen in an exothermic reaction. The end products are carbon dioxide, nitrogen, CO_2 and other gases, dilute acids, and water. When treating inorganic compounds, the process results in the generation of insoluble salts and other precipitates.

The waste stream is injected as a liquid or slurry into a reaction chamber along with oxygen. The oxidation process takes place almost immediately, with residence times ranging from a few seconds to several minutes. Under ideal conditions, once at operating temperature and pressure, the process is self- sustaining if the organic substance has fuel-like properties. If not, fuel is typically added to the waste stream to support the process. The treatment process is controlled by regulating the introduction of the waste/fuel mixture and oxygen once the required temperature and pressure conditions have been attained. Supercritical water oxidation works best on relatively dilute concentrations (1 to 5%) of organic compounds. Catalysts may, however, be required at higher waste concentrations (10 to 20%). Destruction efficiencies as high as 99.9999% have been achieved for a variety of organic compounds (JOH 1988, MOD 1988, MCF 1991, MOD __, ROF 1989, SWA 1990). The waste stream is discharged as clean water after it is cooled and degassed. A fraction of the effluent water stream is recycled during the process for energy conservation. Any salts formed during the process and residual solids, since they are not soluble at supercritical conditions, settle to the bottom of the reaction chamber and are later removed for further treatment and disposal. This type of treatment system may generate enough steam and hot water to be recovered for space heating, power generation, or used for other industrial applications (KIL 1988, HON 1991).

RADIOACTIVE SOURCE TERMS

A wide spectrum of low-level radioactive wastes is routinely generated at Department of Energy facilities. Such wastes include solids, sludges, biological, compressible and noncompressible materials, and aqueous and organic liquids. Some liquids may be immobilized in approved absorption media.

Low-Level Radioactive Waste Radionuclides, Activity, and Volume

The radioactive source term used in this study is derived from information published in DOE's Integrated Database (DOE 1990). A generic radionuclide distribution is constructed from data characterizing waste generation practices for the Oak Ridge National Laboratory. The source term collapses six different types of waste forms into a single waste stream. It is assumed that such wastes would be introduced in a low-level radioactive waste processing facility as long as the waste would meet the waste acceptance criteria. Accordingly, it is envisioned that such wastes would be brought in from various production areas or research facilities to be commingled with other waste forms. Because the waste would already meet the acceptance criteria, it is assumed that there would be no restrictions on how the waste would be handled and processed.

The radiological source term shown in Table 1 is based upon an overall average concentration of 6.0 Ci/m^3 prorated by nuclide and waste stream distributions. The six waste streams include uranium/thorium, fission products, induced activity, tritium, alpha emitters (<100 nCi/g), and other nonspecified wastes. It is recognized that this selection is not all comprehensive, but is assumed to capture typical beta, gamma, and alpha emitters. It is assumed that 1,000 m^3 are generated yearly, with 330 m^3 being compressible or incinerable wastes.

Mixed Wastes

Mixed wastes are generated during various production or research activities, often when chemicals are introduced as cleaning agents or solvents. Most activities, however, do not create new products or agents that are chemically hazardous. Given the broad range of waste streams, radionuclides, and activity typically generated by DOE facilities, a simple approach was used in developing the source term. Mixed waste data were extracted from a DOE document used to verify compliance of the Toxic Substances and Control Act (TSCA) incinerator for compliance with national emission standards for hazardous air pollutants and other internal DOE documents (DOE 1986, ADA 1990, ROS 1992). The radiological source term shown in Table 1 is based on apportioning the radionuclide inventory to the incinerable liquid waste volume. The liquid waste forms considered here include biological aqueous solutions, biological wastes, scintillation fluids, oils, and spent solvents. Although not comprehensive, this selection is believed to be broad enough to capture typical beta, gamma, and alpha emitters. It is assumed that such liquid wastes are generated at a rate of about 98,000 liters (26,000 gallons) per year.

RADIOLOGICAL RISK ASSESSMENT

The radiological risk assessment was performed using the EPA's CAP88-PC computer code (EPA 1992). The code calculates doses associated with airborne releases, including exposures due to ingestion, inhalation, plume immersion, and ground-deposited radioactivity. The code contains atmospheric data for various locations in the United States. Atmospheric dispersion is based on a modified Gaussian model. All ingested foods are assumed to be grown locally with the ingestion rates based on the NRC model described in Regulatory Guide 1.109.

Exposure Model and Scenarios

The atmospheric data were selected for the Oak Ridge National Laboratory. In addition, the following data were used to describe local weather conditions: average temperature, 17°C.; rain fall, 50 cm/y; and a lid height of 1,000 m. An incinerator stack height of 30 m was used for all releases.

Credit was taken for stack plume buoyancy (at 1.6E+05 cal/s) for incineration only. Similarly, a stack height of 10 m was assumed for wastes processed by compaction and supercritical water oxidation with a plume rise momentum of 6.0 m/s. It was assumed that the hypothetical resident was located at 300 m away from either stack, the closest distance allowed by the code. Agricultural productivity for the State of Tennessee was assumed regarding milk, beef, and crop yields consumed by the nearby resident for the ingestion exposure pathway.

Low-Level Radioactive Waste Radioactive Source Term

The low-level radioactive waste source term is shown in Table 2 for compaction and incineration. The source term is based on the waste volume and nuclide concentrations shown in Table 1. For compaction, it is assumed that 0.01% of the activity becomes airborne as the waste is being compressed (NRC 1986). It is also assumed that a high-efficiency particulate air (HEPA) filter with an efficiency of 99.97% is used to treat all exhaust effluents (EPA 1991, IAE 1989, ERD 1976). For incineration, the same HEPA filter collection efficiency was used. The presence of a wet scrubber and venturi system adds another reduction factor of 10^3 for all particulate emissions. No credit, however, was taken for H-3 and C-14 removal since these are assumed to be released as gases.

Mixed Waste Radioactive Source Term

The mixed waste radioactive source term is shown in Table 3 for both cases, incineration and supercritical water oxidation. As noted earlier, the source term is based on the waste volume and nuclide concentrations shown in Table 1. The HEPA filter collection efficiency is assumed to be 99.97% for both systems (EPA 1991, IAE 1989, ERD 1976). For the incinerator, the presence of a wet scrubber and venturi system adds another reduction factor of 10^3 for all particulate emissions. No credit was taken for H-3 and C-14 reduction. For I-125 and I-131 releases, however, it was assumed that the exhaust treatment system is equipped with a charcoal filter, as is current practice. It was assumed that the charcoal filter has a typical collection efficiency of 90% for radioiodines.

For supercritical water oxidation, the source term was developed from data characterizing radionuclide partition factors in nuclear reactors (NRC 1976, NRC 1979). The partition factor is the ratio of radioactivity between two media, in this case water and vapor phases. This approach is believed to represent a reasonable approximation of how radionuclides might behave at high temperature and pressure at the liquid and vapor interface, since there are no data specifically characterizing this aspect. Three different partition factors were used to model the amount of radioactivity that is assumed to exit the SCWO reactor. The partition factors characterize nuclides that may be released as a gas or vapor, halogen, and elemental forms. For H-3 and C-14, it is assumed that they would be released as vapors. For I-125 and I-131; a partition factor of 0.015 was used. For the remaining radionuclides, a partition factor of 0.001 was applied. A HEPA filter collection efficiency of 99.97% is assumed for all nuclides, except H-3, C-14, I-125, and I-131. As before, it was assumed that the

exhaust treatment system is equipped with a charcoal filter for I-125 and I-131 releases with an overall collection efficiency of 90% for radioiodines.

RISK ASSESSMENT RESULTS AND DISCUSSION

Low-Level Radioactive Waste Compaction and Incineration

Doses and risks to the maximum exposed individual are shown in Table 4. The results indicate that the highest exposure results from consumption of locally grown foodstuffs. The organ with the highest dose is the bone. The radionuclides yielding the highest doses are H-3 and C-14. The effective dose equivalent is 0.074 mrem/y for compaction and 0.001 mrem/y for incineration. A similar relationship holds for the critical organ. The corresponding fatal cancer risks are 1.9E-06 and 2.6E-08 for compaction and incineration, respectively. All dose results are well below the national standard of 10 mrem/yr (EPA 1989).

Although a lower source term was assumed for compaction than for incineration, other assumptions used in this relative risk assessment result in lower doses and risks for incineration. Except for exposure from ground-deposited radioactivity, both waste treatment methods are nearly equal in terms of doses and risks. For compaction, the inhalation, ingestion, and air immersion exposure pathways produce higher doses because the lower compactor stack height limits atmospheric dispersion.

The parameter that drives offsite doses for all particulate nuclides, except H-3 and C-14, is the assumed efficiency of the offgas collection system. For H-3 and C-14, the radioactive source term characterizing the waste governs offsite exposures and doses. Ingestion doses, in part, are higher due to the computer model, which assumes a 100-year activity buildup from airborne deposition.

Mixed Waste Incineration and Supercritical Water Oxidation

Doses and risks for the maximum exposed individual are shown in Table 5 for the mixed waste treatment system. The highest exposure is from consumption of locally grown foodstuffs. The organs with the highest doses are the thyroid gland and bone. The radionuclides yielding the highest doses are I-125 and I-131 for incineration and H-3, C-14, I-125, and I-131 for the supercritical water oxidation treatment. The effective dose equivalent, due to incineration, is 1.5E-04 mrem/y and 4.7E-03 mrem/y to the thyroid. For supercritical water oxidation, the doses are 4.7E-04 mrem/y and 3.7E-03 mrem/y to the thyroid. The corresponding risks are 8.6E-10 and 9.6E-09 for incineration and supercritical water oxidation, respectively. As before, it should be noted that all dose results are well below the national standard of 10 mrem/yr.

Supercritical water oxidation yields higher doses primarily because of the lower stack height resulting in lower atmospheric dispersion. In both cases, the radioiodines source term dominates over particulates by over one order of magnitude.

Doses for ingestion, inhalation, and air immersion, to a lesser extent, are all lower for incineration. Doses due to ground deposited activity are within a factor of two between both waste treatment methods. The parameter that drives offsite doses for particulates depends upon the assumed offgas system collection efficiency of either treatment system. For H-3 and C-14, the radioactive source term characterizing the waste governs offsite exposures and doses. For supercritical water oxidation, offsite doses are controlled by the assumed partition factor used to model the amount of radioactivity escaping the liquid and vapor interface. The partition factor is assumed to apply to all nuclides, except H-3 and C-14. The collection efficiency of the charcoal filter determines how much radioiodines are released from either treatment method.

SUMMARY

The Department of Energy has initiated an Environmental Restoration Program involving the cleanup of currently operating facilities and those that were used in past weapons and civilian nuclear programs. The Environmental Restoration Program will involve a broad range of decontamination and decommissioning

activities generating large amounts of low-level radioactive and mixed wastes. In evaluating several options to treat and process such wastes, the DOE will be required to consider the merits of a number of treatment options. Three treatment options are evaluated in this paper: conventional compaction, incineration, and supercritical water oxidation. Conventional compaction is used for processing compressible low-level radioactive waste. Incineration is used for the treatment of both compressible dry-active waste and liquid mixed waste. SCWO is assumed to be used only for liquid mixed waste. Risk assessment analyses were performed to evaluate the relative merits of (a) compaction and incineration for low-level radioactive waste, and (b) incineration and supercritical water oxidation for the treatment of liquid mixed wastes.

The effective dose equivalent is 0.074 mrem/y for compaction and 0.001 mrem/y for incineration. The radionuclides yielding the highest doses are H-3 and C-14. The effective dose equivalent, due to incineration, is 1.5E-04 mrem/y and 4.7E-03 mrem/y to the thyroid. For supercritical water oxidation, the doses are 4.7E-04 mrem/y and 3.7E-03 mrem/y to the thyroid. The radionuclides yielding the highest doses are I-125 and I-131 for incineration and H-3, C-14, I-125, and I-131 for the supercritical water oxidation treatment.

Offsite doses due to particulate emissions are governed by the assumed collection efficiency of the offgas system. For H-3 and C-14, the source term governs offsite doses. For supercritical water oxidation, offsite doses are controlled by the assumed partition factor used to model the amount of radioactivity escaping the liquid and vapor interface. The partition factor is assumed to apply to all nuclides, except H-3 and C-14. The assumed collection efficiency of the charcoal filter determines how much radioiodines are released from either treatment method.

Table 1. Compressible low-level and liquid mixed waste source terms.

Nuclide	Low-level[a] (Ci/m^3)	Mixed[b] (uCi/mL)
H-3	2.49E-02	2.09E-04
C-14	1.22E-03	2.43E-05
P-32	---	2.72E-05
S-35	---	1.01E-05
Cr-51	1.33E-01	1.46E-06
Mn-54	1.17E+00	---
Fe-59	1.32E-02	---
Co-57	---	1.22E-07
Co-58	1.49E+00	---
Co-60	3.91E-01	---
Zn-65	5.13E-03	6.11E-08
Sr-90	1.73E-01	---
Y-90	1.73E-01	---
Tc-99	2.45E-03	1.94E03
Ru-106	7.67E-02	---
Rh-106	7.67E-02	---
I-125	---	3.86E-05
I-131	---	6.77E-06
Sb-125	3.52E-02	---
Cs-137	5.84E-01	---
Ba-137m	5.53E-01	---
Ce-144	1.76E-01	---
Pr-144	1.76E-01	---
Th-230	---	1.16E-10
Th-232	3.28E-05	---
Th-234	3.98E-03	---
U-235	3.10E-06	---
U-238	1.89E-02	5.58E-05
Pu-238	1.57E-04	---
Pu-239	1.20E-05	6.37E-11
Pu-240	4.20E-05	---
Pu-241	5.78E-03	---
Am-241	2.40E-07	---

a. Drawn from Section 4.0 and Tables 4.3, 4.4, and A.5 from DOE's Integrated Database report. Assumes a yearly generation rate of 330 m^3 of compressible or incinerable waste.

b. Extracted from Tables C-1 and C-2 and Attachment 2 of NESHAPS Report. Assumes a yearly generation rate of 98,000 liters (26,000 gallons) of incinerable mixed liquid wastes.

Table 2. Low-level radioactive waste source term—stack emissions.

Nuclide	Compaction[a] (Ci/yr)	Incineration[b] (Ci/yr)
H-3	8.22E+00	8.22E+00
C-14	4.03E-01	4.03E-01
Cr-51	1.32E-06	1.32E-05
Mn-54	1.16E-05	1.16E-04
Fe-59	1.31E-07	1.31E-06
Co-58	1.48E-05	1.48E-04
Co-60	3.87E-06	3.87E-05
Zn-65	5.10E-08	5.10E-07
Sr-90	1.71E-06	1.71E-05
Y-90	1.71E-06	1.71E-05
Tc-99	2.43E-08	2.43E-07
Ru-106	7.59E-07	7.59E-06
Rh-106	7.59E-07	7.59E-06
Sb-125	3.48E-07	3.48E-06
Cs-137	5.78E-06	5.78E-05
Ba-137m	5.47E-06	5.47E-05
Ce-144	1.74E-06	1.74E-05
Pr-144	1.74E-06	1.74E-05
Th-232	3.25E-10	3.25E-09
Th-234	3.94E-08	3.94E-07
U-235	3.10E-11	3.10E-10
U-238	1.87E-07	1.87E-06
Pu-238	1.55E-09	1.55E-08
Pu-239	1.19E-10	1.19E-09
Pu-240	4.16E-10	4.16E-09
Pu-241	5.72E-08	5.72E-07
Am-241	2.38E-12	2.38E-11

a. Based on a HEPA filter collection efficiency of 99.97% and 0.01% of the activity leaving the container. For H-3 and C-14, it is assumed that all activity is released without any retention or filtration.

b. Based on a HEPA filter collection efficiency of 99.97% and a decontamination factor of 10^3 for activity retained in the scrubber, venturi, and deposited elsewhere in the offgas treatment system. For H-3 and C-14, it is assumed that all activity is released without any retention or filtration.

Table 3. Liquid mixed waste source term—stack emissions.

Nuclide	Supercritical[a] Water Oxidation (Ci/yr)	Incineration[b] (Ci/yr)
H-3	2.05E-02	2.05E-02
C-14	2.38E-03	2.38E-03
P-32	8.01E-10	8.01E-10
S-35	2.96E-10	2.96E-10
Cr-51	4.29E-11	4.29E-11
Co-57	3.60E-12	3.60E-12
Zn-65	1.79E-12	1.79E-12
Tc-99	5.67E-08	5.67E-08
I-125	5.67E-06	3.78E-04
I-131	9.95E-07	6.63E-05
Th-230	2.63E-13	2.63E-13
U-238	1.64E-09	1.64E-09
Pu-239	1.44E-13	1.44E-13

a. Based on a HEPA filter collection efficiency of 99.97% and a partition factor of 0.001 for all nuclides, except H-3, C-14, and radioiodines. For H-3 and C-14, it is assumed that all activity is released without any retention or filtration. For all radioiodines, a partition factor of 0.015 and a charcoal filter efficiency of 90% are used.

b. Based on a HEPA filter collection efficiency of 99.97% and a decontamination factor of 10^3 for activity retained in the scrubber, venturi, and deposited elsewhere in the offgas treatment system. For H-3 and C-14, it is assumed that all activity is released without any retention or filtration. For all radioiodines, a charcoal filter efficiency of 90% is used.

Table 4. Low-level radioactive waste compaction and incineration doses.

	Doses and Risks to the Maximum Exposed Individual[a]			
Pathway	Compaction		Incineration	
	mrem/y	risk	mrem/y	risk
Ingestion	7.0E-02	1.8E-06	8.4E-04	2.1E-08
Inhalation	3.9E-03	1.0E-07	5.0E-05	1.3E-09
Air Immersion	8.4E-08	2.0E-12	8.7E-09	2.1E-13
Ground Surface	1.1E-04	2.6E-09	1.5E-04	3.7E-09
Total	7.4E-02	1.9E-06	1.0E-03	2.6E-08
Critical Organ	Bone			
	2.3E-01	3.9E-07	3.1E-03	5.2E-09
Limiting Nuclides	H-3/C-14	H-3/C-14		

a. Doses represent 50-year dose (EDE) commitments. Risks are for fatal cancers assuming lifetime exposure (71 years).

Table 5. Liquid mixed waste incineration and supercritical water oxidation doses.

Pathway	Doses and Risks to the Maximum Exposed Individual[a]			
	Incineration		Supercritical Water Oxidation	
	mrem/y	risk	mrem/y	risk
Ingestion	1.5E-04	8.2E-10	4.6E-04	9.4E-09
Inhalation	5.4E-07	5.1E-12	1.1E-05	2.7E-10
Air Immersion	6.9E-10	1.7E-14	8.9E-10	2.2E-14
Ground Surface	1.4E-06	2.8E-11	1.0E-06	2.1E-11
Total	1.5E-04	8.6E-10	4.7E-04	9.6E-09
Critical Organ	Thyroid		Thyroid/Bone	
	4.7E-03	7.1E-10	3.7E-03	2.1E-09
Limiting Nuclides	I-125/I-131	I-125/I-131/H-3/C-14		

a. Doses represent 50-year dose (EDE) commitments. Risks are for fatal cancers assuming lifetime exposure (71 years).

REFERENCES

ADA 1990 Correspondence, from Mr. W.D. Adams, ERWM, to Mr. S.P. Cowan, ERWM, Request for Data on Effluent Releases from DOE Incinerators and Associated Radioactive Waste Throughput, EW-92:Gilbert, October 5, 1990.

ASM 19 88 American Society of Mechanical Engineers, *Hazardous Waste Incineration, A Resource Document*, ASME Research Committee on Industrial and Municipal Wastes, January 1988.

DOE 1990 U.S. Department of Energy, *Integrated Data Base for 1990: Spent Fuel and Radioactive Waste Inventories, Projections, and Characteristics*, DOE/RW-0006, Rev. 6, October 1990.

DOE 1989a U.S. Department of Energy, *Environmental Restoration Waste Management Five-Year-Plan*, DOE/S-0070, December 1989.

DOE 1989b U.S. Department of Energy, *Air Quality Permit Application for the Proposed Low-Level Waste/Mixed Waste Incinerator, Technical Area 50, Building 37*, Los Alamos National Laboratory, Los Alamos, NM, February 1989.

DOE 1989c U.S. Department of Energy, *An Assessment of Thermal Destruction Technologies for Application to Department of Energy Mixed Wastes*, Vol. 1, "Technology Assessment, HAZWRAP," DOE/HWP-106, 1989.

DOE 1988 U.S. Department of Energy, *Low-level Radioactive Waste Volume Reduction And Stabilization Technologies Resource Manual*, DOE/LLW-76T, Idaho Falls, ID, December 1988.

DOE 1986 U.S. Department of Energy, *National Emission Standard For Hazardous Air Pollutants Compliance Verification Plan for the K-1435 Toxic Substances Control Act Incinerator*, ORGDP, K/HS-109, Oak Ridge, TN, July 28, 1986.

DOW 1987 Dworsak, G.R., Bechtel National, Inc., letter to W. Phillips, Performance of Anti-Springback Devices, Oak Ridge, TN, September 1987.

EG&G 1980 EG&G Idaho, Inc., *Interim Report: Low-Level Waste, Institutional Waste Incinerator Program*, Idaho National Engineering Laboratory, EGG-WM-5116, April 1980.

EG&G 1982 EG&G Idaho, Inc., *Radioactive Waste Incineration at Purdue University*, Idaho National Engineering Laboratory, DOE/LLW-12T, November 1982.

EG&G 1988 EG&G Idaho, Inc., *Low-Level and Mixed Waste Incinerator Survey Report*, Idaho National Engineering Laboratory, EGG-LLW-8269, October 1988.

EPA 1992 U.S. Environmental Protection Agency, *User's Guide for CAP88-PC, Ver. 1.0*, EPA 402/B-92-001, Office of Radiation Programs, Las Vegas, NE, March 1992.

EPA 1991 U.S. Environmental Protection Agency, *Radiation and Mixed Waste Incineration - Background Information Document*, Vol. 1: "Technology," EPA 520/1-91-010-1, Air and Radiation Research and Development Office, Research Triangle Park, NC, May 1991.

EPA 1989 U.S. Environmental Protection Agency, *NESHAPS for Radionuclides - Background Information Document*, Vol. 1, EPA/520/1-89-005, U.S. EPA, Office of Radiation Programs, Washington, DC, September 1989.

ERD 1976 Energy Research and Development Administration, *Nuclear Cleaning Handbook*, ERDA 76-21, Oak Ridge National Laboratory, October 1979 reprint.

HON 1991 Hong, T.G., *Supercritical Water Reactor For Space Applications*, Phase I Report, NASA contract, MODAR, Inc, Natick, MA, July 1991.

HON 1989 Hong, T.G., Patent, "Method for Solid Separation in a Wet Oxidation Type Process," U.S. Patent No. 4,822,497, April 18, 1989.

IAE 1989 International Atomic Energy Agency, *Treatment of Off-Gas from Radioactive Waste Incinerators*, Technical Reports Series No. 302, Vienna, 1989.

JOH 1988 Johnston, J.B., et al., "Destruction of Pharmaceutical and Biopharmaceutical Wastes by the MODAR Process," *Bio/Technology, Vol. 6*, pp. 1423-1427, December 1988.

KIL 1988 Killilea, W.R., et al., "Supercritical Water Oxidation: Microgravity Solids Separation," *18th Intersociety Conference on Environmental Systems, San Francisco, CA, July 11-13, 1988.*

MCF 1991 McFarland, R.D., et al., *Design Operational Parameters of Transportable Supercritical Water Oxidation Waste Destruction Unit*, LA-12216-MS, Los Alamos National Laboratory, December 1991.

MOD 1990 Modell, M., *Treatment of Pulp Mill Sludges by Supercritical Water Oxidation*, DOE/CE/40914-T1, U.S. Department of Energy, Office of Industrial Programs, Washington, DC, July 1990.

MOD 1988 Modar, Inc., *The Modar Oxidation Process - Process Flow Diagram, Representative Mass and Energy Balance, and System Economics*, Natick, MA, November 15, 1988.

MOD Modell Development Corporation, *Supercritical Water Oxidation - Technical Solutions for Today's Environment*, MODEC, Framingham, MA, paper not dated.

NRC 1986 U.S. Nuclear Regulatory Commission, *Safety Evaluation Report Related to the Volume Reduction Services Facility*, Babcock & Wilcox, Parks Township, PA, (Docket 70-364), Washington, DC, April 1986.

NRC 1983 U.S. Nuclear Regulatory Commission, *Incineration of a Typical LWR Combustible Waste and Analysis of the Resulting Ash*, NUREG/CR-3087, Battelle Pacific Northwest Laboratories, May 1983.

NRC 1979 U.S. Nuclear Regulatory Commission, *Calculation of Releases of Radioactive Materials in Gaseous and Liquid Effluents from Boiling Water Reactors (BWR-GALE Code)*, NUREG-0016, Rev. 1, Washington, DC, January 1979.

NRC 1976 U.S. Nuclear Regulatory Commission, *Calculation of Releases of Radioactive Materials in Gaseous and Liquid Effluents from Pressurized Water Reactors (PWR-GALE Code)*, NUREG-0017, Washington, DC, April 1976.

ROF 1989 Rofer, C.K., and Streit, G.E., *Oxidation of Hydrocarbons and Oxygenates in Supercritical Water - Phase II Final Report*, LA-11700-MS, Los Alamos National Laboratory, September 30, 1989.

ROS 1992 Ross, W.A., et al., "Locations, Volumes, and Characteristics of DOE's Mixed Low-Level Wastes," presented at *Waste Management'92, Tuscon, AZ, March 1992.*

SAN 1991 Bramlette, T.T., et al., *Destruction of DOE/DP Surrogate Wastes with Supercritical Water Oxidation Technology*, SAND90-8229, Sandia National Laboratories, March 1991.

SEC 1990 Stock Equipment Company, *55-Gallon Drum Dry Active Waste Hydraulic Compactor Volume Reduction Report*, Chagrin Falls, OH, 1990.

STA 1987 Staszak, C.N., et al., *The Pilot-Scale Demonstration Project of the MODAR Oxidation Process for the Destruction of Hazardous Organic Waste Materials, Environmental Progress*, Vol. 6, No.1, pp. 39-43, February 1987.

SWA 1990 Swallow, K.C., et al., "Behavior of Metal Compounds in the Supercritical Water Oxidation Process," *20th Intersociety Conference on Environmental Systems, Williamsburg, VA, July 9-12, 1990.*

SWA 1989 Swallow, K.C., et al., "The MODAR Process for the Destruction of Hazardous Organic Wastes - Field Test of a Pilot-Scale Unit," *Waste Management*, Vol. 9, pp. 19-26, 1989.

TES 1991 Tester, J.W., *Supercritical Water Oxidation Technology: A Review of Process Development and Fundamental Research*, MIT-EL 91-003, Massachusetts Institute of Technology, Energy Laboratory, draft, October 1, 1991.

WAC 1991 Communication from Lise Watcher, U.S. DOE-HAZWRAP to William Thurber, SC&A, Inc., December 13, 1991.

Risk Assessment and Development of California's Ward Valley Low-Level Radioactive Waste Disposal Facility

Stephen A. Romano
Vice President and Manager of California Operations

James A. Shaffner
Assistant Manager of Operations
US Ecology, Inc.
Rocklin, CA

ABSTRACT

Risk assessment occupies a central role in the license review process for new low-level radioactive waste disposal facilities, including California's proposed Ward Valley project. While regulatory guidance helps focus risk assessment studies, it is necessary for project-specific judgments to be made on the hypothetical radionuclide release scenarios warranting detailed evaluation. These judgments present a challenge to disposal facility developers and regulators, since risk assessment findings will be scrutinized in both regulatory and public dialogue. This paper addresses both areas of interest and the divergence of focus likely to occur.

The regulatory inquiry requires identification of reasonable but conservative release scenarios, and quantification of potential impacts using conservative assumptions. In California, potential groundwater impacts were evaluated at a desert site with low rainfall and extremely deep groundwater, assuming highly unlikely conditions. Even under these conditions, the hypothetical impact on groundwater is well within regulatory limits. Similar analyses were undertaken for other potential release scenarios.

The regulatory approach to risk assessment is ill-suited to resolving public controversy underway during license application review. Project critics can be expected to note that the applicant has admitted groundwater release is possible and have, in effect, predicted it. Calling attention to the hypothetical, conservative nature of the analysis will invite misunderstanding or derision. Project opponents are also likely to demand their own "risk assessment" of scenarios that defy scientific possibility.

No simple answers exist to resolve this dilemma. Improved approaches will require sensitivity to public perception and better efforts to distinguish the improbable from the impossible. Careful definition of "realistically conservative" scenarios and assumptions can provide the necessary regulatory assurance without promoting unproductive debate.

INTRODUCTION

Scientists and engineers conversant with technical requirements for a low-level radioactive waste disposal facility understand that risk assessment occupies a central role in the licensing process. Regulatory guidance exists to help focus these health and safety-related studies. This guidance is necessarily generic. It is therefore necessary to make project-specific judgments on hypothetical radionuclide release scenarios. These judgments represent a challenge to developers and regulators since the risk assessment findings will be scrutinized in both a technical/regulatory context and a public dialogue context.

A divergence of focus is likely to occur. This divergence is driven by the vastly different ways in which scientists and the public understand and evaluate risk.

RISK ASSESSMENT FROM A REGULATORY PERSPECTIVE

In developing the license application for the proposed Ward Valley disposal facility, US Ecology performed a detailed risk assessment for all credible (or bounding) scenarios under both normal and accident

conditions. These assessments were performed according to guidance in the Nuclear Regulatory Commission's NUREG-1199 and NUREG-1200 and employed industry-recognized computer codes to evaluate hypothetical exposures for each release scenario. The resultant "risk" represented the most likely outcome based on a chain of conservatively postulated circumstances. In all cases the calculated hypothetical exposure (measurement of risk) was well within regulatory limits. The results of these analyses are summarized in Table 1.

These assessments were carefully scrutinized during the review process by California regulators and their consultants. Licensing interrogatories were posed and answered before the regulators were satisfied with the validity of the analyses. The result is scientifically valid risk assessment based on conservative evaluation of release mechanisms, transport mechanisms, and uptake scenarios.

As one would expect for a facility with the favorable site characteristics of Ward Valley, the potential exposures from all pathways demonstrated full compliance with regulatory standards with safety factors of 2-3 orders of magnitude. These results are hardly surprising to most knowledgeable scientists and engineers.

FROM THE PUBLIC'S PERSPECTIVE

What is telling is the refusal of certain members of the public and their elected representatives to be in any way convinced by or to even consider the conclusions of these analyses. In fact, most members of the public consider the conclusions both irrelevant and incomprehensible. This suggests that serious introspection is required concerning the way scientists and engineers evaluate and communicate risk and how the public understands risk.

RISK-REWARD: A PRIMER

The extreme dichotomy that exists between the way scientists calculate risk and the way the public perceives risk invites careful evaluation of the fundamentals of the risk-reward equation from both a quantitative and qualitative viewpoint.

What is risk? According to Webster's Dictionary, risk is "the probability of a negative occurrence or outcome." Unfortunately, the concept of probability often gets lost.

The only motivation for taking a risk is the promise, or at least the prospect, of a reward. The gaming industry understands this principle very well. Who would risk putting a dollar in a slot machine if there was not some prospect of a big reward? No risk, no matter how small, is taken without some implicit or explicit reward calculation. Furthermore, the potential reward must be either quantitatively or qualitatively greater than the risk. Who would put a dollar in a slot machine if the maximum payoff was 75 cents?

When one looks at the concept of risk and reward from a "cost-benefit" standpoint, it seems straightforward. Risk a dollar for a dollar and 10 cents? Yes. Risk a dollar for 95 cents? No. When disagreement exists on the outcome, however, things get complicated. Build a waste site with a minuscule chance of health effects to benefit medicine, academic research, and economic growth? Yes! Build the same waste site and cause irreparable harm to man and the environment with little benefit to society? No!

What causes the dichotomy between the first view, which is widely held by scientists and engineers and supported by facts and rigorous quantitative assessment, and the second view, which is held by much of the public and is fueled by emotion or misinformed assumptions?

Two key assessment factors are often ignored by scientists but employed skillfully by opponents of projects such as these: risk perception and outrage. Throughout the 1980s, we in the so called "hard sciences" became aware of these concepts at seminars taught by our peers in social science. Awareness, however, did not necessarily translate into understanding or responsiveness.

Risk Perception and Outrage

Perception is the phenomenon that allows a rational individual to either magnify or diminish a risk (or reward) based on qualitative (sometimes irrational) factors. If I put 100 coins in a slot machine the most likely outcome is that only 92 coins will be returned - not a good deal. Since I derive pleasure from the possibility of a big return, I take the risk because I may beat the odds - "most won't win, but I will." An inveterate smoker may perceive their personal risk of smoking to be much less than the risk indicated by hard statistical data.

Perception also skews public attitudes about radioactive waste disposal. The public, barraged by the headline-grabbing pronouncements of project opponents and reinforced by a media that loves controversy, tends to perceive a horrific outcome resulting from radioactive waste disposal. Such an outcome is completely belied by the banal reality - throughout its 50-year existence, low-level radioactive waste disposal in the United States has harmed no one.

Outrage results when a group or individual believes that burdens with unacceptable risk are involuntarily imposed with little or no reward. Outrage manifests itself most dramatically in the not-in-my-back-yard (NIMBY) attitude prevalent in development of facilities that are globally perceived to benefit society but locally perceived to be a detriment - facilities such as waste disposal sites, incinerators, and prisons. Individual outrage is often magnified and reinforced in public meetings. While individual outrage can be defused, group outrage can become unmanageable.

As is often the case with waste disposal, perception and outrage can also work in tandem with a synergistic outcome. The combination of risk perception and outrage are likely to magnify the risk while simultaneously diminishing the reward. This, in turn, reinforces the perception and intensifies outrage.

The political process can also skew the balancing of benefits and risks. Outrage results when "false hopes" raised by politicians cannot be implemented. People may perceive that they have been promised by authorities that the project will be derailed, so they don't bother to play the risk - benefit game. When the promises fail they have a sense of betrayal. Benefits and risks are inconsequential to them at this point. Instead, they may have a perception of breach of honor or integrity, which, in turn, fuels outrage outside the risk - reward equation.

A NEW PERSPECTIVE ON RISK ASSESSMENT

What does all this have to do with risk assessment for low-level radioactive waste facilities? It suggests that we, as scientists, should be more comprehensive in our evaluation of risk - including not just quantitative but also qualitative factors. We should develop an appreciation for and sensitivity to the fact that the public (and by extension their elected leaders) have a vastly different view of risk-reward than scientists do. They tend to be skeptical of and ultimately reject the quantitative risk analyses required by the licensing process. They tend to gravitate toward the more understandable "risk assessments" of project opponents, which are expressed in absolutes rather than probabilities. Low-level radioactive waste disposal facilities have a built-in core of opposition that will exist regardless of factual information surrounding a specific proposed facility. This opposition will purvey misinformation to arouse public sentiment, skew perception, and breed outrage.

RISK MEASUREMENT, PROBABILITY AND CONSEQUENCE

Let's look at three concepts of risk assessment that are evaluated differently by scientists and the public - risk measurement, probability, and consequence.

Scientists performing risk evaluation work toward a bottom line - health effects, financial liability, or environmental impacts. The risk assessment for Ward Valley was driven by health and safety regulations. The public's measuring stick is more emotionally driven and therefore more difficult to responsibly quantify: cancer, death, financial burden, catastrophy.

As scientists performing risk assessments, we assign individual probabilities to each event in a chain that contributes to a specific outcome. In general, each event has a decreasing probability of occurrence than the one preceding it, each is dependent on the one preceding, and the outcome can only occur if all events preceding it occur. All probabilities are significantly less than unity. Therefore, the probability of the negative outcome is usually very small.

The public and their elected representatives often assume a probability of one for the occurrence of an event. In other words - if it can occur, it will.

An example of this phenomenon occurred at a hearing before a California State Assembly committee on the Ward Valley project in October 1991. Rather than being praised for a conducting comprehensive verification of risk assessment in the license review process, California's regulators were castigated for not guessing at the largest disaster and related financial liability that *could* accrue to California as a result of the Ward Valley project. "What's the worst case?" The message seemed to be "Give us Chernobyl and assign it a probability of one." Absent was the probabilistic aspect of risk assessment. They did not ask DHS to look at several serious but realistic accidents, assign reasonable probability, and determine a likely "worst realistic case" outcome (as had already been done). Observers to the spectacle were tempted to exclaim "A 747 carrying neutron bombs crashing into the site during an earthquake and meteor shower."

While inferring a probability of one for even the most unlikely occurrence at a low-level radioactive waste disposal facility, elected officials and members of the public may demand a probability of zero for any adverse occurrence. Of course, neither absolute is possible.

As stated, scientists evaluate outcome based on a chain of events with a decreasing likelihood of occurrence. For a properly sited and designed disposal facility, this results in a minuscule likelihood of an adverse outcome. When one takes into account the low probability of container failure, leachate excursions, migration through the vadose zone, migration through groundwater, uptake by the public, dose to a member of the public, and health effects as a result of dose, the calculated risk of the Ward Valley facility producing an adverse outcome is much closer to zero than unity.

However, critics who are allowed the luxury of foregoing scientific rigor in their "risk assessments" short-circuit this process. Project opponents can ignore the hypothetical nature of the calculated dose, ignore the highly unlikely assumptions used to derive the dose in the first place, and express alarm that "Even the proponents confess it may leak." They transform a cogent scientific conclusion, based on conservative assumptions and bounding conditions, that inconsequential releases could occur under certain extreme circumstances into "leaks will occur." Their message becomes that disaster is inevitable.

Negative perception and outrage can lead to adverse outcomes that have nothing to do with actual development of a low-level radioactive waste facility. In Boyd County, Nebraska, outrage resulting from cycles of raised and dashed hopes appears to have negated the risk-reward equation. The outrage, according to a sociocultural study conducted for the Boyd County Monitoring Committee, is causing detrimental community impacts long before the first shovel full of earth is moved. There have been threats and instances of violent behavior. According to the study, family ties and friendships have suffered. The study suggests that quality of life has deteriorated not as a result of the facility but as a result of the idea of the facility. The controversy is apparently exacerbated by long-standing animosity among several local communities. Some communities are considered proponents of the facility and will benefit from its development. Others are opposed and consider themselves unfairly and involuntarily burdened.

Interestingly, concerns associated with the proposed project seem, in some cases, to have evolved into fears that extend to aspects of daily life that have nothing to do with disposal facility: allegations of arrest and harassment, wiretapping, clandestine activities by unrelated organizations.

CONCERNS APLENTY, SOLUTIONS FEW

Concerns are evident, but what about answers? The marked lack of success in siting new facilities in the past decade speaks to the need for risk assessment that is more responsive to legitimate public concerns and more effective in defusing false claims. This is easy to say but monumentally difficult to achieve. In simple terms, we must narrow the gap between the scientists' quantification and the public's perception. On one hand, we must provide education that diminishes the negative impacts of perception and outrage. We must give the public the knowledge it needs to recognize unsubstantiated allegations as unscientific propaganda. Simultaneously we must respond to the public's perspective of risk in the licensing process. This may involve risk assessments that are "user friendly" and include a qualitative component.

We must also moderate our own perspective of reward based on the public's perspective. Reward must be based at least partially on perceived risk rather than simply on actual risk. This may translate into financial and other incentives to communities that would not realistically experience any physical harm from a proposed facility but which have a perception of some impact, fiscal or otherwise.

Consider Needles, California. Needles is 22 miles from the Ward Valley facility across a mountain range. By any conceivable measure, not one atom of buried radiation will ever find its way from the Ward Valley facility to Needles. However, the stigma and negative image of radioactive waste disposal promoted by the media suggest that community compensation is appropriate. Also, public fears and misperceptions, whether based on reality or fiction, can lead to real economic impacts.

While compensation based on perceived risk is appropriate, it is also appropriate to temper the need for such remuneration. By educating the media and the public regarding the societal benefits of medical and industrial uses of radioactive material and, by extension, the disposal of byproducts of such uses, we may gradually reduce the negative image of radioactive waste disposal. That image has so long been promoted by groups opposed to nuclear power that the task is daunting.

All this will not come easily or cheaply. A national commitment may be required to close the gaps that exist in risk-reward perceptions between scientists and the public. It would involve a commitment of money and time by public agencies and private institutions that have a vested interest in the beneficial uses of radioactive materials. Furthermore, the commitment must be real. Lip service will lead to the same outcome as the commitment by the United States to adopt the metric system. How many liters of gasoline have you bought lately?

Table 1. Hypothetical exposures for normal release (mrem/year).

Scenario	Projected dose	Regulatory limit
INTRUDER-GARDEN		
WHOLE BODY	.138	500[a]
THYROID	.137	
RED MARROW	.112	
INTRUDER-CONSTRUCTION		
WHOLE BODY	.0925	500[a]
THYROID	.0955	
LUNG	.0900	
POPULATION-FARM		
WHOLEBODY	.0000738	25
THYROID	.0000430	75
CRITICAL ORGAN	.000158	25
PASTURE		
WHOLE BODY	.0000000197	25
THYROID	.0000000106	75
CRITICAL ORGAN	.000000124	25
INTRUDER-WELL DRILLING		
WHOLE BODY	.840	500[a]
POPULATION WELL		
WHOLE BODY	.305	25
THYROID	.176	75
CRITICAL ORGAN	.648	25
NATURAL RESOURCE RECOVERY		
WHOLE BODY	.00000124	500[a]
LUNG	.0000315	
DECOMPOSITION GASES		
WHOLE BODY	.185	25
THYROID	.191	75
LI-WALL	.170	25
LUNGS	.180	25
BONE	.181	25
BASEMENT GASES		
WHOLE BODY	.135	500[a]
THYROID	.136	
LUNGS	.136	
BONE	.109	
LI-WALL	.143	
OFFSITE POPULATION		
WHOLE BODY	<002	500[a]

a. Inferred "regulatory limit" for modeling purposes. State and federal regulations provide for intruder protection but require a quantitative analysis of intruder scenarios.

Table 2. Hypothetical exposures for accidental releases (mrem/event).

SCENARIO	ONSITE WORKER	OFFSITE INDIVIDUAL
TRENCH FIRE		
(CLASS A TRENCH)		
WHOLE BODY	3.40	1.60
THYROID	.0140	.00660
LUNGS	67.0	32.0
BONE	29.0	14.0
TRENCH FIRE		
(CLASS BC30 TRENCH)		
WHOLE BODY	12.0	5.70
THYROID	.00130	.000640
LUNGS	78.0	37.0
BONE	270.	113.0
WASTE CONTAINER BREAKAGE		
WHOLE BODY	.024	.012
LUNGS	2.6	.013

In Pursuit of an Integrated Mixed Waste Risk Assessment Methodology

D. A. Waite
S. P. Pavlou
Ebasco Environmental

ABSTRACT

Since the time risk assessments came into common usage, chemical and radiological risk assessment methods have been developing in parallel paths chemical methods primarily under Superfund guidance and radiological under Department of Energy and nuclear utility programs. This paper reports on an activity to formulate an integrated mixed waste risk assessment methodology including (a) a comparison of the key elements of the two present methods, (b) a listing of the cosmetic differences in the two methods, and (c) a listing and resolution of the real differences in the two methods.

STATEMENT OF THE PROBLEM

In addition to the separate development paths that have resulted from the different end uses of the assessments, three other circumstances have contributed to the lack of progress in the unification of methods for assessing radiological and chemical risks. These circumstances are:

- Dual EPA and NRC regulatory authority over mixed waste
- Lack of effective communication between the radiological and chemical risk assessment communities
- Published statements from some quarters of the risk assessment community that it is improper and impossible to combine consideration of radiological and chemical risks in a meaningful way.[1]

Any change in the nature of mixed waste regulation in this country is probably not going to be significantly influenced by technical arguments that can be developed for the need of such changes. Similarly, applications to Superfund and nuclear sites will continue to overlap mostly in cases where mixed wastes are encountered, which are few when compared with the total number of contaminated sites.

To an extent, the remaining two contributors to lack of progress are related. It is commonly contended by radiologically oriented assessors that there have been so few chemical risk assessments done that they must be fraught with uncertainty to a degree that would negate any validity they might otherwise have. Likewise, chemical risk assessors often doubt the validity of radiological assessments on the basis of frequent media coverage of such analyses.

Both groups are partially correct and partially incorrect. If one investigates the number of sites that have been examined in the context of chemical risk assessments, one finds that this group far outnumbers the number that have received the same treatment from a radiological standpoint. Many chemists will also contend that, if attention is focused on the carcinogenic risks that are common between chemical and radiological exposures, the effects that contribute to chemical risks are no more uncertain than those that contribute to radiological risk. The truth probably is that both are uncertain, but not to significantly different degrees, no matter how the media might portray them.

The one contributor to lack of progress that the technical community can affect relates to the misimpression that it is both technically improper and conceptually impossible to add carcinogenic risk that arises from chemical exposures to those from radiological exposures. If there was ever any doubt about the error of these impressions, the results of ongoing research and work based on this research should dispel

them.[2,3,4,5] It is now common practice to create lists of priority contaminants at sites, with chemicals and radionuclides compared directly and addressed in a unified fashion. With these reasons for inaction put to rest, on to the solution of the more meaningful task of identifying, in detail, the differences in the present two methods. In this treatment of the topic, we chose to couch the identification process in the context of a simplified system of mathematical equations that are used to assess contaminants being transported in the environment by means of a few representative pathways.

STRATEGY FOR RISK ASSESSMENT

A flow diagram of the risk assessment strategy chosen to guide this work is shown in Exhibit 1. The strategy begins with the specification of a contaminant inventory in some environmental matrix, progresses through the determination of a contaminant concentration in the matrix, to the estimation of the extent of the receptor exposure to the contaminant, to the calculation of the resulting dose and commensurate risk. The strategy with this format and content was chosen because it was simple enough to be easily communicated, complete enough to enable the identification process to proceed with some rigor, versatile enough to be applicable to the environmental pathways of interest, and robust enough to permit all task objectives to be met.

COMPARISON OF ASSESSMENT EQUATIONS

Equations for implementing the adopted strategy for groundwater ingestion and resuspended particulate inhalation are shown in Exhibit 2 along with the definition of terms. Each stage of the strategy is shown separately, with the radiological and chemical equivalents shown side by side.

It is immediately apparent that differences exist in the implementation of the strategy for radiological and chemical contaminants. At the inventory and concentration stages, there are no mathematical expressions offered for chemicals. In these cases the difference in the two approaches is not out of necessity, but rather out of common practice. At chemically contaminated sites the normal source of data is the Remedial Investigation, through which the concentration of the contaminant in the environmental medium is measured. This preference, in the chemical case, of measurement over modeling is prevalent in the comparison of the two methods. Such "normal practice" differences, however are not important to the conclusions of this work because it is possible to start with contaminant inventories and calculate concentrations as easily for chemicals as for radionuclides. These differences in the convenience of methods or the common practice are therefore deemed to be unimportant.

The first true difference in the implementation of the strategy appears at the dose calculation stage. To facilitate the recognition of this difference, the ingestion dose equation has been rearranged in Exhibit 3. The first two terms of the expressions are identical and the product of EF x ED equals t. However, it is not immediately obvious whether the radiological dose factor (DF) equals 1/(BW x AT). One would expect, based on the units alone, that these two quantities are not equal, but the operable question is "are the differences reconcilable?" To determine this a closer examination of AT is required.

In its risk assessment guidance document,[6] EPA offers the following discussion of "averaging time" (AT).

> The averaging time selected depends on the type of toxic effect being assessed. When evaluating exposures to developmental toxicants, intakes are calculated by averaging over the exposure event (e.g., a day or a single exposure incident). For acute toxicants, intakes are calculated by averaging over the shortest exposure period that could produce an effect, usually an exposure event or a day. When evaluating longer-term exposure to noncarcinogenic toxicants, intakes are calculated by averaging intakes over the period of exposure (i.e., subchronic or chronic daily intakes). For carcinogens, intakes are calculated by prorating the total cumulative dose over a lifetime (i.e., chronic daily intakes, also called lifetime average daily intake). This distinction relates to the currently held scientific opinion that the mechanism of action for each category is different. The

approach for carcinogens is based on the assumption that a high dose received over a short period of time is equivalent to a corresponding low dose spread over a lifetime.

This discussion, to a great extent, parallels a radiological discussion of the theory and practice of "dose commitment." Review of Exhibit 4, which lists the values normally assigned to the variables in a chemical risk assessment, indicates that even the 70-year time period of concern is consistent with a lifetime risk radiological dose commitment and adjustments would be possible if other time periods of dose integration were desirable in specific instances. With these parallels in the two dose calculation formulations, it is concluded that DF can be the radiological equal of 1/(BW x AT) and under any foreseeable set of circumstances a single calculational methodology can be devised to treat the two types of contaminants identically.

Even when the calculations are both constrained to a cancer fatality endpoint, the risk equations shown for groundwater ingestion in Exhibit 2 show an apparent difference. The radiological risk equation uses a dose/response slope of 2.5 E-4 per rem, whereas the chemical formulation for carcinogens uses a chemical specific variable "potency factor" for its slope. If these two risk coefficients are BIOLOGICALLY EQUIVALENT and expressed in the same units, then the resulting risks from chemical and radiological exposures should be meaningfully additive since in both cases the risks are based on similarly derived biological data. In contrast, no additivity property results when quantities based on normally used "acceptable" risk are used. This is because the chemical default value for acceptable risk is often orders of magnitude different from that used for radiological risk estimates. Only when the same dose/response risk axis intercept is used in both to quantify acceptable risk cases are the results additive.

Inspection of the particulate inhalation equations in Exhibit 2 will reveal the relevance of an explanation the same as the one given above for the groundwater ingestion pathway. Since the skin exposure pathway is not often brought into play in radiological risk assessments as it is in chemical assessments, this pathway is not examined here.

OVERVIEW OF PREFERRED METHODOLOGY

Since the two differences that are identified in the previous discussions of the assessment equations are both resolvable by a simple variable quantification selection process, the preferred method is not significantly different from either of the methods shown in Exhibit 2. In the context of an AT consideration, the most extensive compilation of relevant dose information is in ICRP 60; therefore, the dose integration period (50 years) used in the derivation of those dose factors is adopted for use in AT in the preferred method.

Resolution of the reference risk was accomplished by adopting the most conservative estimate, which is that involved with the chemicals. Contrary to first appearances, no adjustments are usually required to make the risk calculation portion of the assessment strategies equivalent. This is because each chemical has been characterized experimentally in terms of its potency factor, as has ionizing radiation been characterized by a risk coefficient (potency factor) of 2.5 E-4 per rem.

SUMMARY

A detailed examination of the mathematical formulations used in chemical and radiological risk assessments for representative exposure pathways has shown that the differences in the two are not significant. With the exception of the dose integration time, all variables and input values are consistent across the methods. Applications of the preferred method, which adopts the integration period used in ICRP 60, have shown to yield results that are consistent with other work that is being conducted to develop unified contaminated site prioritization methods. The method had been shown to be especially appropriate where radiological and chemical contaminants make similar contributions to the total risk. Where one or the other predominates in the risk, results have been consistent with those derived from the presently exercised strategy.

EXHIBIT 1

Assessment Flow Diagram

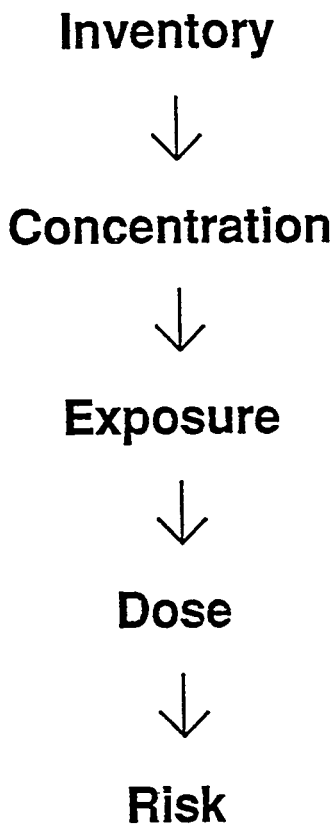


EXHIBIT 2

Assessment Equations

RADIOLOGICAL	CHEMICAL
PATHWAY 1: GROUNDWATER INGESTION	
(1) $C_s = \frac{inventory}{V}$ Where C_s = conc. in soil (Ci/m^3) inventory = known from manifests (Ci) V = volume of soil (m^3)	(1)' No equivalent.
(2) $C_{GW} = C_s \times MF_j \times 10^3 l/m^3$ Where C_{GW} = conc in groundwater (Ci/l) MF_j = modifying factor for radionuclide j. A function of solubility, availability, and contact time.	(2)' C_{GW} measured during RI.
(3) $Dose_j = C_{GW} \times WIR \times DF \times t$ Where $Dose_j$ = dose from radionuclide j (rem) WIR = water ingestion rate (l/day) DF = dose conversion factor (rem/Ci) t = annual exposure duration (days)	(3)' $Dose_j = \frac{C_{GW} \times WIR \times EF \times ED}{BW \times AT}$ Where $Dose_j$ = dose from chemical j (mg/kg-day) WIR = water ingestion rate (l/day) EF = exposure frequency (days/yr) ED = exposure duration (yr) BW = body weight (kg) AT = averaging time (days)
(4) $Risk_j = 2.5E\text{-}04 \times Dose_j$ Where $Risk_j$ = risk from radionuclide j	(4)' $Risk_j = \frac{Dose_j}{RfD_j}$ for noncarcinogens or $Risk_j = Dose_j \times PF_j$ for carcinogens. Where $Risk_j$ = risk from chemical j RfD_j = Reference dose (mg/kg-day) PF_j = Potency factor $(mg/kg\text{-}day)^{-1}$

EXHIBIT 2. (continued).

RADIOLOGICAL	CHEMICAL
Note: 1. DF is a function of ED and BW 2. t = EF 3. No radiological approach equivalent to AT. Radiological dose is annual, chemical dose is average daily.	
PATHWAY 2: SOIL PARTICULATE INHALATION	
(1) $C_{ss,j} = C_{s,j} \times D_{resp}$ Where $C_{ss,j}$ = conc of radionuclide in surface soil (Ci/m^2) $C_{s,j}$ = conc of radionuclide in soil (Ci/m^3) d_{resp} = depth of resuspension (typically 15 cm)	(1)' Chemical concentration in soil, $C_{s,j}$ determined from RI data. Typically arithmetic mean used.
(2) $C_{a,j} = C_{ss,j} \times RF$ Where $C_{a,j}$ = Conc of radionuclide j in air (Ci/m^3) RF = Resuspension factor. Function of particle size in soil. Default to 1E-04 for residential landuse.	(2)' $C_{a,j} = C_{s,j} \times PM_{10} \times 1E\text{-}06 \frac{kg}{mg}$ Where $C_{a,j}$ = Conc of chemical j in air (mg/m^3) PM_{10} = conc of particulate matter ≤ 10 µm. Function of type of disturbance and particle size distribution.
(3) $Dose_j = C_{a,j} \times IR \times t \times REF \times DF$ Where $Dose_j$ = dose from radionuclide j (rem) IR = inhalation rate (m^3/day) t = annual exposure time (days) REF = respirable fraction DF = dose conversion factor for inhalation of particles ≤ 1 µm (rem/Ci)	(3)' $Dose_j = \frac{C_{a,j} \times IR \times ET \times EF \times ED}{BW \times AT}$ Where $Dose_j$ = dose from chemical j (mg/kg-day) IR = inhalation rate (m^3/hr) ET = exposure time (hrs) EF = exposure frequency (days/yr) ED = exposure duration (yrs) BW = body weight (kg) AT = averaging time (days)

EXHIBIT 2. (continued).

RADIOLOGICAL	CHEMICAL
(4) $Risk_j = 2.5E\text{-}04 \times Dose_j$ Where $Risk_j$ = risk from radionuclide j	(4)' $Risk_j = \frac{Dose_j}{RfD_j}$ for noncarcinogens or $Risk_j = Dose_j \times PF_j$ for carcinogens. Where $Risk_j$ = risk from chemical j RfD_j = Reference dose (mg/kg-day) PF_j = Potency factor $(mg/kg\text{-}day)^{-1}$

Note:
1. $PM_{10} = RF * REF$
2. $IR_{rad} = IR_{chem} * ET$
3. $t \neq EF * ED$; $t = EF$
4. DF is a function of ED and BW.
5. There is no radiological equivalent to AT. Radiological dose is annual, chemical dose is average daily.

EXHIBIT 3

Dose Equations Comparison – Ingestion

Rad $D_j = C_{GW} \; WIR \; DF \; t$

Chem $D_j = C_{GW} \; WIR \; \frac{I}{BW*AT} \; EF*ED$

EXHIBIT 4

Parameter Values Typically Used in Chemical Risk Assessment

Parameter	Value
BW — Body Wt.	70 kg
Water Ingestion Rate	2 L/day (adults)
Inhalation Rate	30 m^3/day (adults)
Food Ingestion Rate	
— meat	0.28 kg/meal
— eggs	0.15 kg/meal
— fish	0.284 kg/meal
ED — Exposure Duration	70 yrs
EF — Exposure Frequency	depends on pathway - days/yr or meals/yr

AT = ED * 365 days/yr — noncarcinogens
= 70 yrs * 365 days/yr — carcinogens

REFERENCES

1. King, C.M., et al., *Performance Assessment Methods for Mixed Waste Sites at the Savannah River Plant*, Contract Number: DP-MS-87-80, Savannah River Lab., Aiken SC.

2. Jones, T.D., Griffen, G.D., Walsh, P.J., "A Unifying Concept for Carcinogenic Risk Assessment," *J. Thor. Biol. 105*, 35-61, 1983.

3. Jones, T.D., "A Unifying Concept for Carcinogenic Risk Assessments: Comparison with Radiation Induced Leukemia in Mice and Men," *Health Physics*, Vol. 47, No. 4, p. 533-558, October 1984.

4. Whelan, G., et al., "Development of the Remedial Action Priority System: An Improved Risk Assessment Tool for Prioritizing Hazardous and Radioactive-Mixed Waste Disposal Sites," *Sixth National Conference on Management of Uncontrolled Hazardous Waste Sites; 1985 November 4-6; Washington, D.C., Silver Spring, MD,* Hazardous Materials Control Research Institute, 1985, 432-437.

5. Whelan, G., Hartz, K.E., Hilliard, N.D., *Remedial Action Assessment System (RAAS): Evaluation of Selected Feasibility Studies of Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) Hazardous Waste Sites*, PNL-7229, Pacific Northwest Laboratories, Richland, Washington, April 1990.

6. U.S. Environmental Protection Agency, *Risk Assessment Guidance for Superfund*, Volume I, "Human Health Evaluation Manual" (Part A), EPA/540/1-89/002, December 1989.

Radioactive Waste Characterization[a]

Syed J. Amir
Westinghouse Hanford Company
P.O. Box 1970
Richland, WA 99532

INTRODUCTION

Westinghouse Hanford Company manages certain solid waste treatment, storage, and disposal facilities on the Hanford Site for the U.S. Department of Energy, Richland Field Office. These facilities include radioactive solid waste disposal sites, radioactive solid waste storage areas, and hazardous waste treatment, storage, or disposal facilities. The *Hanford Solid Waste Acceptance Criteria*, WHC-EP-0063, (WHC 1991) defines the criteria that must be met by waste generators for solid waste to be accepted by Westinghouse Hanford Company for treatment, storage, or disposal.

One of the acceptance criteria deals with the inventory of radionuclides in the waste. Solid radioactive waste generators are required to characterize waste streams with sufficient accuracy to properly document the types and quantities of radionuclides. This paper will deal with these requirements and its technical and regulatory basis. This paper will consider the published data on radionuclides, the detection methods for radioactive isotopes, and the cost of radioanalytical services to quantify specific radionuclides.

Low-level radioactive waste generators and site operators may find information in this paper to be helpful in characterizing waste for safe disposal according to environmental regulations.

REGULATORY REQUIREMENTS

This section will deal with state and federal regulations, U.S. Department of Energy orders, Hanford Site requirements, and other rules, regulations, guidelines, and standards as they apply to characterization.

The U.S. Department of Transportation, U.S. Environmental Protection Agency, U.S. Nuclear Regulatory Commission, DOE, individual states, and other regulatory bodies have established standards for radiation and environmental protection. The regulations established by DOT address the transportation issues. The DOE, EPA, NRC, and individual states have established regulations concerning public, worker, and environmental protection. Some of these regulations are specific and others are a set of performance objectives that all DOE sites must observe. These objectives are as follows: keeping the public's dose rate below a fixed level and as low as reasonably achievable (ALARA), preventing intrusion after a loss of institutional control, protecting workers, designing a site that ensures long-term stability of waste with a reduction of active maintenance, and protecting the environment.

As a prelude to meeting these regulations and performance objectives, all radioactive wastes need to be characterized so that their radiological properties are known. Some of these properties include the half-life of the isotopes, activity level, type of radiation (alpha, beta, gamma, neutrons), and the physical and chemical properties of the waste material.

Based on curie content or specific activity, DOT has established the following categories of radioactive waste: limited quantity, low specific activity, Type A, Type B, and highway route controlled quantities. All the commonly known isotopes are divided into these categories.

---

a. Prepared for the U.S. Department of Energy Office of Environmental Restoration and Waste Management under Contract DE-AC06-87RL10930.

Similarly DOE and NRC have certain categories of radioactive waste such as transuranic (TRU), low level, contact handled, remote handled, Category 1, Category 3, greater than Category 3, Class A, Class B, Class C, and greater than Class C. For each of these categories there are some regulations as to the treatment, handling, packaging, storage, and disposal.

The definitions of the various waste categories are given in government documents or in the waste acceptance criteria of waste disposal sites. The regulations concerning public exposure are defined in DOE Order 5400.5 (DOE 1990) and in the NRC's Title 10, Code of Federal Regulations, Part 20. Health standards for workers are given in DOE Order 5480.11 and the NRC's 10 CFR 20. The DOT regulations are covered under 49 CFR. Environmental regulations are listed under 40 CFR. The guidelines to operate DOE sites are given in DOE Order 5820.2A (DOE 1988).

Besides these documents, some requirements come from the performance assessment conducted for each radioactive waste disposal site. The Category 1 and 3 values for the Hanford Site (Tables 1-3) come from the preliminary performance assessment. A revision of these values is expected in 1993. Note that for the NRC sites, the classification notation is Class A, B, or C. The list of isotopes and concentration limits defined for the Hanford Site results from an analysis similar to that used by the NRC to define inventory limits (10 CFR 61). Some significant differences in modeling assumptions do exist. For example, the Hanford Site model calculates dose estimates on the basis of models ICRP-30 and ICRP-48 instead of ICRP-2, which is used by the NRC. Because of the different dose methodology and changes in scenario assumptions, the NRC Class A and C values are somewhat different from the DOE Category 1 and 3 values.

WASTE CHARACTERIZATION REQUIREMENTS

The radioactive waste generators that send their waste to the Hanford Site must comply with the *Hanford Solid Waste Acceptance Criteria* (WHC 1991). As a part of these criteria the waste generator must analyze the waste for its radioactive content. Based on this analysis, the waste is categorized in each of the following areas:

- DOT type (limited quantity, low specific activity, Type A, Type B, or highway route controlled quantity)
- DOE category (Category 1 and 3). In the case of non-DOE waste it will be Class A and C
- Contact handled or remote handled
- Contaminated or noncontaminated
- Transuranic or nontransuranic.

Table 1 lists the radioactivity levels corresponding to the DOT types ("values"), DOE ("Hanford") categories, and NRC class ("limits") for the isotopes commonly found on the Hanford Site. Table 2 lists the same except for the isotopes that are currently listed by the performance assessment to be Category 1 and 3. These two tables are important since the level of radioactivity limits will determine the DOT type and the DOE category of waste that a waste generator has to establish.

Besides determining the DOT type and DOE category, the waste generator has to establish whether the waste is contact handled, remote handled, contaminated or noncontaminated, and TRU or non-TRU. According to the *Hanford Solid Waste Acceptance Criteria* (WHC 1991) if the radiation level at the surface of the waste container is less than 200 mrem/h then the waste is contact handled, and if it is greater than 200 mrem/h then it is remote handled. The waste generator has to make sure that the surface contamination of the container does not exceed 220 dpm/100 cm^2 for alpha contamination and 2,200 dpm/100/cm^2 for beta-gamma contamination. Considering the source of the radioactivity, it is also necessary to determine if the waste

is TRU. TRU waste defined in terms of radioactivity is that waste that has a concentration of greater than 100 nCi/g of certain alpha-emitting TRU radionuclides.

SURVEY OF RADIATION ANALYSIS LABORATORIES

To determine the radioactivity of any waste sample a variety of instruments and methods can be used depending on the accuracy desired. The cost of analysis increases with the sophistication of the method used and the accuracy of measurement. If high accuracy of measurements is imposed for all types of waste then the cost can become prohibitive especially for the high-volume waste generators. In many cases high accuracy is not warranted. A guideline, therefore, has to be developed to recommend the measurement techniques and the level of accuracy for the various isotopes and category or type of waste. Such guidelines can only be general in nature, and in many instances each case has to be studied individually.

To develop the guidelines for the radioactive analysis of waste it was necessary to survey the various approved laboratories in the country that are servicing the waste generators. Through the services of the University of Utah (Slaughter and Sandquist 1993) a survey of various approved laboratories was conducted. Information was collected as to the minimum detectable activity (MDA) of the instrument (LLD), relative response, standard deviation, overall accuracy and cost per sample for various isotopes especially those listed as Category 1 and 3. Based on this information received, Table 3 was generated and gives the MDA, average cost, and other information. These numbers are only representative of the seven laboratories surveyed and should be used for reference. It lists the LLD and the average cost for the Category 1 and 3 isotopes. Table 4 is generated from the same survey and lists the sensitivities of various instruments in the detection of certain isotopes.

Methods for Radioactive Analysis

The following recommendations have been developed using the information generated through the survey.

Process Data

Great emphasis should be given to the process information. In most cases isotopic characteristics of the waste can be identified and the instrumental analysis can be focused. The process knowledge can be used to identify the isotopes that are not present and the level of activity. An example of this could be a facility that handles only ^{137}Cs. Thus process knowledge can be used to help characterize the waste (TRU or non-TRU, DOE category, etc.). Records of such process knowledge should be kept as substantive proof.

Material Balance

In certain instances the process data that have material balance can be used to establish isotopic content in the waste. An example of this could be a test conducted with a limited number of well-identified isotopes and the isotopic inventory is defined in the process.

Gross Radiation Measurement

Gross radiation measurement (GRM) could have a wide application and can be an effective tool used to characterize the waste containing gamma or certain high-energy beta. GRMs, which may entail dose-to-curie scaling, are well suited for routine analysis of limited quantity, low specific activity, and Category 1 types of waste streams. Use of GRMs in characterizing the waste will require that measurements are consistently correlated with the distribution of radionuclides within the particular waste stream analyzed and the radionuclide distributions are initially determined and periodically verified. GRMs can be used in determining the curie level of other drums from a waste stream when one of the representative drums has been analyzed by direct measurement techniques such as gamma spectroscopy. Field instruments may be used for taking GRMs.

Specific Radiation Measurement

Specific radiation measurement (SRM) entails laboratory analysis. It is used especially for the characterization of low- energy gamma and alpha-beta containing waste. SRM targets specific radionuclides using laboratory equipment and chemical separation. The method is more useful in determining TRU, Category 3, greater than Category 3, and very low-level threshold concentrations (2 nCi/g). Threshold concentration is the level of activity below which the material can be released as nonradioactive.

Guidance for Radiation Measurements

The following guidelines are provided to assist the waste generator in meeting the regulatory requirements concerning waste characterization. These guidelines are broad and may not apply to every specific situation.

- The first step in characterization is to use process knowledge to determine the class, category, and type of waste. If there are problem isotopes their estimated concentration should be identified. The problem isotopes are those that have long half-lives, low-energy beta and alpha, and are difficult to detect by GRM.

- The waste generator may take GRMs and determine the general radioactive nature of the waste. The generator should then confer with the disposal site to which the waste is to be sent.

- Radionuclide concentrations should be determined based on the volume or weight of the final waste form. The weight of the container should not be included. If weight is used, an estimate of waste density should be provided.

- Routine measurements (one or two per batch) should be taken for Category 3 waste, which has isotopes that can be analyzed by GRM. For Category 1 waste routine measurements can be taken if process variation could cause an upward change in the waste classification. In the case of problem isotopes (which require SRM) the analysis should be done periodically using GRM. If the process is altered by a factor of 10 or more, confirming analysis should be done again using SRM.

- The isotopic distribution of the trash and similar secondary waste can be based upon the distribution determined for the main stream. Smear samples could also be used for the analysis.

- For the activated metals the isotopic distribution can be determined by an activation analysis calculation.

- For the low specific activity, limited quantity, or Category 1 waste, the characterization data should include all nuclides that contribute greater than 10% of the total activity of the waste matrix. In the case of Category 3, greater than Category 3, Type A, Type B, and TRU waste the characterization data should include all nuclides that contribute greater than 1%. This is a problem if a mixture of short and long half-life nuclides is in the waste (1% does not remain 1%). In this case, it is better to estimate nuclides that are expected to have long half-lives separately, regardless of current percentages.

- Some cases may occur where no isotopes are detected but the waste material cannot be released for nonradioactive disposal. When this occurs, report the isotopes that would most likely be present based on the documented process knowledge. Use the detection limit of the survey equipment to determine the curie values to be reported.

The following rules should be used in determining the category of waste:

- If only one radionuclide is present in the waste, use the value in Table 3 to determine the appropriate category.
- If more than one radionuclide listed in Table 3 is present in the waste, then the sum of the fractions rule is used to determine the proper waste category.
- If the waste contains unlisted radionuclides with half-lives greater than five years, a solid waste engineering analysis must be made to determine the category of the waste.
- Cases may exist where a mixture of components may be below laboratory testing limits, but the sum of the fraction of the radionuclide may be greater than Category 1. Laboratory testing limits should be able to determine 1/20 of the Category 1 quantity to allow confident use of the sum of the fractions rule.

Table 1. Common isotopes on the Hanford Site.

		DOT Values			Hanford Categories		NRC Limits	
Radionuclide	Half-Life	LSA (mCi/g)	A1 (Ci)	A2 (Ci)	1 (Ci/m3)	3 (Ci/m3)	A (Ci/m3)	C (Ci/m3)
Ag(m)-110	249.8 days	.3	7	7	unlimited	not established	< or = 700	not established
Am-241	432.7 yr.	.0001	8	.008	10 nCi/gm	100 nCi/gm	< or = 10 (nCi/gm)	10 (nCi/gm)< and <100 (nCi/gm)
Ba(m)-137	2.552 m.	.3	30	30	unlimited	not established	< or = 700	not established
C-14	5730 yr.	.3	1000	60	.0006	8	< .80	.8< and < 8
Cd-109	462 days	.3	1000	70	unlimited	not established	< or = 700	not established
Ce-141	32.5 days	.3	300	25	unlimited	not established	< or = 700	not established
Ce-144	284.6 days	.3	10	7	unlimited	not established	< or = 700	not established
Cm-242	162.8 days	.005	200	.2	2E+03(nCi/gm)	2E+04(nCi/gm)	< 2000 nCi/gm	<20000 nCi/gm & >2000 nCi/gm
Co(m)-58	9.15 hr.	.3	1000	1000	unlimited	not established	< or = 700	not established
Co(m)-60	10.47 m.	.3	7	7	300	none	< or = 700	not established
Co-58	70.88 days	.3	20	20	unlimited	not established	< or = 700	not established
Co-60	5.27 yr.	.3	7	7	300	none	< or = 700	not established
Cr-51	27.7 days	.3	600	600	unlimited	not established	< or = 700	not established
Cs(m)-134	2.91 hr.	.3	1000	10	unlimited	not established	< or = 700	not established
Cs-134	2.065 yr.	.3	10	10	unlimited	not established	< or = 700	not established
Cs-137	30.17 yr.	.3	30	10	.02	4.6E+03	< or = 1	< 4600 or > 44
Eu-152	13.48 yr.	.3	20	10	N/A	N/A	N/A	N/A
Eu-154	46.1 m.	.3	10	5	unlimited	not established	< or = 700	not established
Eu-154	8.59 yr.	.3	10	5	N/A	N/A	N/A	N/A
Eu-155	4.71 yr.	.3	400	60	unlimited	not established	< or = 700	not established
Fe-55	2.73 yr.	.3	1000	1000	unlimited	not established	< or = 700	not established
Fe-59	44.51 days	.3	10	10	unlimited	not established	< or = 700	not established
H-3	12.3 yr.	.3	1000	1000	5E+00	none	< or = 40	not established
I-125	60.1 days	.3	1000	70	unlimited	not established	< or = 700	not established
I-129	15700000 yr.	.3	1000	2	1E-03	8E-02	< .008	< .08 and > .008
I-131	8.04 days	.3	40	10	unlimited	not established	< or = 700	not established
Mn-54	312.2 days	.3	20	20	unlimited	not established	< or = 700	not established
Na-22	2.605 yr.	.3	8	8	unlimited	not established	< or = 700	not established
Nb(m)-94	6.26 m.	.3	77	77	.0008	.2	< .02	< .2 and > .02
Nb(m)-95	3.61 days	.3	20	20	unlimited	not established	< or = 700	not established
Nb-94	20400 yr.	.3	100	100	.0008	.2	< .02	< .2 and > .02
Nb-95	34.97 days	.3	20	20	unlimited	not established	< or = 700	not established
Ni-59	76000 yr.	.3	1000	900	3.0E+00	2.2E+02	< 22	< 220 and > 22
Ni-63	100 yr.	.3	1000	100	2E+00	7E+02	< or = 3.5	< 700 and > 70
Pb-212	10.64 hr.	.3	6	5	unlimited	not established	< or = 700	not established
Pm-147	2.623 yr.	.3	1000	25	unlimited	not established	< or = 700	not established
Po-210	138.38 days	.005	200	.2	unlimited	not established	< or = 700	not established
Pr(m)-144	7.2 m.	.3	1000	1000	unlimited	not established	< or = 700	not established
Pr-144	17.28 m.	.3	100	100	unlimited	not established	< or = 700	not established
Pu-241	14.4 yr.	.005	1000	.1	5E+01 (nCi/gm)	3.5E+03(nCi/gm)	< 350 nCi/gm	<3500 nCi/gm & >350 nCi/gm
Ru-103	39.27 days	.3	30	25	unlimited	not established	< or = 700	not established
Ru-106	1.02 yr.	.3	10	7	unlimited	not established	< or = 700	not established
Sb-125	2.758 yr.	.3	40	25	unlimited	not established	< or = 700	not established
Se-75	119.78 days	.3	40	40	unlimited	not established	< or = 700	not established
Se-79	65000 yr.	.3	1000	1000	.007	.07	N/A	N/A
Sm-151	90 yr.	.3	1000	90	N/A	N/A	N/A	N/A
Sr-85	64.84 days	.3	30	30	unlimited	not established	< or = 700	not established
Sr-90	29.1 yr.	.005	10	.4	5E-03	7E+03	< or = .04	<7000 or >150
Ta-182	114.4 days	.3	20	20	unlimited	not established	< or = 700	not established
Tc(m)-99	6.01 hr.	.3	100	100	7E-03	3E+00	< .3	< 3 and > .3
Tc-99	213000 yr.	.3	1000	25	7E-03	3E+00	< .3	< 3 and > .3
Te(m)-127	109 days	.3	300	20	unlimited	not established	< or = 700	not established
Te-127	9.4 hr.	.3	300	20	unlimited	not established	< or = 700	not established
Te-129	1.16 hr.	.3	100	20	unlimited	not established	< or = 700	not established
Te(m)-129	33.6 days	.3	30	10	unlimited	not established	< or = 700	not established
Th-232	14100000000 yr.	.3	unlimited	unlimited	N/A	N/A	N/A	N/A
U-235	704000000 yr.	.005	100	.2	N/A	N/A	N/A	N/A
U-238	4470000000 yr.	.3	unlimited	unlimited	N/A	N/A	N/A	N/A
Y(m)-90	3.19 hr.	.3	10	10	unlimited	not established	< or = 700	not established
Y-90	2.67 days	.3	10	10	unlimited	not established	< or = 700	not established
Zn-65	243.8 days	.3	30	30	unlimited	not established	< or = 700	not established
Zr-95	64.02 days	.3	20	20	unlimited	not established	< or = 700	not established

Table 2. Category 1 and 3 isotopes.

		DOT Values			Hanford Categories			NRC Limits
Radionuclide	Half-Life	LSA (mCi/g)	A1 (Ci)	A2 (Ci)	1 (Ci/m3)	3 (Ci/m3)	A (Ci/m3)	C (Ci/m3)
Am-241	432.7 yr.	.0001	8	.008	10 nCi/gm	100 nCi/gm	< or = 10 (nCi/gm)	10 (nCi/gm)< and <100 (nCi/gm)
C-14	5730 yr.	.3	1000	60	.0006	8	< .80	.8< and < 8
Cm-242	162.8 days	.005	200	.2	2E+03(nCi/gm)	2E+04(nCi/gm)	< 2000 nCi/gm	<20000 nCi/gm & >2000 nCi/gm
Co(m)-60	10.47 m.	.3	7	7	300	none	< or = 700	not established
Co-60	5.27 yr.	.3	7	7	300	none	< or = 700	not established
Cs-137	30.17 yr.	.3	30	10	.02	4.6E+03	< or = 1	< 4600 or > 44
H-3	12.3 yr.	.3	1000	1000	5E+00	none	< or = 40	not established
I-129	15700000 yr.	.3	1000	2	1E-03	8E-02	< .008	< .08 and > .008
Nb(m)-94	6.26 m.	.3	77	77	.0008	.2	< .02	< .2 and > .02
Nb-94	20400 yr.	.3	100	100	.0008	.2	< .02	< .2 and > .02
Ni-59	76000 yr.	.3	1000	900	3.0E+00	2.2E+02	< 22	< 220 and > 22
Ni-63	100 yr.	.3	1000	100	2E+00	7E+02	< or = 3.5	< 700 and > 70
Pu-241	14.4 yr.	.005	1000	.1	5E+01 (nCi/gm)	3.5E+03(nCi/gm)	< 350 nCi/gm	<3500 nCi/gm & >350 nCi/gm
Se-79	65000 yr.	.3	1000	1000	.007	.07	N/A	N/A
Sr-90	29.1 yr.	.005	10	.4	5E-03	7E+03	< or = .04	<7000 or >150
Tc(m)-99	6.01 hr.	.3	100	100	7E-03	3E+00	< .3	< 3 and > .3
Tc-99	213000 yr.	.3	1000	25	7E-03	3E+00	< .3	< 3 and > .3

Table 3. Instrument performance and cost of category 1 and 3 isotopes.

Radionuclide	Half-Life	Min. Detectable Act.	Hanford Cat.1 (Ci/m3)	Avg. Sample Cost	Avg. Cost 10 Samples
Am-241	432.7 yr.	3.0e-8	10 nCi/gm	$199.00	$1,966.00
C-14	5730 yr.	3.0e-6	.0006	$180.00	$1,757.00
Cm-242	162.8 days	8.0e-8	2E+03(nCi/gm)	$208.00	$2,028.00
Co-60	5.27 yr.	1.0e-8	300	$149.00	$1,466.00
Cs-137	30.17 yr.	2.0e-7	.02	$147.00	$1,446.00
H-3	12.3 yr.	4.0e-4	5E+00	$114.00	$1,120.00
I-129	15700000 yr.	4.0e-6	1E-03	$181.00	$1,780.00
Nb-94	20400 yr.	1.0e-8	.0008	$168.00	$1,648.00
Ni-59	76000 yr.	7.0e-6	3.0E+00	$207.00	$2,016.00
Ni-63	100 yr.	3.0e-6	2.0E+00	$207.00	$2,016.00
Pu-241	14.4 yr.	5.0e-6	5E+01(nCi/gm)	$250.00	$2,500.00
Se-79	65000 yr.	5.0e-6	.007	$300.00	$2,750.00
Sr-90	29.1 yr.	5.0e-7	5.00E-03	$133.00	$1,310.00
Tc-99	213000 yr.	7.0e-6	7.0E-03	$183.00	$1,780.00

Table 4. Sensitivities of various instruments.

Table 4a. Proportional Counter.

Isotopes	Type of Radiation	Average MDA (mCi/g)
^{90}Sr	Beta	1E-6
Gross counting	Beta	1E-5
Gross counting	Alpha	1E-5

Table 4b. Alpha Spectroscopy.

Isotope	Average MDA (mCi/g)
^{238}Pu	1E-6
^{139}Pu	1E-8
^{241}Am	1E-8
^{242}Cm	1E-8
^{244}Cm	1E-8

Table 4c. Liquid Scintillation Counter.

Isotope	Average MDA (mCi/g)
^{3}H	5E-4
^{14}C	5E-6
^{63}Ni	5E-6
^{79}Sc	5E-6
^{99}Tc	5E-5
^{99}Pu	1E-5

Table 4d. Semiconductor.

Isotopes	MDA (mCi/g)
^{60}Co	2E-8
^{94}Nb	2E-8
^{137}Cs	2E-8
^{241}Am	2E-8
^{129}I	2E-8
Gross gamma	1E-5

MDA = Minimum detectable activity

REFERENCES

DOE, 1988, *Radioactive Waste Management*, U.S. Department of Energy Order 5820.2A, U.S. Department of Energy, Washington, D.C.

DOE, 1990, *Radiation Protection of the Public and the Environment*, DOE Order 5400.5, U.S. Department of Energy, Washington, D.C.

DOE, 1991, *Radiation Protection for Occupational Workers*, DOE Order 5480.11, U.S. Department of Energy, Washington, D.C.

NRC, 1991, *Technical Position on Waste Form*, Revision 1, U.S. Nuclear Regulatory Commission, Washington, D.C.

WHC, 1991, *Hanford Solid Waste Acceptance Criteria*, WHC-EP-0063-3, Westinghouse Hanford Company, Richland, Washington.

Slaughter, D.M., and G.M. Sandquist, 1993, *Westinghouse Hanford Site Low-level Waste Characterization Guidance Document*, Nuclear Engineering Laboratory, University of Utah, Salt Lake City, Utah.

10 CFR 20, 1992, "Standards for Protection Against Radiation," *Code of Federal Regulations*, as amended.

10 CFR 61, "Licensing Requirements for Land Disposal of Radioactive Waste," 1991 Edition, Title 10, *Code of Federal Regulations*, Part 61, U.S. Environmental Protection Agency, Washington, D.C.

Intrusive and Nonintrusive Site Characterization Using Geophysics (Lecture Notes)

David L. Campbell
Joh Mikesell
Gary Olhoeft
Bruce Smith
Chief Branch of Geophysics
U.S. Department of the Interior
Geological Survey
Denver, CO 80225

I. GEOPHYSICS OVERVIEW

- Geophysics Pros:

  - Can monitor directly in situ
  - Measures active processes
  - "Sees" in 3-D
  - Measures at many scales
  - Measures remotely

II. APPLYING GEOPHYSICS TO WASTE SITE PROBLEMS

  - Monitoring radiation
  - Modeling groundwater movement
  - Locating lost (buried) sources

- Radiation:

  - Geophysics addresses gamma radiation only.
  - For alpha, beta radiation, must use geochemical sampling. Because alpha and beta radiation is absorbed by only mm of water, rock, or air, the sampling is necessarily intrusive.
  - Big need: cheap, in-situ radiation sampling methods. Especially, water sampling tools with sensitive detection thresholds, to allow (i) early detection along perimeter of a facility, and (ii) working back upstream to trace sources and paths.

- Groundwater:

  - Most effective tool: electrical Gph DC, EM, IP, GPR.

- Sources:

  - If associated with ferrous metal (drums, tanks), try magnetics first (cheapest, quickest). But if an electrical survey will be done anyway, it can also find metallic sources.
  - Mobility of source elements: do they dissolve in water, complex by clays (zeolites), etc.?

III. GEOPHYSICAL GAMMA RAY DETECTION

- Gamma ray penetration

  - Gamma rays can penetrate 1000' air. Try airborne survey? Such surveys typically cost $20/line-mi for each data set, and you may want to add EM to rad (i.e., $40/line-mi).

- Airborne flight specifications
  - For recon of big sites, air surveying is much cheaper than ground work.
  - Rule of thumb: fly at elevations 1/2 to 1/3 the line spacing. So to sample along lines 200m apart, fly about 100m AGL. Safety issue: can it be done?
  - Flat topography means fixed wing okay; rough topo means pay more and use a helicopter.
- Gamma ray spectra
  - Main peaks in natural gamma spectrum are for K, U, Th.
  - Other peaks (e.g., Cs-137 @ 662 Kev) may be usable.
  - Transport of Ra-222 gas can cause map artifacts.
- Total count instruments or spectrometers?
  - TC instruments do not let you distinguish chemical species. So, use spectrometers, if at all possible.
- Borehole gamma ray detection a possible complication
  - In a unit with soluble radioactive sources, an aquifer may show high natural gamma counts. Even in LL Waste Sites, such radiation can be (though usually it is not) 1000x background. This means two problems:
    - borehole probe and cable may itself become contaminated and have to be disposed of. Need radiation detectors at the draw-works to monitor for this and for health hazards to the loggers.
    - most detectors have a dynamic range of only a few orders of magnitude. So this case would peg the instrument, and you still would not know how bad the radiation is in the hole!
  - proposed design for a four-sensor instrument to cover the ranges of possible radiation. Not commercially available, so far as we know.

IV. GEOPHYSICAL WELL LOGGING

- tells lithology and groundwater.
- best for groundwater: electrical and neutron-neutron logs.
- typical constraints of waste site boreholes:
  - established for continuous monitoring.
  - are immediately cased and grouted to keep from short circuiting the hydrology.
- Casing requirements
  - Galvanic electrical logs need uncased boreholes.
  - Induction electrical logs can work through PVC casing, not steel.
  - Rad logs okay (may need special processing, though).
- Neutron-neutron logging
  - Sensitive mainly to hydrogen (moisture). Moisture gradients do drive ions, including radioactive chemicals, through the ground.
  - Also will show chlorine (PCE, TCE. . .).

- n-n lows mean water, natural gamma highs show lithology. Example: a perched water table.

V. ELECTRICAL GEOPHYSICS

- Acronyms

  - GPR "Ground Penetrating Radar." Sees dielectric constants. Penetrates maybe 30m max. Bad in clay.
  - HFS "High Frequency Sounder." Sees combination of dielectric constants and conductivity. About 20m max. USGS-BGP only.
  - VLF "Very Low Frequency." Sees conductivity. Average about 30m. Source: Navy navigation stations. Air or ground. USGS-BGP specialty.
  - LIN "Low Induction Number." Sees conductivity. Maybe 15m. Common commercial gear, several variations.
  - TEM "Time-domain Electromagnetic." Sees conductivity. Sees 10m-200m. Common commercial gear.
  - EM "Electromagnetic." Umbrella designation for all the induction techniques listed above.
  - IP "Induced Polarization." Galvanic technique. Sees chargeability. Wide depth range. Good for clays, organic contaminants.
  - DC "Direct Current." Galvanic technique. Wide depth ranges. Sees resistivity (1/conductivity).

- Present capabilities of electrical geophysics.

  - best at inorganic contaminants, artifacts.
  - so-so at dealing with cultural interference (power lines, heavy vehicles, pipelines).
  - more work needed on organic contaminants, heterogeneity.

- Example: Brookhaven brine pits (Ref: Smith, Sengpiel, Plesha and Horton, 1992, Society of Exploration Geophysicists Annual Meeting Abstracts, p. 340-3)

  - Airborne EM survey at 0.9, 7.2 and 56 kHz. Contractor's product shows conductivity at a given frequency, an amalgam of ground conductivities at many depths. "Sengpiel processing" gives resistivity map at 10m and at 30m depth . The 10m map shows brine running into nearby streams. The 30m map (below water table) shows a leaking well and highs that may only reflect geology.

- Example: Useful GPR processing (Gary Olhoeft's method)

  - remove ringing due to multiples
  - calibrate the antennas
  - derive actual dielectric values in the ground
  - adjust for topography

- DNAPL: Dense Non-Aqueous Phase Liquid

  - Examples: Mercury, chlorinated solvents
  - Problem: Organic fluids (like chlorinated solvents, common in LL Waste Sites) are known to mobilize ions that otherwise would be captured by clay, zeolite units. Can some of these ions be radiation sources?

- Possible problem with DNAPL spills

- DNAPL can drop right through the water table and run down the deeper impervious layer to concentrate in an unexpected place. Sampling of the groundwater (typical practice) will miss this hazard altogether!
- Unwise to drill: you might punch through the impervious layer and let the DNAPL contaminate still deeper units!
- To test for this, use Induced Polarization. We know IP sees clays and also changes to the clays wrought by organic contaminants (studies by Olhoeft and Ridley of BGP). Far more work needed, though!

• Geophysics Advisor Expert System

- Gary Olhoeft's DOS computer program "Geophysics Adviser Expert System v. 2.0" (USGS Open-file Report 92-526; disk costs $6.00 from USGS-Map Sales/Bldg 810 Federal Center/Denver CO 80225, Phone 303-236-7476) asks appropriate questions about a spill and then recommends the best geophysical method to trace its migration. Covers 108 specific spillants and several generic spillants and many geological conditions.

VI. SUMMARY POINTS:

1. Except for gamma work, available geophysics addresses questions of groundwater/lithology (plus/minus buried junk), not radiation.

2. Airborne for large sites; ground gph for detail follow-up.

3. Use magnetics for ferrous junk; shallow EM for groundwater, GPR for sandy soils, IP for clays and DNAPLs.

4. Beware of differences between state-of-the-practice and state-of-the-art. Good state-of-art processing can often salvage ambiguous state-of-practice survey data.

The Innovative Application of Surface Geophysical Techniques for Remedial Investigations

Wayne R. Saunders, OYO Geospace, Fort Myers, FL
Spence Smith, ICF Kaiser Engineers, Boston, MA
Park Gilmore, Fishbeck, Thompson, Carr & Huber, Aida, MI
Stephen Cox, Blasland, Bouck, & Lee, Edison, NJ

ABSTRACT

When researchers are investigating potential subsurface contamination at hazardous waste landfills, the surface geophysical techniques they may use are often limited. Many geophysical surveys are concerned with areas next to and not directly within the landfill units. The highly variable properties of the materials within the landfill may result in geophysical data that are either difficult or impossible to interpret. Therefore, contamination at these sites may not be detected until substantial lateral migration away from the unit has occurred. In addition, because of the poor resolution of some techniques, the landfill as a whole must be considered as a source, where discrete disposal areas within landfill units may be the actual "point" sources of contaminants. In theory, if specific sources within the landfill are identified and isolated, then reduced time, effort, and expenditures will be required for remediation activities.

In the summer of 1989, the Idaho National Engineering Laboratory (INEL) investigated a small potentially hazardous waste landfill to determine if contaminant "hot spots" could be identified within the landfill and to determine if significant vertical and lateral migration of contaminants was occurring away from these locations. Based on the present hydrogeologic conditions, researchers anticipated that subsurface flow would be primarily vertical, with the zone of saturation at a depth greater than 150 meters. This necessitated that the survey be performed, for the most part, directly on the capped portion of the landfill. Focused geophysical surveys conducted off the landfill would not have provided useful information concerning conditions directly beneath the landfill. This paper discusses the planning, application, and analysis of four combined sensing methods: two methods of electromagnetic induction [low induction (Em) and time domain (TEM)], ground penetrating radar (GPR), and soil gas.

INTRODUCTION

In July 1989 the Idaho National Engineering Laboratory, located near Idaho Falls, Idaho, had solicited a contractor to "demonstrate innovative, nonextractable or nonintrusive monitoring technologies to locate areas of probable high hazardous waste contamination that may eventually escape the landfill." A demonstration, using a combination of geophysical and soils gas survey techniques, was proposed to meet this objective; the authors believe that the most effective nonintrusive approach for landfill investigations is to "screen" landfilled areas using these techniques before intrusive procedures (drilling, excavation, etc.) are used. The authors proposed to combine non intrusive technologies used successfully in the past for landfill investigations with other technologies that have not been commonly applied (in combination) in landfill investigations.

Most geophysical techniques applied in hazardous waste landfill investigations are limited in effectiveness, since the geophysical technologies being implemented to characterize the subsurface are commonly not performed directly on the landfill, but immediately next to the landfill. This is caused by the belief that many geophysical techniques do not work effectively directly over the landfilled areas due to interferences from the wide variety of buried materials, structural inhomogeneities, and poor resolution of the instrument readings.

SURVEY OBJECTIVES

There were two primary objectives for the innovative technology demonstration: to demonstrate the effectiveness of combining innovative, nonintensive technologies to locate anomalous "hot spots" believed to represent areas of contamination within a landfill, and identify the potential pathways for leachate migration away from the landfill. These two primary objectives were to be accomplished by combining geophysical techniques to (a) confirm the subsurface lithology and depth of consolidated bedrock, (b) characterize the waste materials within the landfill, (c) characterize the vertical and horizontal extent of the landfill body and locate buried drums and other containers used historically for the disposal of waste materials, and (d) delineate and map areas of potential migration of contaminants away from the landfill.

Geophysical survey methods initially proposed to meet the objectives included an electromagnetic induction (terrain conductivity) survey to locate buried metal; a complex resistivity survey (if quantities of buried metal within the landfill were limited, and the geoelectric properties of the surface soils supported the use of this technique) to help define subsurface lithology and contaminant migration; a time-domain electromagnetic survey to detect anomalous areas believed to represent subsurface contamination and help define subsurface lithology; a ground penetrating radar (GPR) survey to define subsurface lithology and characterize the anomalous "hot spots" identified with terrain conductivity; and a soil gas survey to identify volatile organic compound contamination in the unsaturated zone.

The area chosen for the demonstration was a 12-acre (estimated) landfill situated in a former sand and gravel pit operation. Geohydrologic conditions at the site were such that potential contaminant migration was expected to be nearly vertical beneath the site, since the groundwater table exists at a depth of approximately 450 feet below land surface. A conceptual model for data acquisition using the proposed geophysical and soils gas techniques, and how these techniques would accomplish the aforementioned project objectives, is presented as Figure 1. Solid arrows represent techniques that provide primary information supporting a particular objective, while dashed arrows represent those techniques that supply secondary information for a particular project objective. Both complex resistivity and time-domain electromagnetic induction (TEM) were used to provide information for the delineation of contaminant movement. It was the investigators' belief (later confirmed by initial geophysical measurements) that a considerable amount of buried metal and highly resistive surface soils would make collection of useable complex resistivity measurements difficult. This negated the use of the complex resistivity option. However, if at least two techniques could obtain each objective, the elimination of complex resistivity would not preclude obtaining information on contaminant migration.

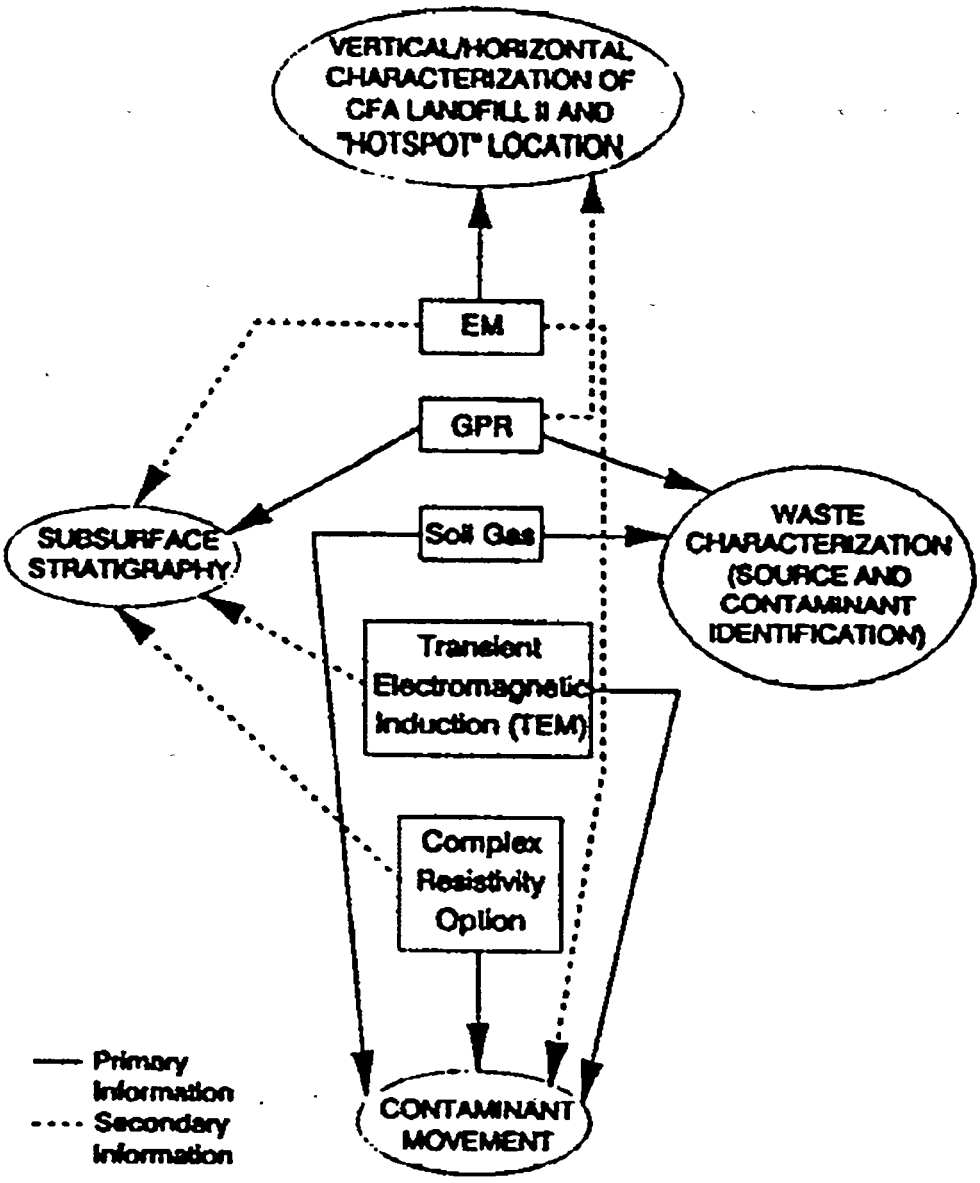


Figure 1.

SITE DESCRIPTION, WASTE DISPOSAL HISTORY, AND WASTE CHARACTERISTICS

The entire INEL facility encompasses about 890 square miles of the eastern portion of the Snake River Plain in southern Idaho, south of the Lemhi and Lost River Ranges. The area is a physiographic depression that extends from the Idaho-Oregon border in the west to the Yellowstone Plateau to the east. This area has an average altitude of 4,900 feet above sea level. The closest major community is Idaho Falls, Idaho, approximately 45 miles east of the facility. The landfill is located within the Central Facilities Area on the southwestern portion of INEL (Figure 2). Terrain around the landfill is gently rolling high desert plain. No surface water bodies are located near the landfill.

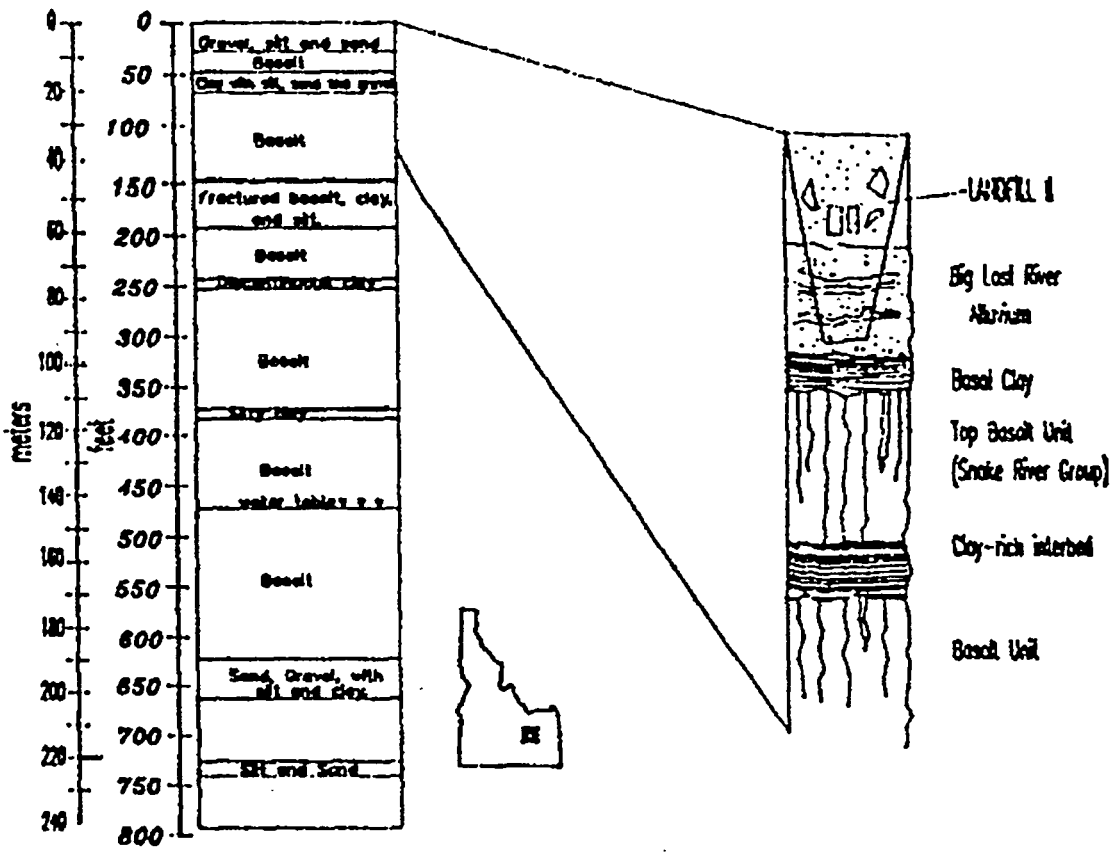


Figure 2.

Figure 2 also provides a stratigraphic column typical of the facility. The column was developed with information provided by the contractor operating the facility (Kuntz et al. 1984). Cross-hole lithologic correlation of stratigraphic data between boreholes is difficult, since stratigraphy varies not only laterally but also vertically. The hydrogeologic characteristics of the underlying basalt and interbedded sediments, and the capping alluvial deposits (including the basal clay) are primary controls affecting the dynamics of groundwater flow and, consequently, influencing the movement of contaminants in the area of the landfill. The authors' approach to determining potential contamination migration pathways is based upon the lithologic characteristics and thicknesses of sediments in the upper beds and those capping the basalt. It is believed that the first interbed is a laterally extensive feature underlying a large area that included the entire landfill.

Initially, it was assumed from interviews with site personnel that the landfill may be up to 30 feet thick in areas. Additionally, the basal clay was believed to be continuous beneath the landfill, and would act as a semi-confining unit to retard or prevent the flow of any contaminants from the landfill to the aquifer.

A list of materials known to be disposed of in the landfill was gathered from an extensive background information review. These materials included chromate solution (55,682 gal), asbestos (43,243 ft^3), resins (38,768 lb), waste oil sludge (8,122 gal), and cadmium sulfide (quantity unknown). An additional 120 drums (6,600 gal) of trichloroethylene (TCE) may have been disposed of in the landfill. If the chromate solution had been buried in metal drums, the authors estimated that over 1,000 metal drums could be present within the landfill. In terms of potential contaminant migration, the chromate solution and the TCE were of the greatest concern, given their respective solubilities and transport characteristics. Although large quantities of asbestos were believed to have been emplaced in the landfill, it was believed to have been buried in drums or cardboard

and wood containers and was considered to be fairly immobile. Migration of asbestos within the subsurface was not a concern for this investigation.

The upper alluvium had hydrogeologic parameters such that migration of liquid could occur with minimal attenuation in shallow soils. Boring logs from monitoring wells installed near the landfill indicated that a clay exists at the bottom of the natural alluvial materials, located at the interface of these materials with the upper basalt flow (Ansley et al., 1988). Boring logs for monitoring wells located south of the landfill, outside the previous gravel pit operations, indicated that this clay is 4 to 6 feet thick. The material covering the clay unit appears to be a sand containing minimal fines. As reported during mining operations at the pit, this clay unit was confirmed by interviews with the gravel pit operators, who stated that gravel removal operations often went to the first basalt flow existing directly beneath the clay. Determining the extent to which a clay layer exists beneath the landfill was considered crucial, since it could act to retard chromate solution and TCE migration. Where clay at the interface does not exist, the chromate solution and TCE would theoretically continue to migrate into the basalt and move quickly through fractures to the interbed between the two basalt units. The geoelectric effect of the chromate solution would tend to increase the electrical conductivity of the subsurface. Therefore, it was feasible to utilize electrical methods to separately monitor the movement of these constituents through subsurface materials. The soil gas analysis would be used to estimate the degree to which TCE and other volatile organic compounds existed and are migrating away from the landfill.

The chemical composition of the buried resins was unclear. Inventory information indicated that the resins were probably in solid form. The authors were unable to make an accurate prediction of the effect (if any) of the resins upon the geoelectric properties of the subsurface materials. Previous experience in applying electrical geophysical techniques where waste oil sludge occurs has indicated that the electrical properties of the sludge can act either as a conductor or insulator. Most refined hydrocarbon products are inherently poor conductors; however, waste oils may contain other contaminants (such as heavy metals) that may increase conductivity. The cadmium sulfate was expected to be in solid form; however, the lack of information concerning physical characteristics and quantities of this material made it difficult to estimate the degree to which this material could partition from soils and contribute to the formation of leachate. However, because the area has high evapotransportation rate, and the measured annual infiltration from precipitation is minimal (<1.5 inches/year), leachate formation was assumed to be minimal over the short term.

In addition to the preceding hazardous constituents, the landfill is also known to contain "sanitary wastes." The presence of these wastes is indicated by the high levels of methane found in soil gas samples taken from monitoring wells during installation (Ansley et al., 1988).

USE OF INNOVATIVE GEOPHYSICAL METHODS

The basis for the authors' approach in using a combination of geophysical methods was to characterize changes in the physical and geoelectrical properties of earth materials resulting from disturbance during the emplacement of the fill materials or changes resulting from potential migration of waste constituents within the subsurface. By detecting and distinguishing various anomalies within the subsurface, the authors attempted to identify both disturbed materials (fill) and undisturbed naturally occurring materials. Many geophysical methods have commonly been used to characterize the physical and electrical properties of natural materials. Different lithologic compositions in subsurface materials may yield unique physical and geochemical reactions upon the introduction of contaminants. When contaminants are introduced into these natural materials, they may alter the physical and geoelectrical properties of natural materials. This may allow materials to be indirectly sensed by the geophysical methods.

Establishment of a properly designed (spaced) grid is the first component of geophysical and soil gas investigations at hazardous waste sites. Figure 3 represents the locations for the EM, GPR, and TEM surveys. If the grid spacings are too large, target resolution may not be achieved. To insure that targets were accurately located, horizontal and vertical data first were established at the site, allowing correlation of results to permanent reference points to correct geophysical data for differences in elevation. A grid system of 25-foot

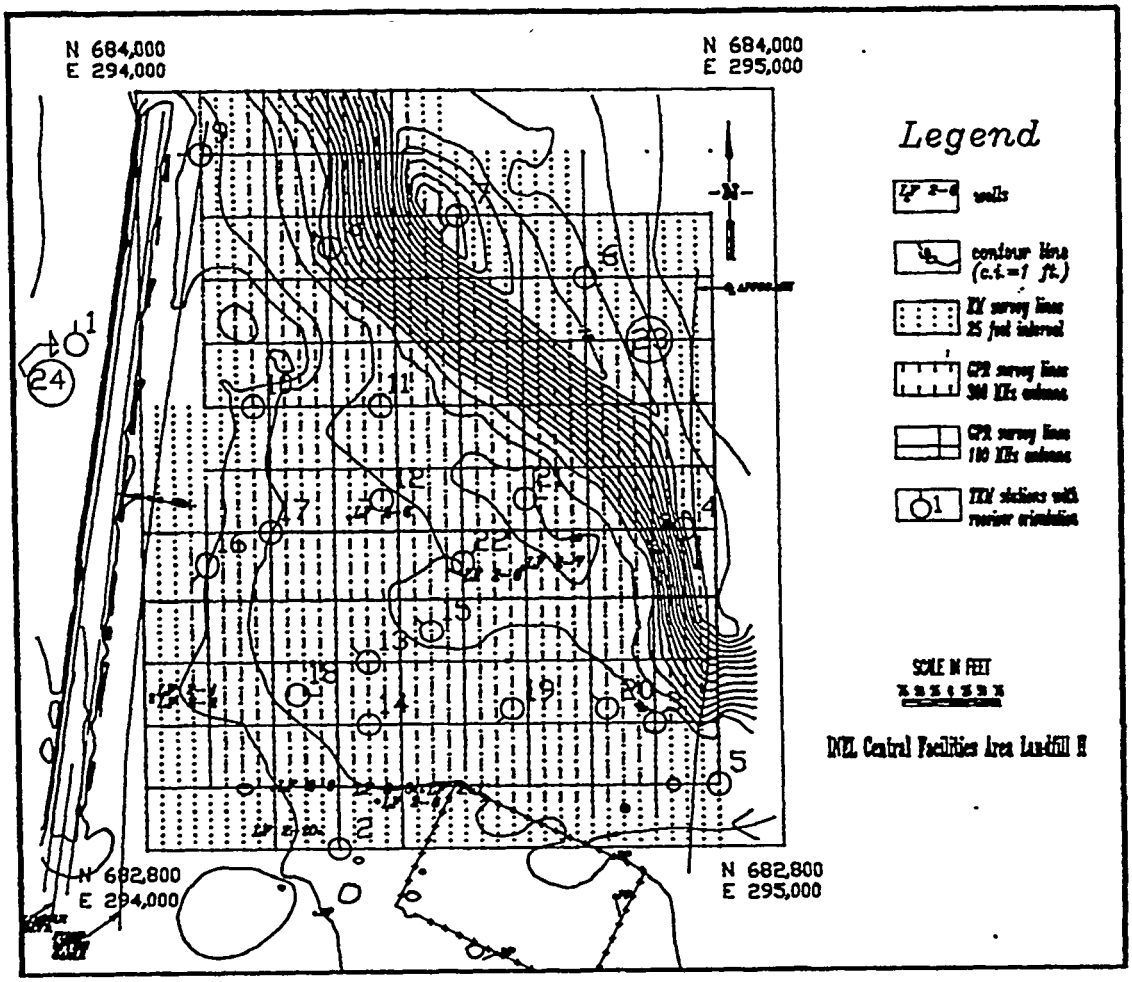


Figure 3.

centers was established over an area measuring 1000 by 1200 feet. This grid spacing was chosen based upon the anticipated target size and total coverage of the site. The background information indicated to the authors that the disposal of drums had probably occurred in specific defined locations within the landfill; the need for a closer grid spacing was deemed unnecessary. Although it was believed that wastes had been segregated by waste type and container, the location of segregated areas was not clearly known. A topographic survey with 1-foot contour intervals was conducted over the gridded area. The topographic information was necessary to allow for the correction of the geophysical data at a specific grid point. A computer-aided design drawing (CADD) map was produced from the survey grid and was subsequently used for both geophysical and soil gas data presentations.

TERRAIN CONDUCTIVITY

The terrain conductivity survey was performed using the Geonics EM31DL Terrain Conductivity Meter with data digitally stored using the Omnidata Polycorder. The reader is referred to the Geonics Technical Notes TM-6 regarding the operation of EM31DL and the theory of electromagnetic induction at low frequency. The terrain conductivity survey was an initial first step toward focusing application of supplemental geophysical techniques (TEM, GPR) to investigate any anomalies identified and to confirm or deny the application of complex resistivity at this site.

The terrain conductivity survey was carried out at two depths of exploration, 0 to 3 meters and 1.5 to 6 meters, accomplished by changing the orientation of the two coils, which are part of the EM31DL to the horizontal and vertical dipole modes, respectively. Terrain conductivity measurements were taken using both dipoles. The instrument was rotated 90 degrees upon its common axis along each survey line to assist in the determination of lateral conductivity changes. This assisted the authors to determine an orientation of an anomaly and its approximate horizontal location.

Two components of the electromagnetic field were also measured—the quadrature and in-phase components. The quadrature phase is linearly proportional to the earth's conductivity and ideal for measuring general earth conductivity, yet is influenced by highly conductive zones. The in-phase component is extremely sensitive to highly conductive objects such as buried metal, has no direct relationship to the earth's conductivity, but can be very valuable in the detection of buried metal objects in highly conductive soils. If highly conductive subsurface conditions exist (such as in a landfill), use of the quadrature phase alone would not adequately detect a buried metal target unless that target is located directly beneath a particular measurement station. By employing in-phase readings in conjunction with quadrature phase readings, the effects of the earth's conductivity can be determined, and assessed, and the presence or absence of buried metal may be interpreted.

Operational checks of the instrument, in accordance to the manufacturer's instructions, were performed twice daily in an area approximately 200 feet south of the landfill; the area was historically known to be unaffected and representative of natural subsurface conditions. Background readings consisted of recording conductivity values in the quadrature phase for both horizontal and vertical dipole orientations. The data from these soundings were used as a baseline (or background) for the comparative analysis of measured anomalies within the landfill area. No significant changes in the conductivity were found during checks in the background area, except for small changes attributed to the typical drift in instrument readings and changes in atmospheric conditions, moisture content, etc., during the survey. Background conductivity (2-3 mmhos/m) readings indicated a relatively low conductivity for the subsurface materials (i.e., high resistivity, which would be expected in relatively dry, coarse-grained materials. A reconnaissance survey was performed over the entire grid area and in areas outside the grid on 100-foot centers to gain an understanding of the range of conductivities within the study area. These data were used to determine the approximate limits of the landfill, the adequacy of the extent of the grid area, and the approach for a more detailed terrain conductivity survey (if needed).

The terrain conductivity data were interpreted using two main approaches. The data were initially interpreted along each survey line following the plotting of distance-conductance plots with DAT3IQ software, which allowed the interpreter to construct both x-y and contour plots. Plots were constructed for both dipoles, both orientations, and both the quadrature and in-phase components to identify changes in subsurface conductivities associated with landfill boundaries and buried metal. The terrain conductivity data were contoured using Surfer TM Version 4.0 by Golden Software using a minimum-curvature interpolation algorithm. Other algorithms were tried and compared, but the authors believed the minimum-curvature interpolation yielded the best interpretation.

Detection of buried metal entailed analysis of the contours of high-conductivity readings (both quadrature and in-phase). Detection of contamination requires the analysis of both high conductance and low conductance anomalies, depending on the contaminant of interest. Of the contaminants of interest at the landfill (chlorinated solvents and chromate solution) the solvents were expected to reduce terrain conductance, while the chromates were expected to increase terrain conductance. However, if the concentrations of solvents were not sufficiently high to affect the bulk conductivity of the subsurface materials, they could not be readily discerned from the effects of the buried metal objects and chromate solutions.

The EM profile plots were especially useful in determining location to be surveyed with GPR. When the EM plots were interpreted in conjunction with GPR survey data, the profiles provide a means of correlating the two methods and confirming the existence of either buried objects (e.g., pipes, drums) or zones of significant contamination. EM contour plots were constructed to enhance interpretation of the data and

improve the understanding of conditions at the landfill. Various contour intervals and conductivity ranges were plotted during this evaluation. Figure 4 details some of the EM survey results. Figure 4 was used to indicate the suspected boundary of the landfill, identified by only contouring a maximum conductivity value of 20 mmhos/m at a contour interval of 2 mmhos/m, and had identified anomalous "hot spots" as highly conductive zones. These areas are assumed to represent either buried metal, localized contamination (chromate solution), or both. Through the use of GPR, TEM, and soil gas techniques, a more definitive conclusion concerning these targets could be drawn.

GPR SURVEY

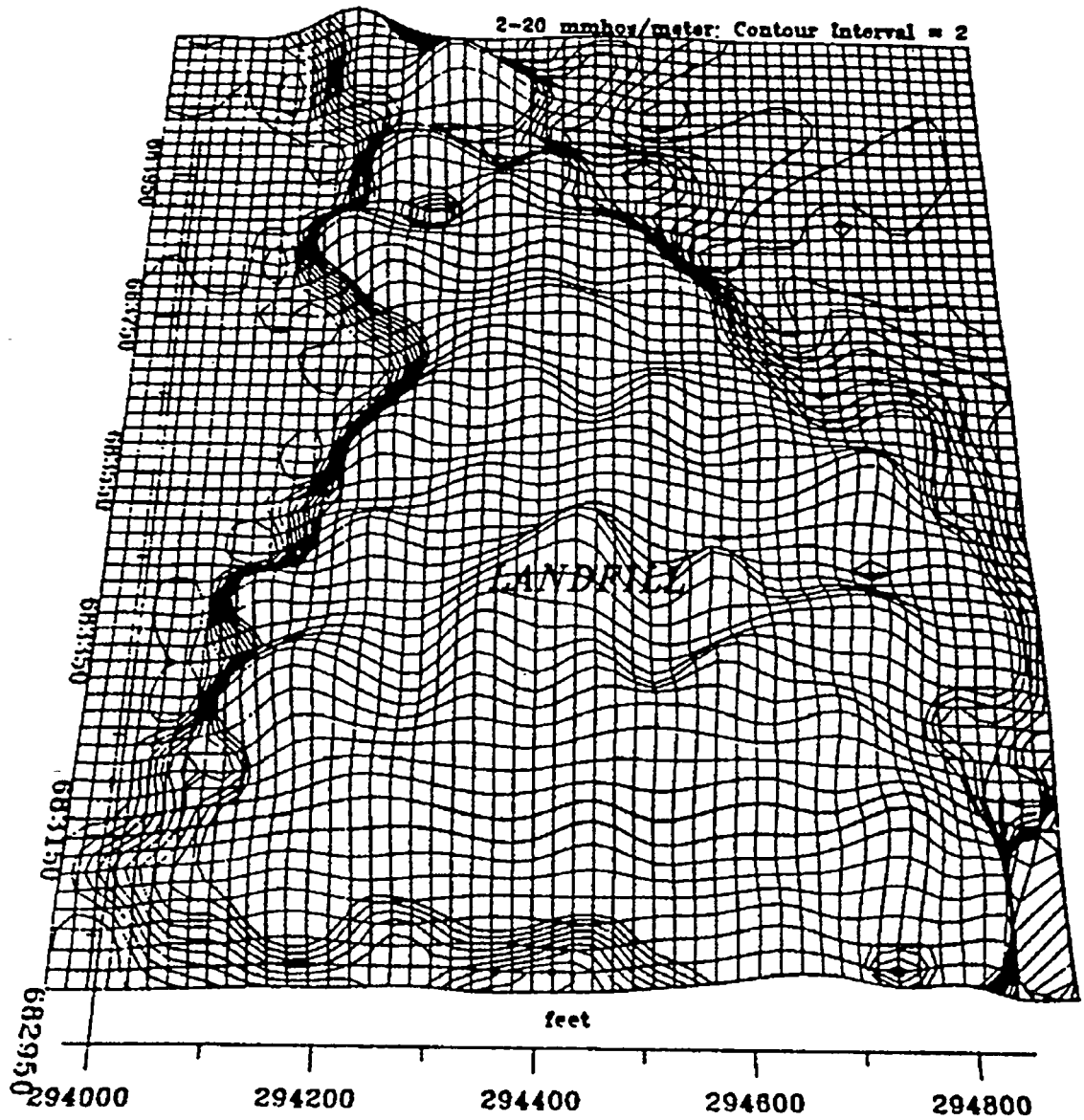
GPR was used to confirm and further characterize the interpreted EM anomalies ("hot spots") and to assist in the characterization of the subsurface lithology. The GPR survey covered the entire landfill and some of the surrounding undisturbed area. Antenna frequencies and time ranges were selected, which correspond to the following apparent depths of exploration: 0 to 22 feet and 0 to 56 feet. The depths of exploration were determined by calculating "average" wave propagation velocities and by identifying lithologic boundaries from the GPR records next to the onsite monitoring wells. GPR propagation velocities are governed in part by the dielectric constant of the medium. Dielectric constants can be defined as the specific inductive capacity of the medium. The dielectric constant is similar to the conductivity in porous formations in that it changes proportionally with the amount of water present (Telford, et al., 1976). The 0 to 22 foot configuration was employed to characterize lithologic changes and to identify potential contaminant migrations. These exploration depths were achieved by using 300 and 100 Mhz antenna frequencies, respectively.

Initially, the 300 Mhz antenna survey was performed, yielding an average depth of exploration of approximately 22 feet and a propagation velocity of 0.28 feet per nanosecond as determined from wide-angle reflection and refraction (WARR) measurements. Upon completion of the 300 Mhz antenna survey, the 100 Mhz antennal survey was performed. The 100 Mhz survey was performed with a bistatic (separated transmitted and receiver) configuration, with a high power transmitter. In undisturbed areas and in areas where buried metal was not prolific, the 100 Mhz antenna was able to explore interpreted depths up to 56 feet below the land surface.

The landfill was surveyed with the 100 Mhz antenna over the 100-foot survey grid in both a north/south and east/west directions (Figure 3). Combining the 100 Mhz and 300 Mhz surveys, approximately 46,450 lineal feet of GPR data was obtained. Within the landfill, the depth of exploration was partially limited due to the "ringing" effect. "Ringing" occurs when the GPR signal encounters a highly conductive object (metal) in the near surface. A portion of the electromagnetic wave is reflected back toward the antenna, while the other portion of the wave continues to greater depths. The reflected portion of the wave, which has a high energy, continues to reflect back and forth between the highly multiple "images" throughout the GPR record, obscuring any deeper reflections. These deeper reflections, occurring at a lesser energy level, are obscured on the GPR record by the "ringing" effect. This effect can be partially removed by digitally processing the recorded wave records using a computer software package known a RADAN. RADAN is a ground-penetrating radar-signal processing package designed to process GPR data acquired with the GSSI's radar systems. For this survey, we used RADAN techniques that involved finite or infinite impulse filtering, deconvolution or migration (hyperbolic summation and Kirchoff Migration), automatic gain, and stacking.

Finite impulse response filtering, when applied to a feature in the data, will produce a finite filtered version of that feature resulting in an output that corresponds in time and space to the input. Infinite impulse filters operate by combining new data along with previously recorded data in some average form. Both finite and infinite filtering can be performed both horizontally and vertically. By knowing the frequency of the data (in cycles per scan), the operator can determine at which frequency the filtering should be set. Only low pass filtering was used on the GPR records at this particular site, since the deep scans were not affected by the "ringing" effect.

Another filtering scheme that was used consisted of deconvolution. Deconvolution is a unique type of filter used to increase the vertical (time) unit resolution of the data. Deconvolution functions by making the



Contoured electromagnetic induction (EM) survey data clearly delineates the boundaries of the Central Facilities Area Landfill II.

Figure 4.

antenna pulse smaller, as if a wider bandwidth antenna were employed.

Migration is an imaging process that focuses the beam of the GPR antenna, and is used to provide a more accurate picture of the subsurface objects by eliminating the distortions caused by the data collection process. For this particular survey, the Kirchoff Migration method was employed. This method works by summing along a hyperbola placed on the data, and placing a resulting average at the apex of the hyperbola. This process is repeated with the apex on every point of the data, requiring that the operator specify the hyperbola width and velocity.

The authors also utilized the stacking option, which reduces the size of the data file, enhances minimal reflection records, and causes the GPR record to be reduced horizontally. For example, a reflector having a slight change in depth over a significant lateral distance is more easily recognized by the stacking procedure, shortening the lateral distance and an apparent change in depth.

The following interpretations of the GPR data were made: the 300 Mhz survey confirmed the EM anomalies, and the depths of 300 Mhz anomalies were 8 - 10 feet though not all EM anomalies were buried drums but other metal objects; some of the drums appear to be buried in trenches: GPR records indicate "block-like" structures, which may be buried boxes or crates. The 100 Mhz GPR survey indicated that the bedrock (basalt) varies in depth from near the surface in the northwestern portions of the landfill to up to 30 feet in the southern portion of the landfill; depth to the interbed cannot be determined in all instances because of the change of lithologic character (from clay to sand) and hence the reflective nature of the interbed. In summary, the GPR surveys provided good correlation with the EM survey data as to the location and extent of the principal landfill area, and indicated the possible presence of potential discrete contaminant sources.

TEM SURVEY

The TEM method was employed to better understand the extent to which contaminants may have migrated from the landfill and accumulated in the basal clay along the top of the basalt flow and within the interbed between the top basalt flow and the deeper basalt flow. Additionally, TEM was used to characterize the depth, thickness, and resistivity of the subsurface stratigraphy.

The time-domain electromagnetic method (TEM) is a surface geophysical method used to measure the geoelectric section of the subsurface. The selection of TEM over the common geophysical technique known as surface resistivity is that with TEM near-surface inhomogeneities can be minimized. With surface resistivity, these inhomogeneities can cause interference to the resistivity survey, resulting in unacceptable data. This condition would certainly be prominent in a landfill environment. The TEM method is typically used for deep conductivity measurements associated with the mineral exploration activities. However, the TEM method has been used in recent years for subsurface mapping related to water resource investigations. These surveys were used mainly for lithologic descriptions or for mapping areas of salt water intrusion along coastal areas.

Until recently, TEM methods could not be used for shallow-depth measurements because of the quick decay of the induced electromagnetic field and the inability of the equipment to make appropriate measurements rapidly, although TEM instrumentation has been improved to be effective for shallow investigations A new time-domain system developed by Geonics, Ltd., is capable of exploring depths as shallow as five to ten meters, although shallower investigation depths result in increased interference problems. To minimize these interferences, the authors used a smaller (5 meters square) multi-turn transmitter antenna. The antenna allowed us to complete soundings in areas where subsurface interference (drums, pipes, cables, etc.) existed, and minimized the interference from nearby overhead power lines. The authors employed the Geonics Protem EM47 Model II for the TEM soundings. This particular apparatus can normally sense depths between 5 and 150 meters, with the exploration depth controlled by the loop size and the electrical current applied to the loop. A total of 22 soundings was performed over the survey grid. Representative plots of these soundings are indicated on Figure 5. The receiver coil was placed at a minimum distance of 10 meters from the 5-meter multi-tome antenna and 3 meters from the transmitter control unit.

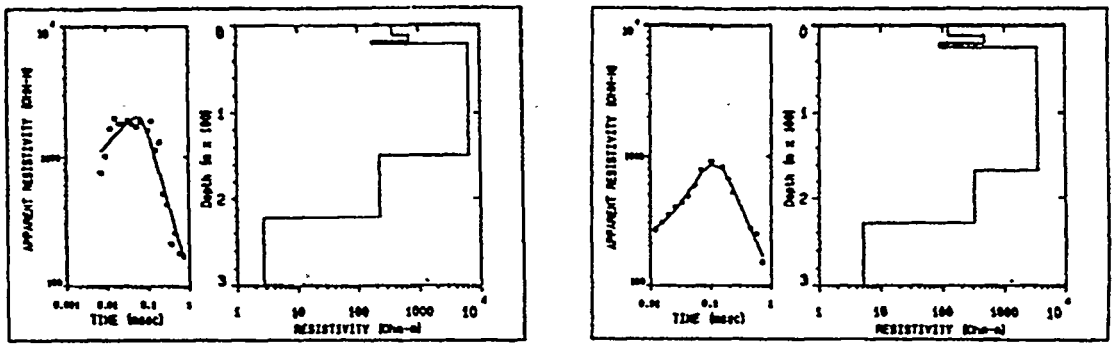


Figure 5.

The authors believe that the use of the standard 40-meter-by-40-meter coil in a landfill environment would have yielded unacceptable data due to interference problems of buried metal. This assumption was confirmed by attempting to perform TEM soundings using the 40-meter coil, resulting in an inability to make any repeatable measurements; data off the landfill also exhibited interference form nearby power lines. The location of the TEM soundings with the 5-meter multi-turn coil was based on the previous EM survey and the location of the Identified anomalies. All measurement stations were referenced rigorously to the established grid and double-checked by two individuals. In most cases, the TEM station locations indicated limited interference to the data. However, some stations were located in areas that were too close to areas of significant amounts of buried metal. In addition, at some locations the receiver coil could have been moved with respect to the transmitter locations to reduce measurement interference.

The TEM data were interpreted using TEMIXGL computer software developed by Interpex of Golden, Colorado. TEMIXGL is a series of forward inverse modeling programs for interpreting the electromagnetic sounding data developed with time-domain electromagnetic induction equipment. The data were plotted and the number of layers to exist were entered into the computer with predicted thicknesses of each layer. Our assumed number of layers was based upon background measurements taken near existing monitoring wells off the survey site. Figure 5 presents the TEM results drawn from the data. Some general conclusions can be made regarding the TEM survey: the soundings could identify the overburden materials, the first basalt, the interbed, the second basalt, and the water table; the depth of the basal clay could not be defined: the second interbed layer could not be defined; water table definition was problematic depending on the station location (i.e., interferences); placement of the measurement station was of paramount importance to avoid interference from the landfill environment; all measurement stations should have been surveyed with EM to avoid possible subsurface interference; possible contaminant migration into the basalt and interbed appears to be very localized; and perched water table conditions (if they exist in this area) could cause resistivity values to be lowered significantly, yielding possible error in interpretation of contaminant presence. No perched ground water zones were evident in the background materials we reviewed for this site.

Overall, TEM proved to be a valuable geophysical tool in the exploration of landfills if measurement stations are located properly and measurements carefully performed. The use of the 5-meter multi-turn loop was of paramount importance for the success of this survey. The standard (40-meter) loop configuration would not have worked as the Interface potential would have been increased.

SOIL GAS SURVEY

Soil gas sampling was conducted over most of the landfill to define the potential source areas for chlorinated solvent contamination and to delineate contaminant movement as an integral part of the innovative technology demonstration. Figure 6 indicates the location of the soil sampling points and the sampling grid. The collection of the data and the analysis of the samples was conducted by TARGET Environmental Services, Inc. The EM and GPR survey results provided a good indication of the potential areas where drums may be buried. However, we were not expected to be able to delineate the movement of volatile solvents with either of these methods because of low contaminant concentrations expected in the vadose zone.

Soil gas samples were collected at 50-foot centers within the landfill, around anomalous areas identified by the EM and GPR surveys, at a total of 179 locations. A one half-inch hole was driven to a depth of approximately four feet by using a drive rod or electric hammer (Wacker) drill. The system was then purged with ambient air drawn through a dust and organic vapor cartridge. A stainless steel probe was inserted to the full depth of the hole and sealed off from the atmosphere. A sample of in-situ soil gas was then withdrawn through the probe to displace ambient air from the sampling system. A second sample of soil gas was withdrawn through the probe and encapsulated in a preevacuated glass vial two atmospheres of pressure (15 psi); the self-sealing vial was then detached from the sampling system, packaged, labeled, and stored for laboratory analysis. Figure 6 presents the locations of the soil gas sample locations.

The soil gas data were contoured using the Golden Software's Surfer graphics package with the minimum curvature interpolation method. The following contaminants were detected from the soil gas analysis: chloroform; 1, 1- dichloroethane (1, 1 - DCA); 1,1,1 trichloroethane (1, 1, 1 -TCA), tetrachloroethylene (PCE); trichloroethylene (TCE); and 1,l-dichloroethene (1,1-DCE). The distribution of the compounds indicated a common area of occurrence in the southeastern portion of the site. The locations of other anomalous "highs" vary among the individual compounds. Using soil gas methods alone, it is often difficult to pinpoint the exact source locations since observed patterns may result from the nonuniform movement of liquid through heterogeneous (anisotropic) materials.

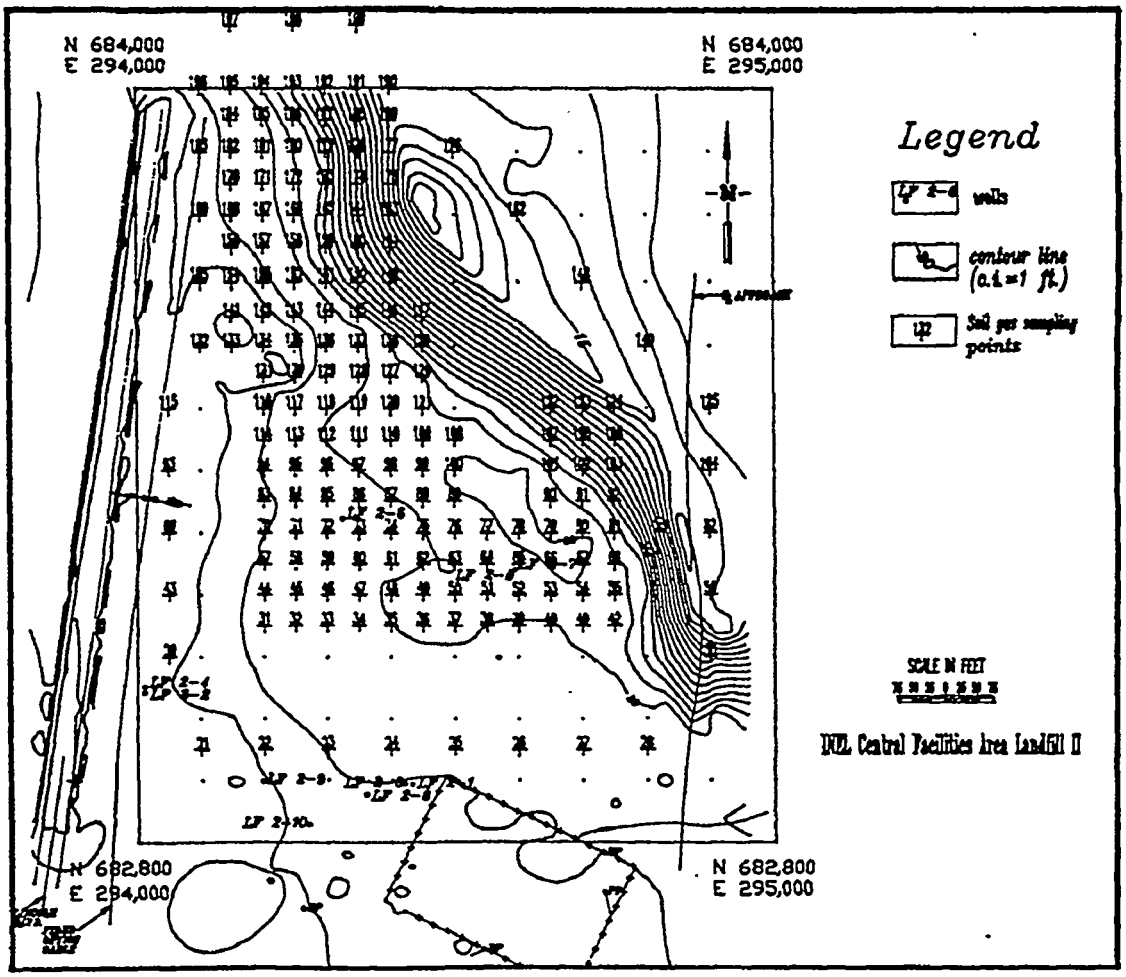


Figure 6.

RESULTS AND CONCLUSIONS

The geophysical methods chosen for this demonstration were able to identify the landfill boundaries, locate potential "hot spot" anomalies, recognize potential buried drums and boxes, and identify lithologic units and their depths. The soil gas survey confirmed the presence of organics in the landfill and indicated that they were associated with the buried metal that was located and characterized with the EM and GPR methods. Although contaminant movement seems to be presently limited to a few "hot spots," the authors believe that the contamination has reached the interbed in one location and possibly three others. However, with the water table at such a significant depth, we presently believe that contamination is unlikely and would be confirmed by installing and sampling additional monitoring wells.

Our demonstration could not reliably detect the basal clay above the interbed. Some GPR records seemed to indicate that the clay was present, while none of the TEM soundings suggested its presence. Although the clay is indicated in the boring logs, we believe that there was not a pronounced difference in the geoelectric properties of the materials as was originally expected. Our interpretation of possible contamination present in the interbed, however, makes the prospect of the basal clay being present beneath all parts of the landfill unlikely.

Our surveys indicate that the average thickness of the landfilled materials to be about 14 feet, not the reported 30 feet. If we take the estimate of landfill size based on our EM survey of 14.9 acres, we determined that the amount of waste contained in the landfill was approximately 340,000 cubic yards. Based upon a review of available records of materials emplaced at the landfill by the DOE, a total of 380,000 cubic yards was believed to have been landfilled at the site.

We believe that the basic design of the approach is sound; however, we would refine the approach in future applications to improve the information that is available following the execution of each component. The authors would include the use of the Geonics EM34-3XL to characterize the conductivity of the unconsolidated materials and upper portion of the first basalt layer beneath the landfill; perform a more in-depth analysis of EM and GPR data before the selection of TEM stations to minimize the interference from buried metal; and use several TEM orientations (receiver coil positions) at each station.

Finally, the authors stress that the use of geophysical methods in this type of environment is beneficial if properly applied by trained individuals. Our approach contained sufficient flexibility to meet unexpected field conditions. Many site investigations contain approved work plans that do not allow these adjustments to enhance the effectiveness of data collection or interpretation. These investigations must be guided by a combination of existing site conditions and sound technical and scientific principles, with flexibility available to ensure representative data collection and interpretation.

Since the time of this survey in 1989, many advances in surface geophysical techniques, instrumentation, and software have occurred. The authors are aware that tomographic (seismic and resistivity) could have applications at this site. Advances in portable frequencies sources and 24-bit seismographs would have made three-dimensional surveys possible. This same statement is true for both resistivity and GPR surveys. The authors of this paper argue that technology presently exists that is "off the shelf" and can be immediately applied to hazardous waste sites today. The authors believe that additional advances in equipment and software are still necessary but are in relative reach in the near future.

Our conclusion is that technically competent individuals can solve many of our site characterization problems. Our inability to solve these problems are only bounded by regulations and perceived legal entanglements.

REFERENCES

Ansley, S.L., Hull, L.C., and S.M. Bums, 1988, Informal Report for CFA Landfills II and III-FY-1988, *Characterization of Surfical Sediments*, EG&G Idaho, Inc., EGG-ER-8291.

Kuntz, M.A., et al., 1984, *Preliminary Geologic Map of the Idaho National Engineering Laboratory and Adjoining Areas*, Idaho. USGS Open File Report 84-281.

McNeil, J.D., 1980, *Electrical Conductivity of Soils and Rocks*, Technical Note TN-5, Geonics Limited, Canada.

McNeil, J.D., 1980, *Electromagnetic Terrain Conductivity Measurement at Low Induction Numbers,* Technical Note TN-6. Geonics Ltd. Canada.

Nace, PL., et al., 1975, *Generalized Geologic Framework of National Reactor Testing Station*, Idaho. USGS Prof. Paper 725-B.

Telford, W.M., Geldhart, L.P., Sheriff, R.E. and D.A. Keys, 1976, *Applied Geophysics*, New York, Cambridge University Press.

Ulriksen. C.P., 1982, *Application of Impulse Radar to Civil Engineering,* Department of Engineering Geology, Lund University of Technology, Sweden.

Contaminated Groundwater Characterization at the Chalk River Laboratories, Ontario, Canada

Alan J. Schilk
David E. Robertson
Charles W. Thomas
Elwood A. Lepel
Battelle, Pacific Northwest Laboratories
P.O. Box 999, M/S P8-01
Richland, WA 99352

Douglas R. Champ
R. W. Douglas Killey
James L. Young
Edward L. Cooper
Chalk River Laboratories
Chalk River, Ontario
Canada

ABSTRACT

The licensing requirements for the disposal of low-level radioactive waste (10 CFR 61) specify the performance objectives and technical requisites for federal and commercial land disposal facilities, the ultimate goal of which is to contain the buried wastes so that the general population is adequately protected from harmful exposure to any released radioactive materials. A major concern in the operation of existing and projected waste disposal sites is subterranean radionuclide transport by saturated or unsaturated flow, which could lead to the contamination of groundwater systems as well as uptake by the surrounding biosphere, thereby directly exposing the general public to such materials. Radionuclide transport in groundwater has been observed at numerous commercial and federal waste disposal sites [including several locations within the waste management area of Chalk River Laboratories (CRL)], yet the physico-chemical processes that lead to such migration are still not completely understood.

In an attempt to assist in the characterization of these processes, an intensive study was initiated at CRL to identify and quantify the mobile radionuclide species originating from three separate disposal sites: (a) the Chemical Pit, which has received aqueous wastes containing various radioisotopes, acids, alkalis, complexing agents and salts since 1956, (b) the Reactor Pit, which has received low-level aqueous wastes from a reactor rod storage bay since 1956, and (c) the Waste Management Area C, a thirty-year-old series of trenches that contains contaminated solid wastes from CRL and various regional medical facilities. Water samples were drawn downgradient from each of the above sites and passed through a series of filters and ion-exchange resins to retain any particulate and dissolved or colloidal radionuclide species, which were subsequently identified and quantified via radiochemical separations and gamma spectroscopy. These groundwaters were also analyzed for anions, trace metals, Eh, pH, alkalinity and dissolved oxygen.

Initial results indicate that anions are the predominant solution species (i.e., the mobile form) for most of the radionuclides studied, and such behavior is postulated to be a function of complexation by natural or synthetic organic ligands, although the presence of inorganic complexes cannot be discounted at this time. Thermodynamically predicted aqueous speciation for some radionuclides does not agree with these empirical results, indicating that K_d-based models for predicting radionuclide mobility are inadequate in many cases. Current efforts are being directed toward hollow-fiber ultrafiltration of these groundwaters to concentrate various nominally soluble size fractions (e.g., 3K, 10K, 30K and 100K MW cutoffs) to determine the significance of organic complexation and microparticulates/colloids in the enhancement of radionuclide migration from low-level waste disposal sites (particular attention will be paid to the chemical speciation of ^{129}I, plutonium and ^{14}C). Ultimately, the results from such observations are expected to help generate more realistic retardation factors for a number of radionuclides, thereby contributing to the accuracy of future modeling assessments.

INTRODUCTION

Any candidate site intended for use as a facility for the shallow-land burial of low-level radioactive waste must satisfy the requirements of 10 CFR 61 ("Licensing Requirements for Land Disposal of Radioactive Waste"), subpart D, section 61.5(2), which states that any proposed site must "be capable of being

characterized, modeled, analyzed and monitored." Of primary concern with regard to the licensing of such facilities are the means by which the natural or enhanced migration of radionuclides beyond site boundaries is accomplished. A thorough understanding of these means could lead to the prevention or minimization of such transport, thereby sparing the general public from undue exposure. Furthermore, shallow-land burial has been routinely used for the disposal of low-level radioactive wastes (Riley and Zachara 1992), during which imperfect disposal practices, precipitation infiltration, and groundwater leaching of various waste forms have led to the contamination of many surface and groundwaters. Despite current waste management programs, which are intended to modify and reduce waste streams and contain contaminants from past disposals, the active migration of radioisotopes from many of the aforementioned sites is an almost ubiquitous phenomenon (McCarthy 1988, Olsen et al. 1986, and references therein). Whether one is concerned with projected or existing radioactive waste repositories, a clear and detailed understanding of the mechanisms of radionuclide transport (both natural and facilitated) is critical to any realistic performance assessment.

To ensure the compliance of proposed sites and to perform environmental assessments of existing ones, most investigators use predictive models of radionuclide transport that employ laboratory-derived values for a parameter referred to as the "activity distribution coefficient," or K_d. Such a coefficient is essentially a ratio of the activity per unit mass of soil (or aquifer media) to the activity per unit volume of water, the magnitude of which is related to the extent that the radionuclide in question is retarded with respect to the mobile phase(s) (i.e., due to adsorption on the stationary phase). A number of recent studies, however, have identified significant discrepancies between actual migration rates and those predicted by models for some radionuclides in natural settings (Robertson et al. 1989, and references cited). It is generally acknowledged that transport models based on thermodynamic calculations of radionuclide speciation[a] (Rai and Sern 1978) and laboratory-scale analyses (e.g., column and batch studies using "ideal" radiotracers, which may be in some physico-chemical form other than those of actual mobile species in groundwaters), fail to produce reliable results because they disregard the potential for radionuclide complexation by natural and manmade organic species as well as "dissolved" microparticulate/colloidal material (Bondietti 1982, Champ et al. 1985, McCarthy 1988, McCarthy and Zachara 1989, Petit 1990, Warwick et al. 1991). Consequently, the current study supports the contention that to understand the mechanisms that determine the extent of radionuclide migration (or retardation) in an existing or proposed natural setting, it is imperative that species exhibiting facilitated transport be examined in actual field situations (particularly those that have contained radionuclides for many years) and subsequently compared with results predicted from laboratory and thermodynamic data. Fundamental information of this sort can then be incorporated into models for more accurate predictions of radionuclide movement from repositories, and thereby enhance strategies for site planning or remediation by manipulating mobilization (for pump-and-treat methodologies) or deposition (for ensuring containment).

Several mature low-level waste management and experimental disposal sites exist at CRL and are excellent analogues for shallow-burial facilities located in humid environments. These sites provide a unique and invaluable opportunity to study the long-term behavior and transport of a number of important radionuclides (virtually all of those discussed in 10 CFR 61), which have resided in a shallow groundwater flow system for nearly 40 years. This continuing study will sample groundwaters from various CRL waste disposal sites and attempt to characterize the actual mobile radionuclide species by various analytical techniques, determine revised K_d values based on the observed speciation, compare the physico-chemical species of observed migrating radionuclides with predictions based on revised retardation equations, and investigate the roles of organic complexation and microparticulates in the enhancement of radionuclide transport.

SITE DESCRIPTION

The CRL facility is located nearly 200 km northwest of Ottawa and covers approximately 37 km^2 next to the Ottawa River (Figure 1). The local geology is made up of a variety of unconsolidated Quaternary sediments of glacial, fluvial and aeolian origin overlying a topographically irregular and locally fractured

a. The term "speciation" refers to the individual physico-chemical forms of an element, which together make up its total concentration in a sample (Florence 1982).

bedrock of Precambrian granitic gneiss, typical of much of the Canadian Shield. The surficial deposits (generally less than 30 meters in thickness) are fine to medium sands with interbedded layers of clayey silt, both of which are composed largely of quartz and aluminosilicate minerals, associated alteration products, trace amounts of hydrated oxides of iron and manganese, sulfides, carbonates and organic matter (<0.2%; Champ et al. 1985). An annual precipitation of approximately 75 cm is distributed evenly throughout the year and recharges a water table normally less than 5 meters from the ground surface. The large amounts of available water have led to the formation of numerous swampy areas throughout the region, which contain bog deposits of peat and other organic matter.

The CRL Liquid Disposal Area, located about 800 meters northwest of Perch Lake, incorporates a series of lined and unlined trenches excavated from surface sands and includes the Chemical and Reactor pits (Figure 2) of the current study. Low-level waste disposals to the former began in the mid-1950s and included a host of radionuclides, acids, alkalis, complexing agents and salts, which originated from various operations at the facility (Killey and Munch 1984). According to Champ et al. (1985), the total inventory of ^{60}Co on the aquifer matrix downgradient of the Chemical pit is 370 GBq (10 Ci), while the quantity of α-emitters disposed at this site was estimated to be 185 GBq (5 Ci). A short subsurface flow path exists from the pit to the East Swamp Stream with a groundwater residence time from six months to two years and a mean flow of 5-25 cm/day. Earlier investigators (ibid.) identified radioisotopes of Co, Zr, Ru, Sb, Cs, Ce, Eu, Fe, Sr, Ni, I, Tc, Pu, Am and Cm in downgradient water samples. Nonetheless, routine monitoring of Perch Lake, which receives drainage from the East Swamp Stream, indicates that radionuclide concentrations do not exceed levels prescribed for permissible drinking water (Killey et al. 1984).

The Reactor pit has received low-level aqueous wastes from CRL's rod storage bays since 1956. Disposed α-emitters total approximately 580 GBq (15.8 Ci), while groundwater flow and residence times are essentially equivalent to those observed at the Chemical pit 200 meters to the northeast. Champ et al. (1985) have determined the presence of radioactive Co, Ru, Sb, Cs, Fe, Sr, Ni, Pu and Am in groundwater effluent.

Waste Management Area C is located 2 km west of the Liquid Disposal Area and includes a series of unlined trenches within a large sand ridge, the latter of which forms the southern margin of Lake 233 (Figure 3). This facility is still in operation and, since 1963, has received mixed low-level solid wastes from CRL, industry, hospitals and universities throughout Canada. Water discharges to the southwest from Lake 233 via the subsurface sands and travels at rates between 15 and 30 cm/day, leading to a total residence time of approximately two to four years below Area C (Killey and Mattie, unpublished data). Tritium is the primary radionuclide of concern at this site in terms of quantity, although anomalously high concentrations of ^{14}C have been detected in the surrounding vegetation while ^{60}Co and ^{36}Cl are present in the groundwater, as well. Impermeable polyethylene covers, which appear to have eliminated the infiltration of precipitation and subsequent release of tritiated water, were installed over a large portion of this site in 1983, but ^{14}C is apparently still migrating from the area (R.W.D. Killey, pers. comm.).

EXPERIMENTAL

Groundwaters were sampled at each of the above sites from existing multi-level piezometers (3 mm I.D. plastic tubing) which were known from previous investigations to intercept the subsurface plumes of migrating radionuclides. Samples were drawn via a self-priming, bellows-type metering pump with polypropylene wetted parts (manufactured by Gorman-Rupp) from a single depth or two adjacent depths, simultaneously. Individual piezometers were flushed for about 30 minutes before collection to ensure representative sampling of interstitial waters (as opposed to borehole-retained material), and pump flow rates were maintained as low as possible to preclude resuspension of any particulate matter held by the local aquifer medium (i.e., rates were generally less than 100 mL/min, but in no case faster than about 180 mL/min at a specific depth).

Following the flush procedure, samples were passed through a sterile prefilter unit (produced by Gelman Sciences), which is comprised of a 1.0 μm (nominal) gauze layer followed by 0.8 μm and 0.2 μm membranes,

to retain a majority of the particulate, or undissolved, materials.[a] During this process, groundwater temperature was measured in a flow-through lucite cell with a mercury thermometer, while pH and Eh were determined with an Orion Research Specific Ion Meter (model 407A/F) using a combination pH electrode and a standard calomel electrode/platinum inlay electrode (Corning). Standardization of these methods was assured through the use of pH 7.0 and 4.0 buffers and a Zobell's solution (Garrels and Christ 1965), respectively. Dissolved oxygen and alkalinity were quantified with a Hach Digital Titrator Kit, the former via the Winkler method with azide modification and a Jarrell Ash Division (Fisher Scientific) digital titrator with a prestandardized solution of phenylarsine oxide. Titration of a sample to pH 4.8 with the digital titrator employing a 0.16N H_2SO_4 solution generated alkalinity results. Ferric/ferrous iron concentrations were determined using a colorimetric/absorbance method, which employed ferrozine (3-(2-pyridyl)-5,6-diphenyl-1,2,4-triazine) to produce a pink-colored complex with Fe^{2+} in acidified, filtered aliquots. After the initial determination of ferrous iron, samples were treated with hydroxylamine hydrochloride to reduce the Fe^{3+} to Fe^{2+}, and the process was repeated to obtain ferric iron (by difference). Aliquots were also drawn for analyses of trace metals (filtered and acidified; inductively coupled plasma - atomic emission spectrometry), anions (filtered, unacidified; ion chromatography) and organic carbon content (filtered, unacidified; solution analysis).

Prefiltered groundwaters were subsequently passed through a large volume water sampler (Robertson and Perkins 1975) designed at Battelle's Pacific Northwest Laboratory (PNL) for the removal of charged and uncharged soluble species of migrating radionuclides. This unit is comprised of six stacked resin (powder) chambers, which are 20 cm in diameter and 2.5 cm (0.6 cm) thick and separated by sturdy glass-fiber filter sheets. Water enters from the base of the unit and spreads out radially before entering the first of two cation exchange resin beds (Dowex 50 x 8, Na^+ form, 200-400 mesh), the redundant bed being present in case the first is compromised or becomes saturated. This resin was originally in the H^+ form, but was converted in order to eliminate the potentially destructive or denaturing effects on existing radionuclide speciation upon passage through the bed(s) as a function of the resulting highly acidic solution (see, e.g., Robertson 1986). Following the cation beds are duplicate layers of anion exchange resin (Dowex 1 x 8, Cl^- form, 200-400 mesh) for retention of negatively charged species, and two activated aluminum oxide powder beds for the removal of those radionuclides, which may have existed in soluble, nonionic forms.[b]

Effluent from the large volume water sampler was directed into a plastic-lined barrel and subsequently pumped through an integrating water flow meter to determine the total volume processed at each well site. Interstitial water within the sampler was expelled by pumping air through the unit before modular disassembly, and the individual resin and powder beds (as well as the prefilter assemblies) were carefully packaged for shipment to PNL for radiological characterization. Specifically, nondestructive γ-ray spectrometry was performed by placing the filters, resins, and powders in standard geometries and counting them with a Ge(Li) detector followed by computer-assisted data reductions. Aliquots of the above were then leached with acid, and the resulting solutions subjected to various radiochemical procedures for quantification of radioisotopes not amenable to γ analysis.

RESULTS AND DISCUSSION

Groundwater samples from the Chemical Pit (piezometer ES-16), Reactor Pit (PLS-38), and Waste Management Area C (C-221) are observed to be slightly acidic and mildly or highly oxidizing in nature. The

---

a. n.b., the precise size cutoff with which to distinguish suspended particles from true "dissolved" species is often debated among researchers and any attempts to delimit such a boundary should be considered, at best, only arbitrary.

b. It is uncertain at this point whether the actual order of the beds is a critical parameter, as different permutations were not investigated (e.g., it is not known if the cation resin leads to some "modification" of the original speciation before contact with the anion beds, thereby affecting the overall qualitative and quantitative results). In any case, future studies will rely on other means to fractionate migrating species in the hopes of mitigating this phenomenon of surface adsorption/modification.

Eh, dissolved oxygen, and ferric/ferrous data indicate that the Chemical and Reactor pits are nearly saturated in terms of oxygen content, while the C Area tends to be somewhat depleted and therefore less oxidizing. Dissolved organic carbon concentrations at the Chemical and Reactor Pits appear to be typical of many shallow aquifers, whereas that in Area C is significantly lower. Furthermore, alkalinity results for the latter indicate an elevated carbonate content at this site, possibly a function of the subsurface geohydrology (e.g., dissolution of underlying tills).

Anion concentrations are summarized in Figure 4. It is apparent that sulfate and chloride are the primary anions in solution at these sites, while nitrate is prevalent at the Chemical Pit only. Such results are reasonable when one considers that two of the primary geochemical inputs into the Perch Lake Basin are (a) dissolved NaCl, originating in the form of several tons of road salt deposited each year, and (b) acid precipitation, composed largely of sulfate (10 mg/L), nitrate (3 mg/L) and chloride (1 mg/L) [see Jackson and Inch (1980)]. The third major input into the Chemical and Reactor Pits, liquid radioactive waste disposals, likely contributed to the nitrate concentration in the former (almost certainly in the form of a HNO_3 component).

Trace elements (Figure 5) appear to reflect the local geologic/mineralogic environment, most notably with regard to the concentrations of Si, Na, Ca, Mg and Fe. The iron content in Area C waters is particularly elevated as, indeed, are most of the metals at this site with regard to those at the Liquid Disposal Area. The elevated soluble iron concentration is most certainly a function of the less oxidizing nature of the groundwater at C Area, which leads to a higher ratio of ferrous iron, the more soluble oxidation state, to ferric iron. In any case, the above groundwater data are not significantly different from those reported in Champ et al. (1985) for the Chemical and Reactor Pits suggesting that, despite disposal practices, which varied both temporally and in content, these groundwaters are apparently quite stable in terms of their geochemical make-up.

Figures 6 and 7 summarize the preliminary results from the radiochemistry/ gamma spectrometry performed on the prefilters, ion-exchange resins and oxide powders. Isotopes of cobalt, ruthenium, antimony and plutonium are present in waters downgradient from the Reactor and Chemical Pits, while only cobalt could be accurately quantified near the C Area. It is readily apparent that anionic species predominate in each case, most often followed by nonionic, cationic and particulate species in order of decreasing concentrations (the only exceptions being lower amounts of nonionic ^{106}Ru at PLS-38 and nonionic ^{60}Co at C-221, and plutonium at Area C). It is suspected that the negatively-charged species are primarily (a) organic macromolecules of natural humic and fulvic acids originating from the decomposition in soils of plant and animal residues (which contain numerous deprotonated alcoholic, phenolic and carboxylic functional groups that effectively scavenge metal cations), and (b) anthropogenic organic chelating agents (such as ethylenediamine tetraacetic acid, EDTA), a number of which were disposed of within the Chemical Pit. Theoretically, such anionic organo-radionuclides would be expected to migrate essentially indefinitely in the subsurface (if sufficiently stable) because of the paucity of attractive forces within stationary aquifer media, i.e., the nature of soil mineral surfaces also tend to generate negative charges (although edge planes in phyllosilicates may be locally positive), thereby repelling anionic species that may be brought into proximity by the aqueous phase and assuring their continued transport.

Other potential forms of these migrating radionuclide-bearing anions may include inorganic colloidal materials, which are mineralogically equivalent to the surrounding soils (i.e., with negative surface charges favorable for the retention of radionuclides), as well as pure inorganic radio-complexes comprised of common aquo-anion ligands (sulfato-, chloro-, hydroxo-, etc., or combinations, thereof). Stable forms of these species would behave in a fashion analogous to that described above. On the other hand, the nature of the cationic species are harder to predict since, by virtue of their overall charge, the aquifer medium would be expected to have retarded their migration and precluded their presence downgradient from the source. Uncertainty exists at this time as to whether these cations are "original" species or were generated as a result of some denaturation phenomena upon passage through the initial cation exchange bed, e.g. an anionic species may enter the cation exchange resin and get stripped of its positively-charged radionuclide (due to the greater affinity of the resin for the metal in question) while the original "vehicle" is subsequently taken up by the anion bed, thereby giving the false impression that the radionuclide itself actually began as a cationic species.

Clearly, additional methodologies are needed in order to further elucidate the actual form of these migrating species, although the initial resin-based studies have afforded invaluable heuristic information. Figure 8 offers some insight into a potential means of accomplishing this task. This diagram appears to suggest that particle size fractionation, at least in the larger fractions, may serve to segregate individual species (although not always in an obvious fashion). For example, one might expect in a natural setting that a majority of the microparticulate/colloidal radionuclide species would reside in the smallest fraction and the least amount in the largest fraction, analogous to the case of particulate ^{106}Ru (and, perhaps, ^{60}Co) at ES-16, since the smaller fraction would exhibit a larger specific surface area and, consequently, a higher radionuclide retention per unit mass.[a] Cobalt-60 at the Reactor Pit, conversely, exists in all three size fractions in subequal amounts, indicating some other phenomena may also be contributing to its overall behavior. If such size and, more importantly, speciation diversity exists in the smaller submicron range, then ultrafiltration would seem an appropriate means of separating individual migrating species into "purer" states for further detailed study.

FUTURE WORK

An Amicon (model DC10L) hollow-fiber ultrafiltration system has been obtained for the next phase of this study, and will be used with four separate size-cutoff fiber cartridges in an attempt to fractionate various migrating radionuclide species drawn from CRL's Chemical Pit plume. This methodology was chosen over stirred-cell membrane ultrafiltration because of its ability to process large volumes of groundwater in a relatively short period of time, and to minimize the tendency toward concentration polarization and surface adsorption processes at the membrane/solution boundary (commonly associated with the stirred-cell technique) as a result of the accompanying intra-fiber shear forces.

Sampled groundwater (approximately 1000 L total) will be added continuously to the system reservoir (see Figure 9a) and pumped through a parallel set of two 100,000 molecular weight (MW) cutoff hollow-fiber filter cartridges, thereby retaining and concentrating all species exceeding about 10 nm or larger, while directing the filtrate to a nearby reservoir. After the total retentate volume drops below 20 L, slightly acidic deionized water will be added to the system reservoir while continuing the recirculation (Figure 9b) in order to purify the retentate and flush it of any remaining salts. Resulting filtrate(s) will be processed as above through 30,000 MW (approx. 5 nm), 10,000 MW (approx. 3 nm) and 3,000 MW (approx. 1 nm) cutoff filters to generate four individual size fractions, which will be transported to PNL (or other laboratories) in light-tight, chilled containers for characterization.

The possibility exists that radionuclide speciation will be somewhat modified during the concentration and/or diafiltration modes because of the rather significant changes occurring within the solution environment (e.g., individual species will be forced into nearer proximity with each other, and counter ions will be excluded, thereby potentially disrupting chemical equilibria). Intermittent sampling of the retentate solution during the above stages may help to identify the effects of such processes, if they occur. Nonetheless, some form of sample reduction is necessary when studying species in such low natural concentrations, and the methodology described above is intended to minimize such perturbations and allow the subsequent characterization of the migratory vehicles, which have led to the facilitated transport of radionuclides at this site. These results will then serve as input to various computer models for testing performance assessment hypotheses at this and other complementary facilities.

---

a. Indeed, a great deal of recent and projected research has targeted a variety of organic (e.g., humic and fulvic macromolecules) and inorganic microparticulate/colloidal material which apparently act as vehicles for the facilitated transport of radionuclides and other contaminants of interest, e.g., Wobber (1991), Williams et al. (1991), Warwick et al. (1991), Lieser et al. (1990, 1986), McCarthy and Zachara (1989), McCarthy (1988), Ramsay (1988), Choppin (1988), Jensen and Jensen (1988) and Boggs et al. (1985).

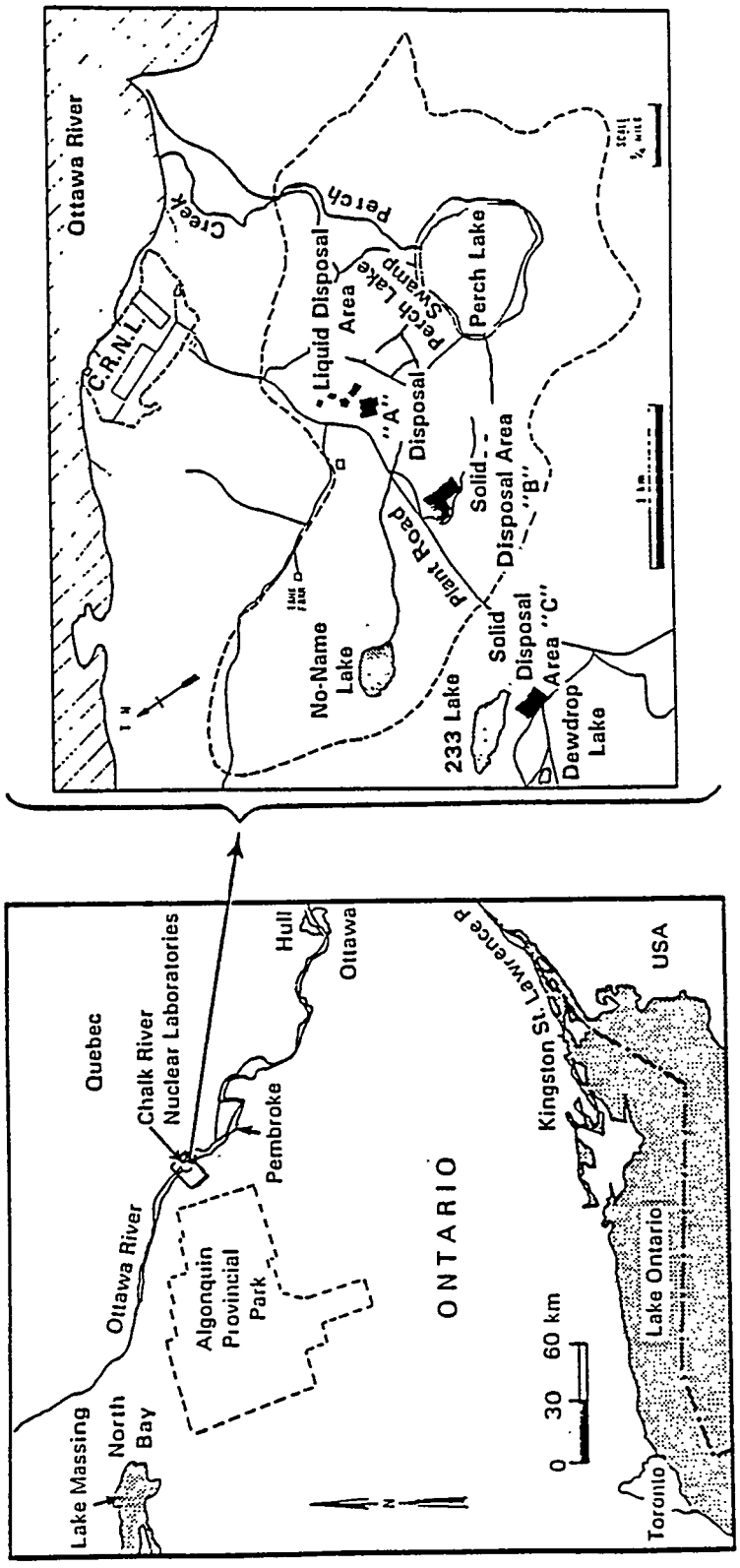


Figure 1. Location of the Chalk River Laboratories and its Liquid and Solid Waste Disposal Areas. The dashed line indicates the limits of the Perch Lake drainage basin.

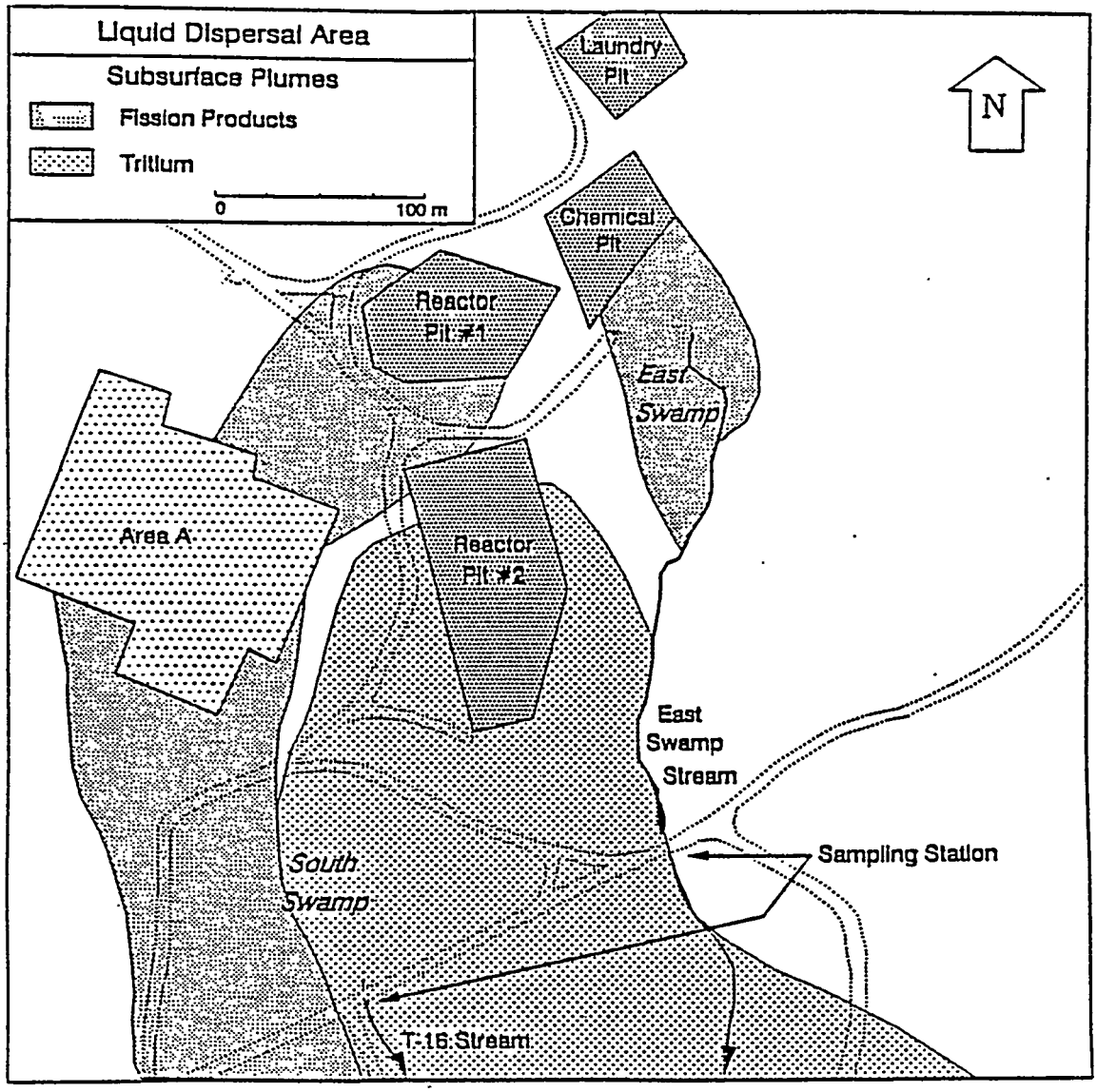


Figure 2. Map of the CRL Liquid Waste Disposal Area, outlining the locations of subsurface contaminant plumes.

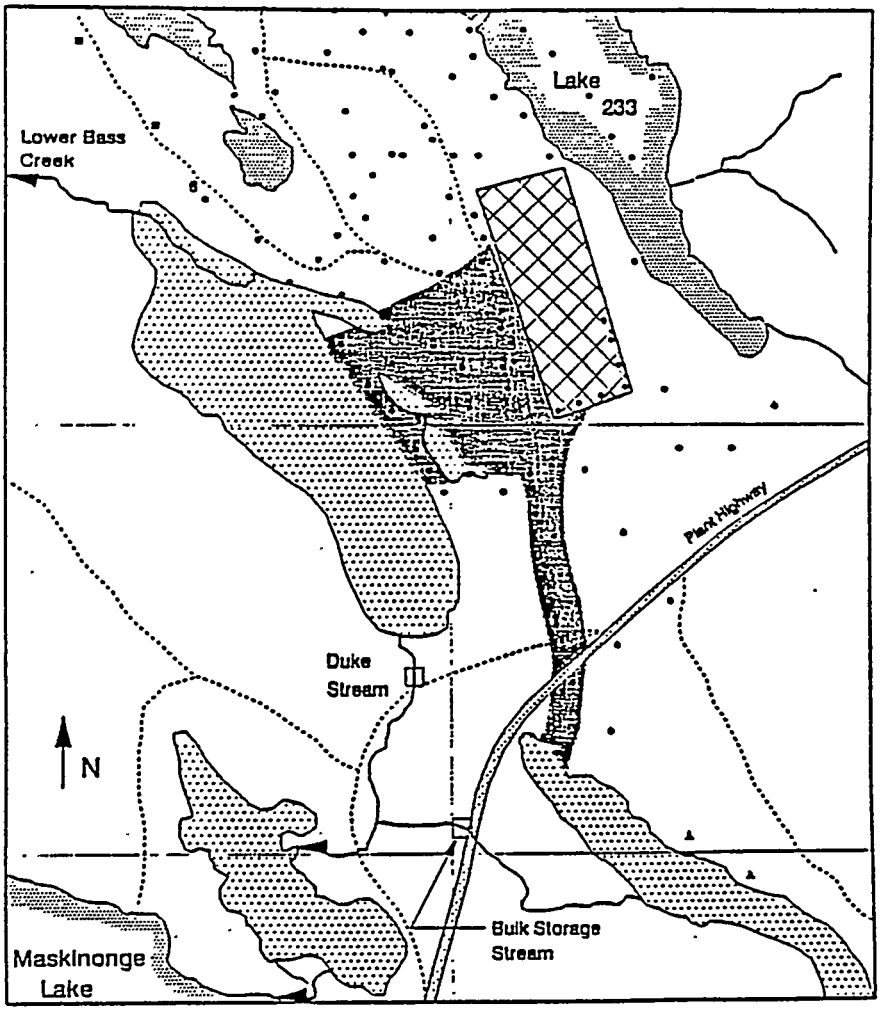


Figure 3. Map showing the extent of aquifer contamination by tritium at CRL's Waste Disposal Area C.

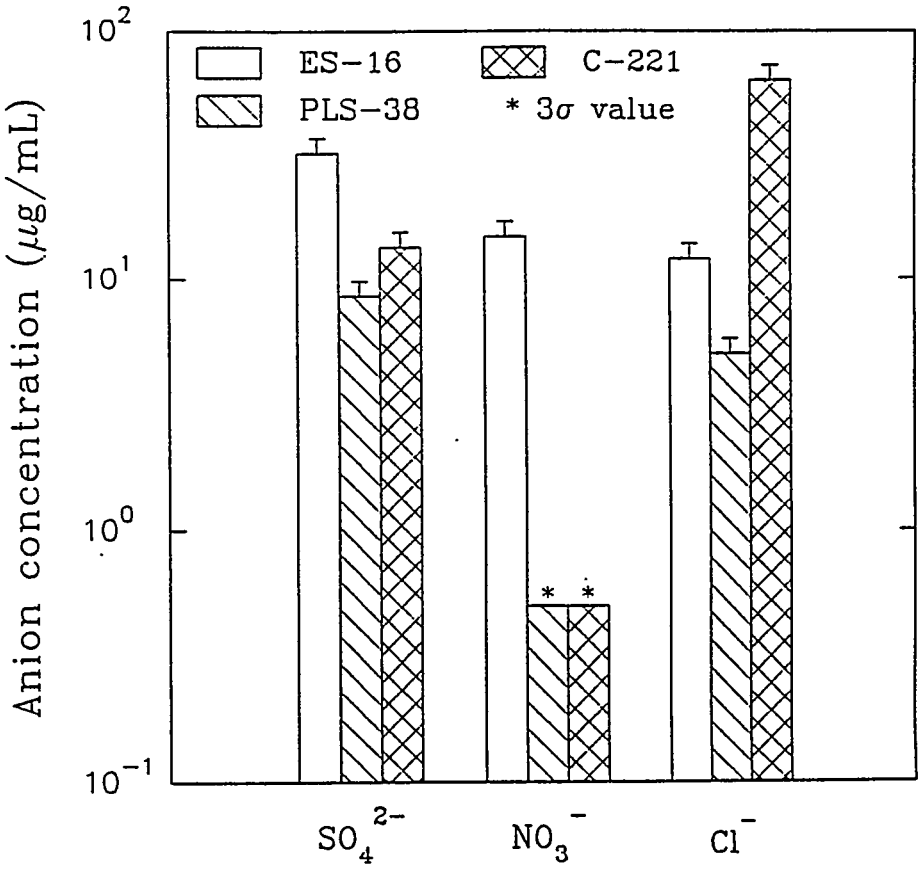


Figure 4. Anion results via ion chromatography.

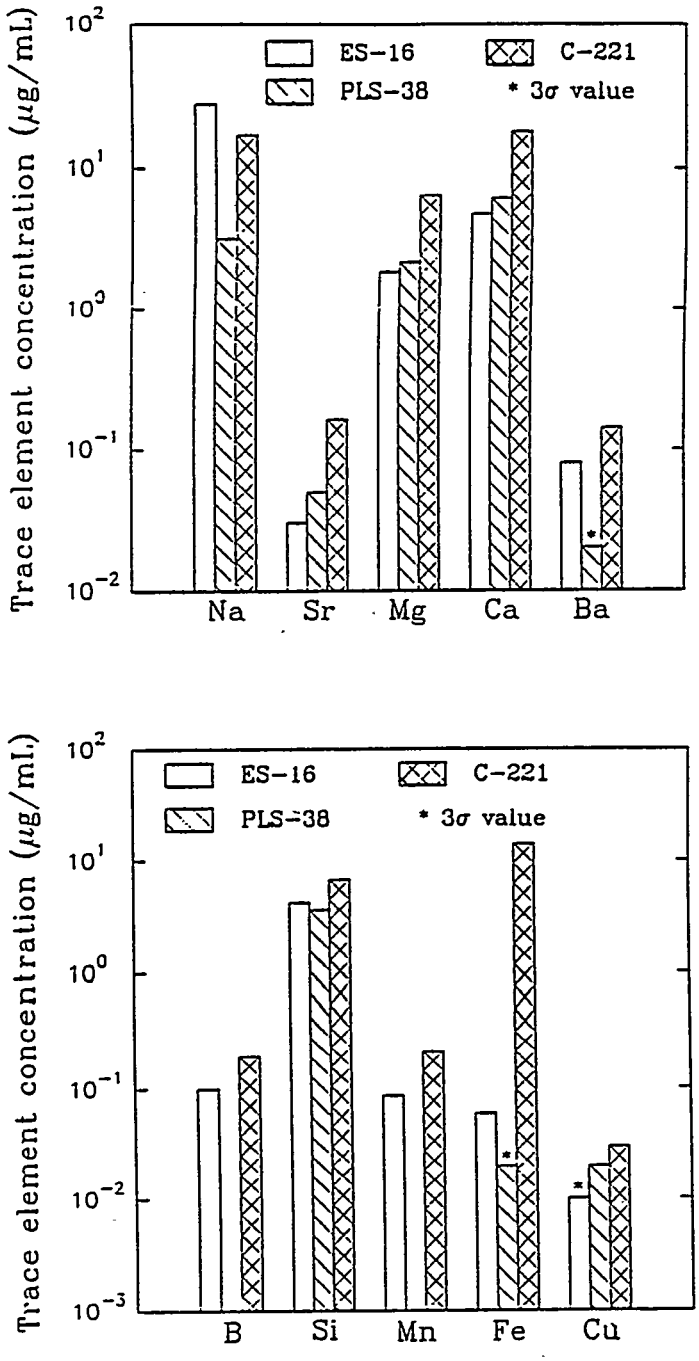


Figure 5. Trace element results via inductively coupled plasma atomic emission spectroscopy.

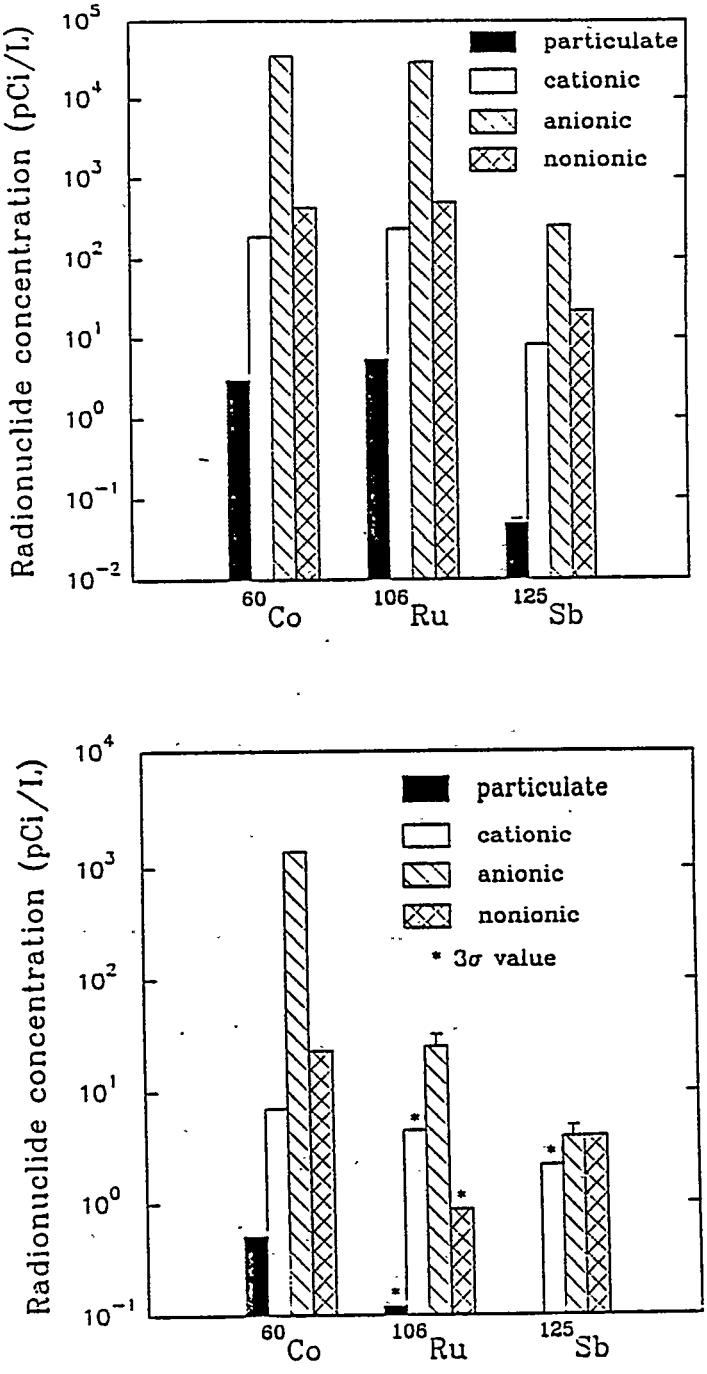


Figure 6. Gamma spectrometry results from CRL's Chemical Pit (ES-16, top) and Reactor Pit (PLS-38, bottom).

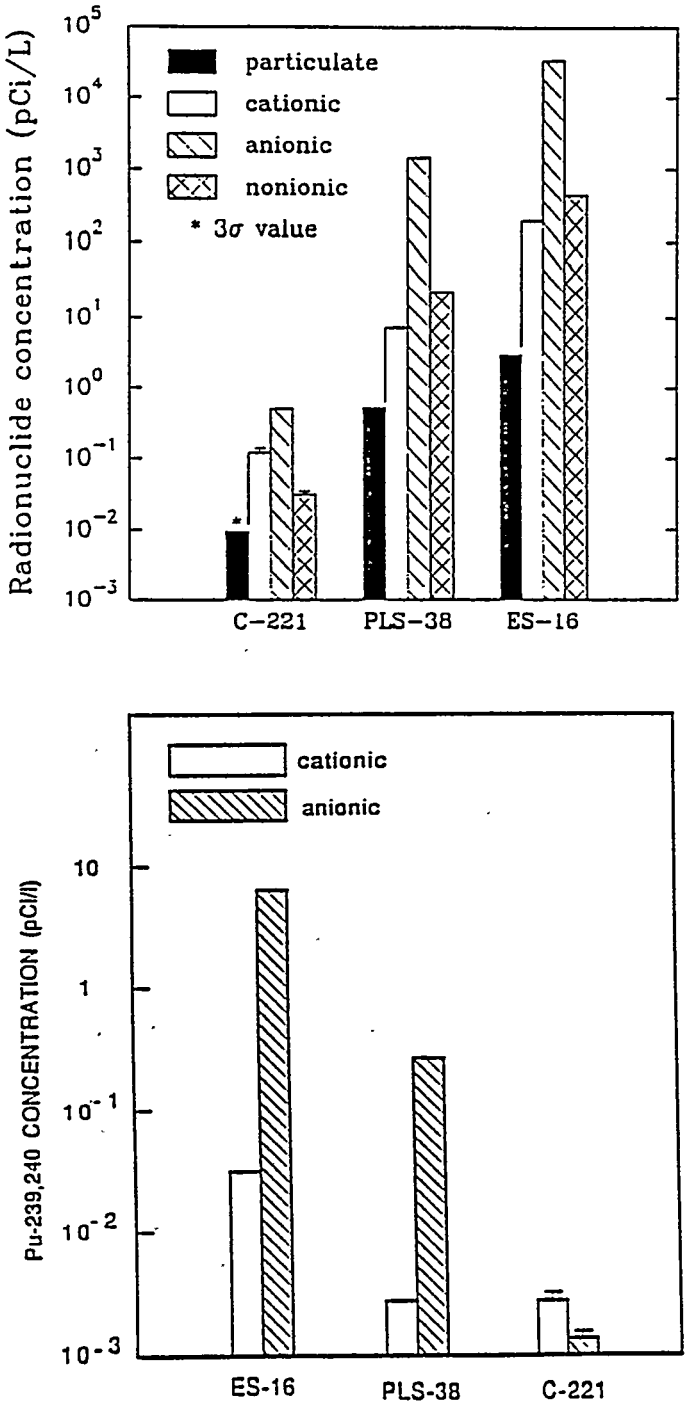


Figure 7. Gamma spectrometry results from CRL's Solid and Liquid Waste Disposal Areas, including Pu concentrations via radiochemistry (bottom).

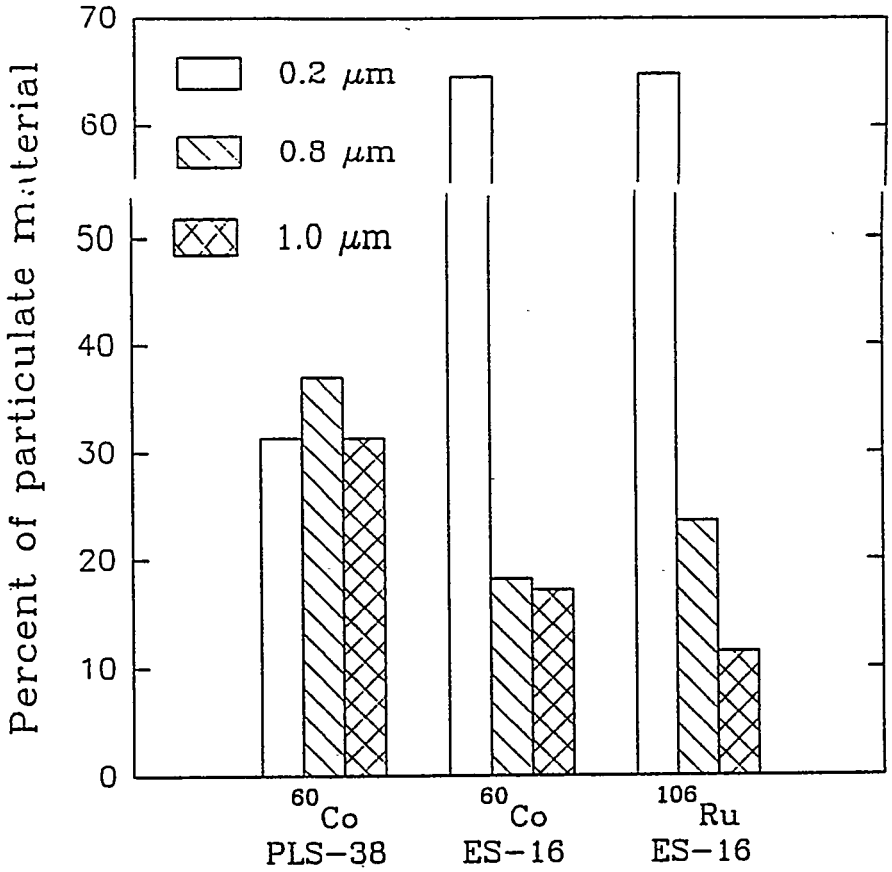


Figure 8. Particulate size fractionation results from the CRL Liquid Waste Disposal Area.

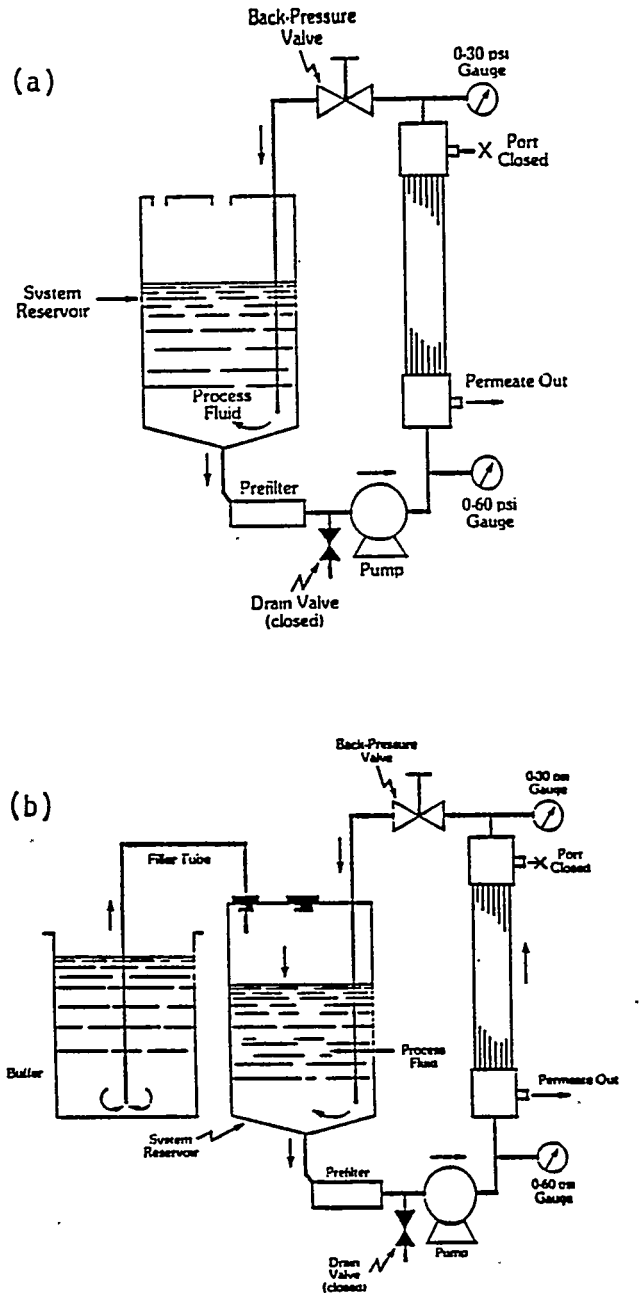


Figure 9. Schematic diagrams of the Amicon DC10L hollow-fiber ultrafiltration system showing the concentration (a) and diafiltration (b) modes.

REFERENCES

Boggs, S., D. Livermore and M. G. Seitz, 1985, "Humic Substances in Natural Waters and their Complexation with Trace Metals and Radionuclides: A Review," ANL-84-78, Argonne National Laboratory, Argonne, Illinois.

Bondietti, E. A. 1982, "Mobile Species of Pu, Am, Cm, Np and Tc in the Environment," In *Environmental Migration of Long-Lived Radionuclides*, IAEA-SM-257/42, International Atomic Energy Agency, Vienna.

Champ, D. R., J. L. Young, D. E. Robertson, and K. H. Abel, 1985, "Chemical Speciation of Long-Lived Radionuclides in a Shallow Groundwater Flow System," *Water Poll. Res. J. Canada* 19(2).

Choppin, G. R. 1988, "Humics and Radionuclide Migration," *Radiochim. Acta* 44/45:23-28.

Florence, T. M. 1982, "The Speciation of Trace Elements in Waters," *Talanta* 29:345-364.

Garrels, R. M. and C. L. Christ, 1965, *Solutions, Minerals and Equilibria*, p.135. Harper & Row, New York.

Jackson, R. E. and K. J. Inch, 1980, "Hydrogeochemical Processes affecting the Migration of Radionuclides in a Fluvial Sand Aquifer at the Chalk River Nuclear Laboratories," NHRI Paper No. 7, Scientific Series No. 104, National Hydrology Research Institute, Inland Waters Directorate, Ottawa, Ontario.

Jensen, B. S. and H. Jensen, 1988, "Complex Formation of Radionuclides with Organic Ligands Commonly Found in Ground Water," *Radiochim. Acta* 44/45:45-49.

Killey, R. W. D. and J. H. Munch, 1984, "Subsurface Contaminant Transport from the Liquid Disposal Area, CRNL: (1) Hydrogeology and Tritium Contamination near the Chemical Pit," Atomic Energy of Canada Limited, Report AECL-7691, 105pp.

Killey, R. W. D., J. O. McHugh, D. R. Champ, E. L. Cooper, and J. L. Young, 1984, "Subsurface Cobalt-60 Migration from a Low-Level Waste Disposal Site," *Environ. Sci. Technol.* 18:148-157.

Lieser, K. H., A. Ament, R. Hill, R. N. Singh, U. Stingl, and B. Thybusch, 1990, "Colloids in Groundwater and Their Influence on Migration of Trace Elements and Radionuclides," *Radiochim. Acta* 49:83-100.

Lieser, K. H., B. Gleitsmann, S. Peschke and T. H. Steinkopff, 1986, "Colloid Formation and Sorption of Radionuclides in Natural Systems," *Radiochim. Acta* 40:39-47.

McCarthy, J. F. 1988, "Role of Colloidal Particles in the Subsurface Transport of Contaminants," DOE/ER-0384, U.S. Department of Energy, Washington, D.C.

McCarthy, J. F. and J. M. Zachara, 1989, "Subsurface Transport of Contaminants," *Environ. Sci. Technol.* 23:496-502.

Olsen, C. R., P. D. Lowry, S. Y. Lee, I. L. Larsen, and N. H. Cutshall, 1986, "Geochemical and Environmental Processes Affecting Radionuclide Migration from a Formerly Used Seepage Trench," *Geochim. Cosmochim. Acta* 50:593-607.

Petit, J. C. 1990, "Migration of Radionuclides in the Geosphere: What can we learn from Natural Analogues?" *Radiochim. Acta* 51:181-188.

Rai, D. and R. J. Serne, 1978, "Solid Phases and Solution Species of Different Elements in Geologic Environments," PNL-2651, Pacific Northwest Laboratory, Richland, WA.

Ramsay, J. D. F. 1988, "The Role of Colloids in the Release of Radionuclides from Nuclear Waste," *Radiochim. Acta* 44/45:165-170.

Riley, R. G. and J. M. Zachara, 1992, "Chemical Contaminants on DOE Lands and Selection of Contaminant Mixtures for Subsurface Science Research," DOE/ER-0547T, U.S. Department of Energy, Washington, D.C.

Robertson, D. E. 1986, "Evaluation of a Large-Volume Water Sampling Technique for Determining the Chemical Speciation of Radionuclides in Groundwater," In *Speciation of Fission and Activation Products in the Environment*, Elsevier, London & New York.

Robertson, D. E. and R. W. Perkins, 1975, "Radioisotope Ratios in Characterizing the Movement of Different Physical and Chemical Species through Natural Soils," In *Isotope Ratios as Pollutant Source and Behavior Indicators*, International Atomic Energy Agency, Vienna.

Robertson, D. E., M. P. Bergeron, D. Holford, K. H. Abel, C. W. Thomas, D. A. Myers, D. R. Champ, R. W. D. Killey, G. L. Moltyaner, J. L. Young and T. Ohnuki, 1989, "Demonstration of Performance Modeling of a Low-Level Waste Shallow-Land Burial Site," NUREG/CR-4879 vol.2, U.S. Nuclear Regulatory Commission, Washington, D.C.

Warwick, P., A. Hall, P. Shaw, J. J. W. Higgo, G. M. Williams, B. Smith, D. Haigh, and D. Noy, 1991, "The Influence of Organics in Field Migration Experiments (Part 2)," *Radiochim. Acta* 52/53:465-471.

Williams, G. M., J. J. W. Higgo, M. A. Sen, W. E. Falck, D. J. Noy, G. P. Wealthall, and P. Warwick, 1991, "The Influence of Organics in Field Migration Experiments (Part 1)," *Radiochim. Acta* 52/53:457-463.

Wobber, F. J., 1991, "Subsurface Science Program: Program Overview and Research Abstracts," DOE ER-0432, U.S. Department of Energy, Washington, D.C.

Lysimeter Data as Input to Performance Assessment Source Term Codes

John W. McConnell
Robert D. Rogers
Idaho National Engineering Laboratory[a]
P.O. Box 1625
Idaho Falls, ID 83415-1406

Terry Sullivan
Brookhaven National Laboratory
Upton, NY 11973

ABSTRACT

The Field Lysimeter Investigation: Low-Level Waste Data Base Development Program is obtaining information on the performance of radioactive waste in a disposal environment. Waste forms fabricated using ion-exchange resins from EPICOR-II[b] prefilters employed in the cleanup of the Three Mile Island (TMI) Nuclear Power Station are being tested to develop a low-level waste data base and to obtain information on survivability of waste forms in a disposal environment. In this paper, radionuclide releases from waste forms in the first seven years of sampling are presented and discussed. Application of lysimeter data to be used in performance assessment source term models is presented. Initial results from use of data in two models are discussed.

INTRODUCTION

Concern over the practices associated with the disposal of low-level radioactive waste has resulted in a very real need to obtain accurate data on the long-term field performance of these wastes. The U.S. Nuclear Regulatory Commission has enacted regulations that link LLW acceptance criteria to the long-term satisfactory performance of the waste. Under 10 CFR 61, "Licensing Requirements for Land Disposal of Radioactive Wastes," commercially generated LLW is classified as Class A, B, C, or Greater Than Class C. Wastes classified as either Class B or Class C must be stabilized for a minimum of 300 years.

To verify the 300-year stability of waste forms, the NRC originally specified the use of short-term standardized tests with the hope that such tests in principle could provide information relevant to near-surface disposal performance objectives. Those tests, which were initially published in the NRC Branch "Technical Position on Waste Form"[2] and have been revised in Revision 1 of the Technical Position,[3] are currently undergoing critical review to determine their applicability to the 300-year stability requirements.

A central requirement in LLW disposal site design is the need for a detailed understanding of the waste form as the radionuclide source of the site and the effect of that source on site performance. A major requirement in any site licensing is the site performance assessment. The performance assessment is used to predict whether or not a proposed disposal site will meet the performance objectives. Correct assumptions regarding the performance of the buried waste form have a direct bearing on the outcome of the performance

---

a. Work supported by the U.S. Department of Energy, Office of Environmental Restoration and Waste Management, under DOE Contract No. DE-AC07-76ID01570.

b. Mention of specific products or manufacturers in this document implies neither endorsement or preference nor disapproval by the U.S. Government, any of its agencies, or EG&G Idaho of the use of a specific product for any purpose.

assessment. Conservative assumptions of radionuclide release rates will result in over-design of containment, while under estimating the release of especially mobile constituents will over-predict containment performance.

A useful experimental device that will provide hard data for determining waste form stability is the lysimeter. Lysimeters are ideal systems for obtaining actual field test data because, when properly designed and operated, they can be used to isolate soil/waste systems under actual environmental conditions. Such conditions cannot be duplicated by standard laboratory testing. Lysimeters lend themselves to instrumentation used for acquiring environmentally related data and for collecting and storing migrating precipitation and mobilized radionuclides.

The Field Lysimeter Investigation: Low-Level Waste Data Base Development Program, funded by the NRC, is obtaining information on the performance of radioactive waste in a disposal environment, and the requirements of 10 CFR 61 are being investigated. Waste forms are being field-tested to develop a LLW data base and to obtain information on survivability of waste forms in a disposal environment.

The purpose of this paper is to present the experimental results of two instrumented, operational lysimeter arrays over seven years of operation. This study was developed to field-test waste forms composed of solidified ion-exchange resin materials from EPICOR-II prefilters used in the cleanup of the TMI Nuclear Power Station Unit 2.[4] Waste used in the study is significant because it has a high loading of radionuclides and is comprised of ion-exchange media of the type used by the nuclear industry.

METHODS AND MATERIALS

Wastes used in the experiment were taken from EPICOR-II prefilters used to decontaminate water at TMI-2 and include a mixture of synthetic organic ion-exchange resins from prefilter PF-7 and a mixture of organic-exchange resins and an inorganic zeolite from prefilter PF-24. Solidification agents employed to produce the 4.8 × 7.6-cm cylindrical waste forms (Figure 1) used in the study were Portland type I-II cement and DOW vinyl ester-styrene (VES). Seven of the waste forms were stacked end-to-end and inserted into each lysimeter to provide a 1-L volume. Table 1 lists waste form description by lysimeter number. The PF-7 waste contained 89% of the radionuclides as Cs-137, while PF-24 contained 94% Cs-137. The PF-7 waste also contained 5% Sr-90, and PF-24 contained 1% Sr-90. There were also significant amounts of Cs-134 and trace amounts of Co-60 and Sb-125 found in those wastes. Details on waste-form formulations are given in Reference 5.

Ten lysimeters were used in this study five at Oak Ridge National Laboratory (ORNL) in Tennessee and five at Argonne National Laboratory-East (ANL-E) in Illinois. The lysimeters were designed to be self-contained units that will be disposed at the termination of the study. Each lysimeter is a 0.91 × 3.12-m right-circular cylinder divided into an upper compartment that contains fill material, waste forms, and instrumentation, and an empty lower compartment for collecting leachate (Figure 2). Four lysimeters at each site are filled with soil; a fifth, used as a control, is filled with inert silica oxide sand. The lysimeters at ANL-E contain soil indigenous to the site, while the ORNL lysimeters contain soil taken from Savannah River Laboratory in South Carolina. The soil columns are 0.91 m in diameter 2.21 m deep.

Instrumentation in each lysimeter includes moisture cup soil-water samplers and soil moisture/ temperature probes. The probes are connected to an onsite data acquisition system (DAS), which also collects data from a field meteorological station located at each site. Fine porous cup soil-water samplers and a lysimeter leachate collection compartment comprise the water sampling components of each lysimeter as seen in Figure 2. Lysimeter design, installation, instrumentation, operation, and data acquisition are provided in Reference 6.

Monitoring of the lysimeters at ANL-E and ORNL began with the collection of liquid samples in September 1985 (three months from the time of placement) and has continued with sample collection on approximately a quarterly basis thereafter, except in FY-91, in which the winter sampling was skipped. Samples of liquids were taken from locations near the waste forms and from the leachate collectors to track the

migration of radionuclides. The water samples were analyzed for beta and gamma-producing nuclides. Each month, data stored on a cassette tape in the DAS were retrieved and translated into an IBM PC-compatible disk file. Soil moisture and temperature at three elevations in each lysimeter, along with a complete weather history, were recorded on a continuing basis by the DAS. Testing results are presented in References 7-12, as well as in this paper.

RESULTS AND DISCUSSION

Weather and Soil Data

Precipitation, air temperature, wind speed, and relative humidity are being recorded by the ANL-E and ORNL DAS during the life of the experiment. Figure 3 shows the cumulative precipitation for each site since the initiation of field work. Examples of the lysimeter soil temperature and moisture data recorded at ANL-E and ORNL can be found in References 7 through 12. Data recorded in FY-92 indicate that the lysimeter soil columns at both sites have remained moist during the last reporting period. The average soil moisture of ANL-E lysimeter soils was 54.7% of the soil moisture holding capacity; for ORNL, this value was 38.9%.

By using the cumulative rainfall data from each site since the time the lysimeters were placed in operation, it is possible to calculate the volume of water that has been received by the exposed lysimeter surfaces (6,489.5 cm^2). The cumulative volume of precipitation received by each ANL-E lysimeter was 3,886.1 L; at ORNL, this value was 5,790.7 L. It appears that the throughput is dependent on lysimeter fill material and on site conditions (e.g., the period of time that the soil surface was frozen and the amount of precipitation received as snow). The total volumes of precipitation that have moved through the lysimeters represent an average 2.35 pore volumes for the ANL-E soil lysimeters and 7.32 pore volumes for soil lysimeters at ORNL, while the control lysimeters at ANL-E and ORNL were 8.60 and 9.28 pore volumes, respectively.

Radionuclide Data

Four samplings from moisture cups and leachate collectors were taken at each site every 12 months. Figures 4 through 10 show the cumulative amounts of nuclides as determined in water samples obtained from number 3 moisture cups (22.4 cm below the waste form in the soil column) and leachate collectors (51.2 cm below the waste form and soil column) for all sampling periods.

These data show that not all nuclides consistently appeared in the water obtained from the moisture cups or the leachate collectors. The nuclide that appeared with the most regularity at both sites was Sr-90. Consistent significant occurrences have been observed in all the number 3 cups at both ANL-E and ORNL. There are standout amounts of Sr-90 retrieved from moisture cup samples at both sites. Those include a cumulative total of 1,095,575 pCi from cup 3-3 at ANL-E (Figure 4) and 104,434 pCi from cup 1-3 at ORNL (Figure 5).

During the past 12 months, leachate collector water from the control lysimeters at each site contained amounts of Sr-90 at least an order of magnitude larger than releases from the soil lysimeters (Figures 6 and 7). This is comparable to the previous year's findings.[7-12] For leachates, intersite-comparable quantities of Sr-90 were found in ANL-E 1, 2, and 4 and ORNL 2, 3, and 4 (Table 2). For the ORNL lysimeters, the total amount of the nuclide released in leachate water was comparable to or greater than that in the cups. These data follow a trend seen over the past 18 months and make it appear that a pulse of Sr-90 could be moving through the soil columns of the ORNL lysimeters. The percent of total Sr-90 being measured in the leachate collector water and number 3 cups is somewhat inconsistent between the two sites (Table 2). Perhaps this represents a difference in how the environment at the two sites affects the movement of Sr-90 being released from the waste forms. This difference is also seen when the percent of total Sr-90 found in the leachate water from the two control lysimeters is examined. The percent passing through the ORNL control has increased to four times that of ANL-E (Table 2).

Gamma-producing nuclides have occurred with regularity at both sites. ANL-E cup 2-3, below a cement waste form containing large amounts of Cs-137, has received significant quantities of Cs-137 (Figure 8). Since June of 1987, Cs-137 has been appearing in ANL-E cup 5-3. The quantity of this nuclide abruptly increased in each of the sampling periods during the last three years (Figure 8).[12] There continues to be no sustained occurrence of Cs-137 in any ANL-E leachate collector water. Measurable amounts of Cs-137 began to occur in ORNL cup 5-3 during the May 1988 sampling and have continued in subsequent samplings for a total of 2,010 pCi (Figure 9). Also, Cs-137 has been detected consistently in water from the ORNL lysimeter leachate collectors (Figure 10). Breakthrough of Cs-137 into the ORNL-5 leachate collector occurred in November 1988 (Figure 9), and thus far, a total of 234,508 pCi have passed through the soil column of that lysimeter.

At ANL-E, recovery of Sr-90 in cup 3 and the leachate collectors indicates a uniformity of waste form performance. More Sr-90 was found in ANL-E cups 3-3 and 3-4 (VES waste forms) than in the other ANL-E cups, but the effect appears to be moderated by the distance traveled in soil from the waste form to the leachate collector. Movement of the nuclide into the leachate collector of ANL-E cup 5 is much greater than that of the other lysimeters and thus provides evidence of the moderating effect of soil. Greater quantities of Sr-90 are moving through the ORNL lysimeters than the ANL-E lysimeters. There appears to be no correlation between the type of waste form and the amount of nuclide recovered in the leachate collector. About 0.045% of the Sr-90 contained in ORNL-5 has now been recovered in leachate from that lysimeter. Recovery of Sr-90 in the ORNL cups is comparable for those lysimeters containing the cement waste forms and one of the two containing VES waste forms. These data together with those from ANL-E continue to indicate that cement and VES have comparable releases.

Use of Lysimeter Data for Performance Assessment Source Term Calculations

A past evaluation has shown that data obtained from the operation of the lysimeters does have a relationship with performance assessment code parameters.[10] The operational lysimeters provide continuous data from the near-field (that area comprised of the waste form and surrounding soil). These data relate directly to waste form stability. Information obtained from the data includes the mass balance of released constituents, the solubility of radionuclides in a site-specific geochemical system, as well as an indication of the retardation or dispersion of released constituents during transport to the far-field. Also, soil-pore water chemistry (radioactive and inorganic constituents), soil mineralogy, soil water/mineral mass ratio, net infiltration rate, soil profile moisture and temperature, porosity, and hydraulic conductivity are being or could be extracted from lysimeter output. Such data are invaluable as inputs into performance assessment and source term codes since they represent a field data set that contains complete information that characterizes environmental, hydrogeological, geochemical, and waste form effects.

MIXBATH/BLT

The first five years of collected lysimeter data were used as inputs for the model Mixbath,[13] which is a one-dimensional precursor or subroutine to the two-dimensional Breach, Leach, and Transport (BLT) code.[13] Use of Mixbath is intended to predict the release of nuclides from a waste form in a failed container surrounded by a porous medium containing a solute. The solute is treated as a well-stirred fluid (i.e., a mixing bath), and solute concentration is calculated using a mass balance that depends on the solute flow rate, the amount of partitioning between the porous medium (soil) and solute (leachant), the size of the mixing bath (a single volume), the radioactive decay rate, and the rate of nuclide release from the waste form. Modeling of the system is accomplished using a one-dimensional finite difference model. The distance of movement of radionuclides in the soil was taken as 51.2 cm to the leachate collector and 22.4 cm to moisture cup number 3.

Releases of Cs-137 and Sr-90 from the waste forms were modeled. The most appropriate release process was considered to be diffusion from a cylinder (the shape of the waste forms). The waste form diffusion coefficients were available from data in Reference 14. Calculations for the mass balance of the solute concentration required Darcy velocities (volumetric flow rate per area), which were estimated from lysimeter leachate collector analytical data.[11] Soil/water retardation coefficients (K_d) were estimated from previous published work.[15,16]

Figure 11 shows plots of predicted and measured Sr-90 cumulative activity releases versus time for ORNL 5. A Darcy velocity of 3.6 E-6 cm/s was used, with a K_d of 0 cm^3/g. Two predictions are shown using waste form diffusion coefficients of 4×10^{-10} cm^2/s and 5×10^{-11} cm^2/s. With the latter, the Mixbath prediction and measured values agree within one order of magnitude. Releases of this magnitude appear to be consistent with those measured during other work using these waste forms.[14]

The results as shown in Figure 11 indicate that sufficient cumulative activity data were present to show similarities between the predicted and measured curves. These plots appear to be typical of the predictions made about Sr-90 release from cement waste forms.

Data from a comparison of cumulative Cs-137 activity from ORNL-3 appear to give a reasonable prediction (see Figure 12). This demonstrates how the measured value of the diffusion coefficient and close approximations of the retardation coefficient (K_d) can significantly increase the accuracy of the prediction. This plot used a Darcy velocity of 3.12 E-6 cm/s, a K_d of 1 E+3, and a waste form diffusion coefficient of 3.3 E-14 cm^2/s. From these data and those from Sr-90, it appears that Mixbath performed adequately for the purposes of this preliminary performance assessment. It helped identify those areas in which additional data (soil K_d values and dispersivity) will be required in order to use the lysimeter data effectively in performance assessment modeling.

DUST

The Disposal Unit Source Term (DUST) code was used to model the release of the radionuclides Cs-137 and Sr-90 from the lysimeter waste forms. DUST is a one-dimensional code that can model release by a finite difference method or by a mixing cell cascade approach, and has the ability to simultaneously model three different types of release mechanisms: diffusion, dissolution, and surface rinse. The mixing cell model is limited in that it does not take diffusional release into consideration. Therefore, for these simulations, the finite difference model was selected because it is more flexible and capable of handling a variety of different parameters. A further description of the models in the code is given in Reference 17. DUST is not yet available, but details may be obtained from T. M. Sullivan, Brookhaven National Laboratory.

The release of CS-137 and Sr-90 from Portland types I-II cements located in lysimeters 5 at ORNL and ANL-E were chosen because releases from other lysimeters were substantially lower and the data were not sufficient to model. At ANL, lysimeter 5 contained resin waste type I solidified in cement; at ORNL, lysimeter 5 contained resin waste type II, which was also solidified in Portland type I-II cement (see Table 2). Diffusional release is believed to be the controlling mechanism for a cement-solidified waste. The waste form diffusion coefficients for Portland type I-II cements were presented in Reference 14. Measured values were 9.6 E-10 cm^2/s for Sr-90 in Portland type I-II cements and 5 E-11 cm^2/s for Cs-137 in Portland type I-II cements. The Darcy velocities ranged from 2.59 E-6 cm/s at ANL-E to 3.6 E-6 cm/s at ORNL (Reference 14). The soil bulk density values were 1.55 g/cm^3 at ANL-E and 1.60 g/cm^3 at ORNL (Reference 6). Moisture content values were calculated using the effective soil porosity and the fraction of saturation values found in Reference 9. In lysimeter 5 at both sites, the moisture content was calculated as 21%. The distribution coefficients have not been measured for Sr-90 or Cs-137; therefore, they were estimated by fitting the model predictions to the data. The cumulative leachate activity collected from the lysimeters over the first six years of operation of the experiment, which was used to make comparisons to the DUST code predictions, represented less than 0.03% of the total inventory of Sr-90 in lysimeter 5 at ORNL and ANL-E. At ORNL, the collected amount represented less than 1.5 E-5% of the Cs-137 inventory in lysimeter 5 (Table 2).

Concentrations and flux traces were matched to moisture cup 3 and the lysimeter leachate collector. The concentration and flux traces were taken at points 23 and 51 cm below the waste forms. In this report, the cumulative leachate activity collected 51 cm beneath the waste form is used as the performance measure. Initial amounts of Cs-137 and Sr-90 varied at ORNL and ANL-E because the control lysimeters contained different resin types. In ORNL lysimeter 5, the type I waste form had a total initial inventory of 3.29 E-3 Ci of Sr-90 and 1.432 Ci of Cs-137 (Reference 6). The type II waste form at ANL-E had total initial inventory of 1.84E-2 Ci of Sr-90 (Reference 6). Cesium-137 was not modeled at ANL-E for lack of sufficient releases.

The cumulative activity retrieved from the lysimeters is less than 0.03% in comparison to the total inventory for Sr-90 and less than 1.5 E-5% for Cs-137 (Table 2). Therefore, either the waste form release rates are much lower than anticipated or transport processes are controlling release through the soil column. At that level, it is possible that random fluctuations (noise) are being seen and release patterns may not develop for several more years.

The domain of the model was extended to 52 cm below the waste form. This ensures that boundary conditions (BCs) will not significantly affect the predicted concentrations. Therefore, the results in Figures 13 and 14 are obtained using a bottom BC of zero dispersive flux. A concentration trace continued to be taken at the location of the filter fabric, which is 51 cm below the waste form.

As shown in Figure 13, the actual data for Sr-90 from ORNL lysimeter 5 are compared with the DUST code predictions of releases using zero dispersive flux BC, K_d = 24, and dispersivity = 8.5. Also shown are predicted releases using zero concentration flux BC, K_d = 10, and dispersivity = 0.6. The measured waste form diffusion coefficient of 9.6 E-10 cm^2/s was used. The predicted releases of zero dispersive flux BC show a very good fit to the actual data. The DUST curve that is generated with the zero dispersive flux BC is rising at a much more shallow slope than the zero concentration BC curve, indicating lower predicted releases over an extended time frame.

Figure 14 shows the actual data for Sr-90 at ANL-E lysimeter 5, which covers a period of six years. In addition, the DUST predictions of 20 years of cumulative leachate activity is plotted in two cases, using dispersive flux BCs. The measured waste form diffusion coefficient of 9.6 E-10 cm^2/s was used. Case 1 has a dispersivity of 0.6 and a K_d of 24.5. Case 2 has a dispersivity of 8.5 and a K_d of 10. Case 2 releases less activity over six years than case 1; however, at 20 years, the amount of activity released by case 2 is an order of magnitude higher than the amount in case 1. Over 20 years, case 2 will have released 33% of the total Sr-90 inventory, whereas case 1 will have released 3.3% of the total Sr-90 inventory. Case 1, also, is a better fit to the actual data at six years, indicating a predicted higher dispersivity and K_d than previously thought.

CONCLUSIONS

A greater recovery of Sr-90 has occurred in terms of quantity and percentage of inventory than for other nuclides. Next in abundance is Cs-137. Compared to Sr-90, the occurrence of Cs-137 appears insignificant. Cesium-137 continues to occur in the moisture cups at ORNL and has been found in moisture cup 2 at ANL-E (below 22.4 cm of soil) but not in any leachate waters (through 51.2 cm of soil).

On a cumulative basis, more Sr-90 is being removed from the ORNL lysimeters. During the past 48 months, Sr-90 continues to be found in higher concentrations in leachate water from the control lysimeters at both sites, with more found at ORNL. It seems that the limiting step in receiving Sr-90 in the leachate is not release of the nuclide from the waste forms (because Sr-90 is found in number 3 cups), but rather it is the soil characteristics (including soil and quantity of soil water) that limit movement.

On two occasions, lysimeter data have been reviewed to determine the possibility of using these data to initiate limited performance assessment modeling. The results from a preliminary evaluation that was carried out last year using Mixbath indicated that in lysimeters with experimentally determined diffusion coefficients, where high enough leachate concentrations of nuclides existed to compare predicted and experimental results, a computer code could be tested. This year, further refinements made it possible to model some of the lysimeter Sr-90 release data using the DUST computer code. It is strongly recommended that the lysimeter experiments be continued. Rapidly increasing radionuclide release shows that data from future years could be used to obtain a reliable, quantitative understanding of nuclide movement.

Data provided by these lysimeter experiments have been shown to be useful in computing many parameters used as input to performance assessment codes.[10] Also, to limit model/prediction uncertainties, several parameters need to be measured in the laboratory. The most important include the site-specific soil retardation coefficients and dispersivity. The utility of this reliable source of data will be demonstrated through

continued operation of the lysimeters. NRC planning recommends that these lysimeters be augmented by experiments containing solidified decontamination wastes and activated metals from commercial plants. The U.S. Department of Energy at the Idaho National Engineering Laboratory is investigating the use of lysimeter systems based on the design presented here. These systems will provide data for calculating parameters to be used in performance assessments of LLW disposal sites and for verification of the codes used in those performance assessments in accordance with DOE orders governing the disposal of LLW.

REFERENCES

1. Code of Federal Regulations, 10 CFR 61, "Licensing Requirements for Land Disposal of Radioactive Wastes," Office of the Federal Register, 1982.

2. U.S. Nuclear Regulatory Commission, "Technical Position on Waste Form," 1983.

3. U.S. Nuclear Regulatory Commission, "Technical Position on Waste Form," Revision 1, 1991.

4. J. W. Mcconnell, Jr., *EPICOR-II Resin/Liner Research Plan*, EGG-TMI-6198, Idaho National Engineering Laboratory, 1983.

5. R. M. Neilson and J. W. Mcconnell, Jr., *Solidification of EPICOR-II Resin Waste Forms*, GEND-INF-055, Idaho National Engineering Laboratory, 1984.

6. R. D. Rogers, J. W. Mcconnell, Jr., E. C. Davis, and M. W. Findley, *Field Testing of Waste Forms Containing EPICOR-II Ion Exchange Resins Using Lysimeter*, NUREG/CR-4498, Idaho National Engineering Laboratory, 1986.

7. R. D. Rogers, J. W. Mcconnell, Jr., M. W. Findley, and E. C. Davis, *Lysimeter Data from EPICOR-II Waste Forms--Fiscal Year 1986*, EGG-TMI-7417, Idaho National Engineering Laboratory, 1986.

8. R. D. Rogers, J. W. Mcconnell, Jr., M. W. Findley, and E. C. Davis, *Lysimeter Data from EPICOR-II Waste Forms--Fiscal Year 1987*, EGG-TMI-8004, Idaho National Engineering Laboratory, 1988.

9. R. D. Rogers, J. W. Mcconnell, Jr., E. C. Davis, and J. D. Jastrow, *Annual Report of the TMI-2 EPICOR-II Resin/Liner Investigation: Low-Level Waste Data Base Development Program for Fiscal Year 1988*, NUREG/CR-5229, Vol. 1, Idaho National Engineering Laboratory, 1988.

10. J. W. Mcconnell, Jr., R. D. Rogers, E. C. Davis, and J. D. Jastrow, *Annual Report of the TMI-2 EPICOR-II Resin/Liner Investigation: Low-Level Waste Data Base Development Program for Fiscal Year 1989*, NUREG/CR-5229, Vol. 2, Idaho National Engineering Laboratory, 1990.

11. J. W. Mcconnell, Jr., R. D. Rogers, R. D. Johnson, J. D. Jastrow, and D. S. Wickliff, *Annual Report of the TMI-2 EPICOR-II Resin Liner Investigation: Low-Level Waste Data Base Development Program for Fiscal Year 1990*, NUREG/CR 5229, Vol. 3, Idaho National Engineering Laboratory, 1990.

12. J. W. Mcconnell, Jr., R. D. Rogers, J. D. Jastrow, D. S. Wickliff, and R. R. Brey, *Annual Report of the TMI-2 EPICOR-II Resin Liner Investigation: Low-Level Waste Data Base Development Program for Fiscal Year 1991*, NUREG/CR 5229, Vol. 4, Idaho National Engineering Laboratory, 1991.

13. T. M. Sullivan and C. J. Suen, *Low-Level Waste Source Term Model Development and Testing*, NUREG/CR-5681, 1991.

14. R. M. Neilson, Jr. and J. W. Mcconnell, Jr., *EPICOR-II Resin Waste Form Testing*, NUREG/CR-4637, EGG-2457, 1986.

15. T. M. Sullivan and C. J. Suen, *Low-Level Waste Shallow Land Disposal Source Term Model: Data Input Guides*, NUREG/CR-5387, 1989.

16. D. Isherwood, *Geoscience Data Base Handbook for Modeling a Nuclear Waste Repository*, NUREG/CR-0912, Vol. 1, 1981.

17. T. M. Sullivan, *Selection of Models to Calculate the LLW Source Term*, NUREG/CR-5773, BNL-NUREG-52295, October 1991.

Table 1. Lysimeter waste-form composition.

Lysimeter Number	Fill Material	Waste Form Description	Waste Weight Percent
1	Soil	Cement with PF-7 waste	24
2	Soil	Cement with PF-24 waste	24
3	Soil	VES with PF-7 waste	61
4	Soil	VES with PF-24 waste	61
5 ANL-E	Silica oxide	Cement with PF-7 waste	24
5 ORNL	Silica oxide	Cement with PF-24 waste	24

Table 2. Comparison of total Sr-90 and Cs-137 inventory per lysimeter to total amounts in lysimeter water.

		Percent total inventory Sr-90x10^6				Percent total inventory Cs-137x10^6			
		Moisture cups		Leachate water		Moisture cups		Leachate water	
Lysimeter Number	Solidification agent	ANL	ORNL	ANL	ORNL	ANL	ORNL	ANL	ORNL
1	Cement	59	545	27	1,078	—	—	—	2.0
2	Cement	181	406	53	493	0.9	—	—	0.1
3	VES	3,998	381	193	69	—	—	—	0.7
4	VES	289	35	69	469	—	—	—	0.1
5	Cement	89	384	7,581	45,356	15.0	0.1	—	86.0

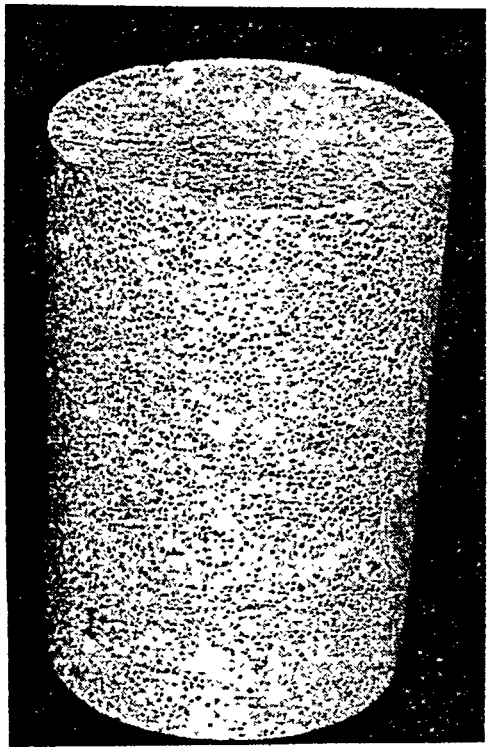


Figure 1. Example of an EPICOR-II waste form.

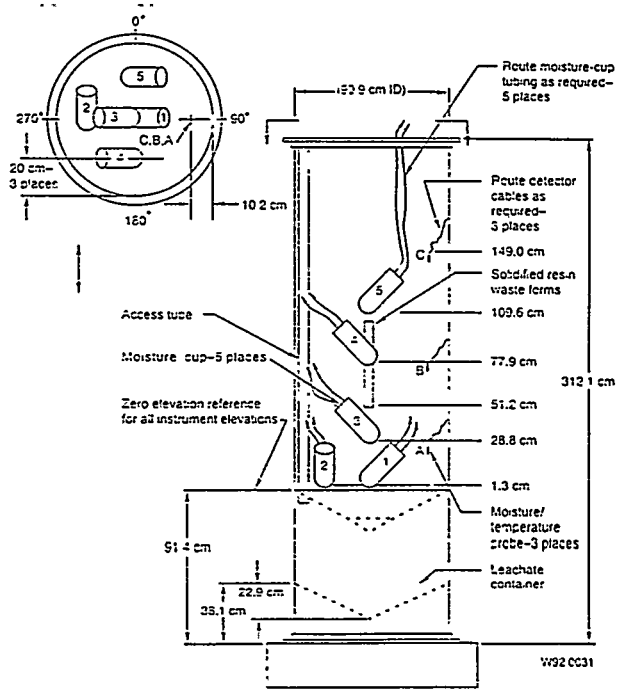


Figure 2. Lysimeter vessel component locations. The base of the soil column is the zero elevation reference.

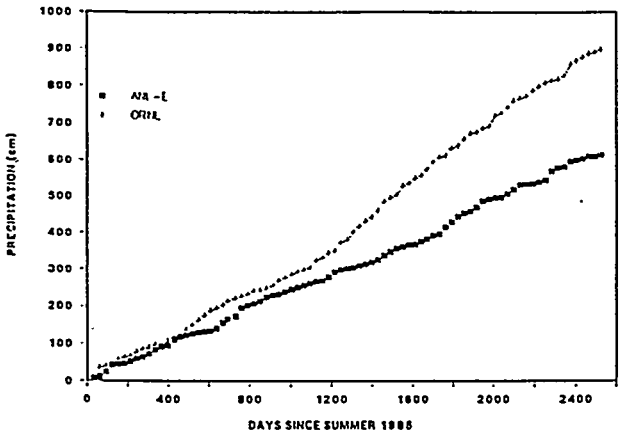


Figure 3. ANL-E and ORNL cumulative precipitation.

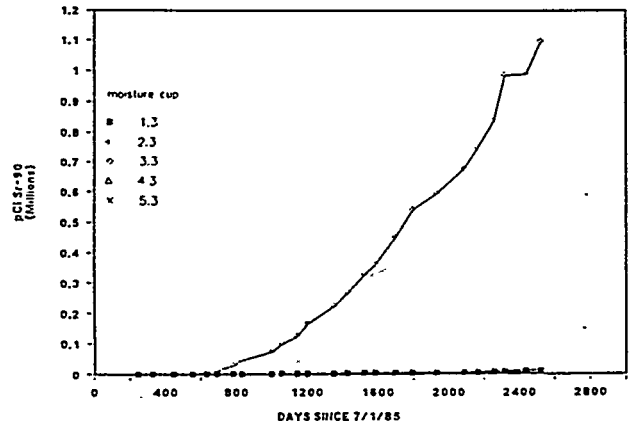


Figure 4. ANL-E cumulative Sr-90 collected in moisture cup number 3.

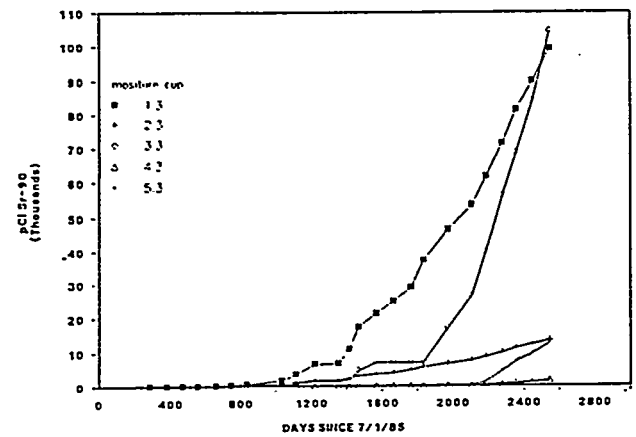


Figure 5. ORNL cumulative Sr-90 collected in moisture cup number 3.

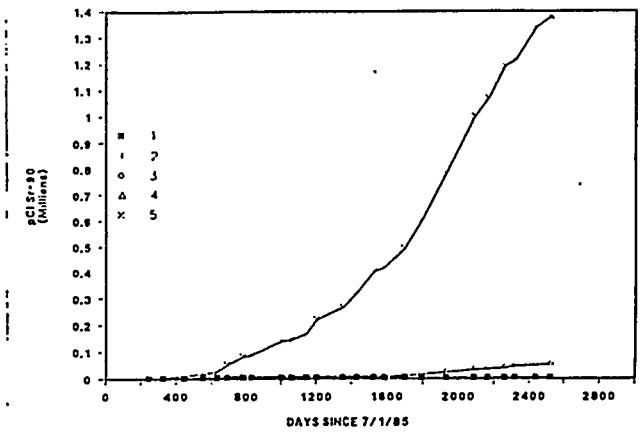


Figure 6. ANL-E cumulative Sr-90 collected in lysimeter leachate collectors.

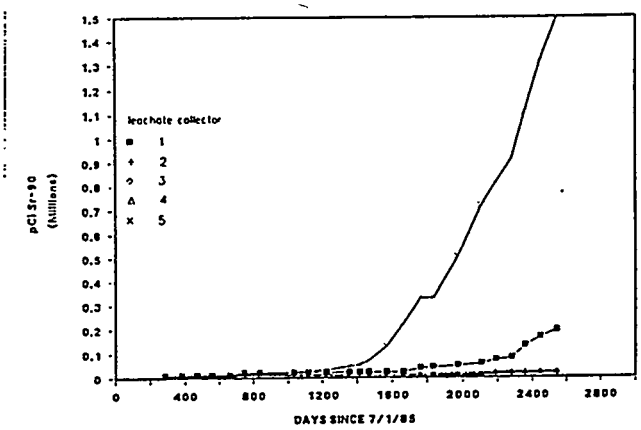


Figure 7. ORNL cumulative Sr-90 collected in lysimeter leachate collectors.

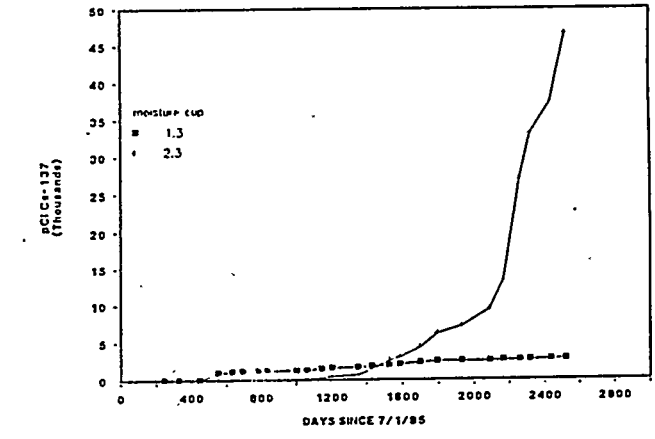


Figure 8. ANL-E cumulative Cs-137 collected in moisture cup number 3.

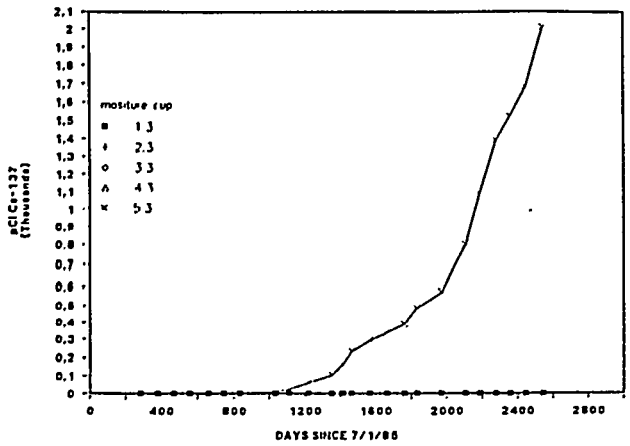


Figure 9. ORNL cumulative Cs-137 collected in moisture cup number 3.

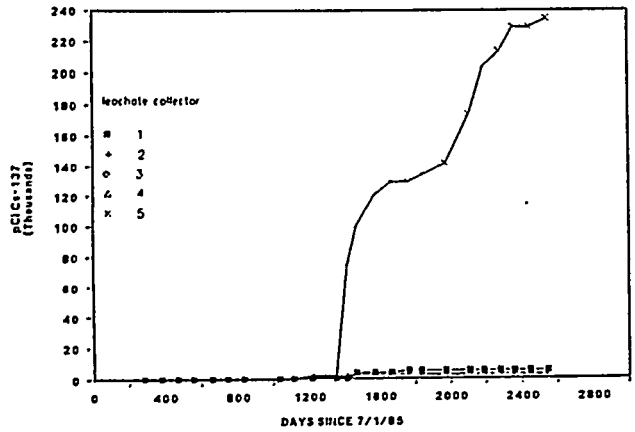


Figure 10. ORNL cumulative Cs-137 collected in lysimeter leachate collectors.

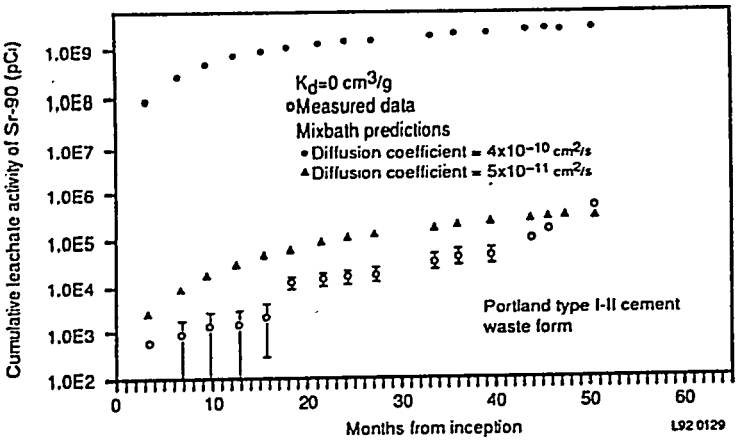


Figure 11. Comparison of Sr-90 cumulative activities for measured data from ORNL lysimeter 5 leachate collector (51.2 cm of soil) and Mixbath predicted results.

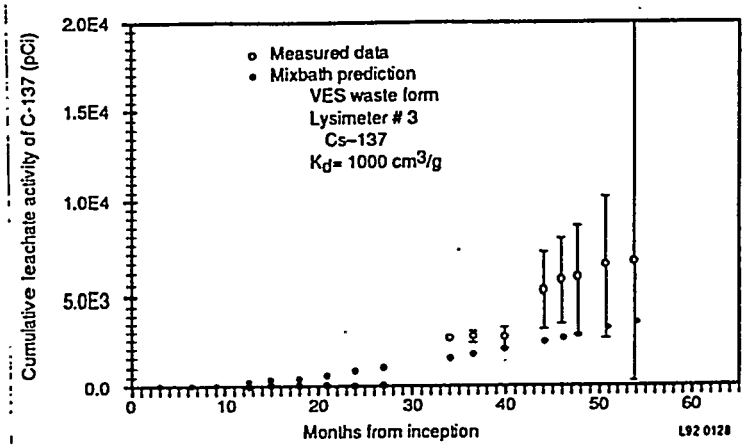


Figure 12. Comparison of Cs-137 cumulative activities for measured data at ORNL lysimeter 3 leachate collector (51.2 cm of soil) and Mixbath prediction.

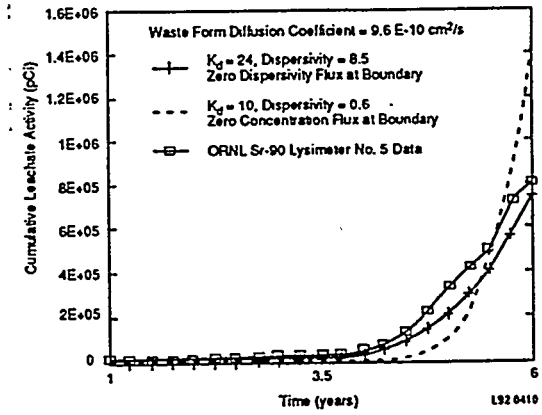


Figure 13. Data for Sr-90 at ORNL lysimeter number 5, compared with two sets of estimated K_d and dispersivity values.

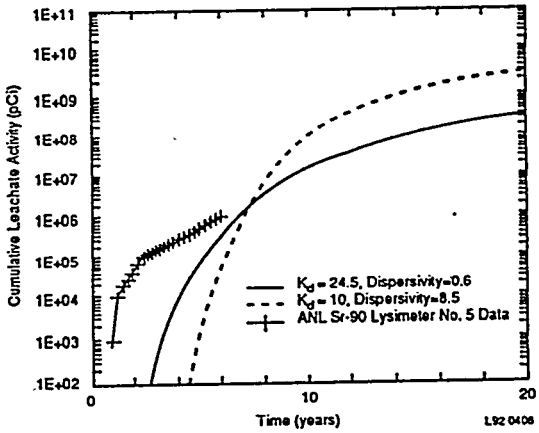


Figure 14. Six years of data for Sr-90 at ANL-E lysimeter number 5, compared with two sets of estimated K_d and dispersivity values for 20 years.

Aboveground Roofed Design for the Disposal of Low-Level Radioactive Waste in Maine

John A. Alexander
University of Maine
Orono, ME 04469

INTRODUCTION

The conceptual designs proposed in this report resulted from a study for the Maine Low-level Radioactive Waste Authority to develop conceptual designs for a safe and reliable disposal facility for Maine's low-level radioactive waste (LLW). Freezing temperatures, heavy rainfall, high groundwater tables, and very complex and shallow glaciated soils found in Maine place severe constraints on the design. The fundamental idea behind the study was to consider Maine's climatic and geological conditions at the beginning of conceptual design rather than starting with a design for another location and adapting it for Maine's conditions.

The study was done by a group of 12 faculty members and graduate students at the University of Maine. Disciplines of the participants included: groundwater hydrogeology, nuclear physics, environmental engineering, geology, geotechnical engineering, soil science, structural engineering, and materials engineering.

The conceptual designs recommended are entirely above ground and consist of an inner vault designed to provide shielding and protection against inadvertent intrusion and an outer building to protect the inner vault from water. The air dry conditions within the outer building should lead to almost indefinite service life for the concrete inner vault and the waste containers. This concept differs sharply from the usual aboveground vault in its reliance on at least two independent, but more or less conventional, roofing systems for primary and secondary protection against leakage of radioisotopes from the facility. Features include disposal of waste in air dry environment, waste loading and visual inspection by remote-controlled overhead cranes, and reliance on engineered soils for tertiary protection against release of radioactive materials.

Historical Background

The history of solid waste disposal in general, and low-level radioactive waste (LLW) disposal in particular, has often involved burying the waste. Burial was usually the cheapest way to dispose of all types of wastes, and in the case of LLW, the covering soil also provided cheap radiation shielding between the waste and the biosphere.

Unfortunately, this simple burying of waste, although cheap, has caused the contamination of groundwater in several instances. By the time the public became concerned about groundwater and the resulting threat to public health, large quantities of radioactive and nonradioactive wastes had been buried. The massive ongoing remedial effort to contain and clean up these crude burial sites requires the expertise of people who can deal with groundwater contamination. These include environmental and geotechnical engineers, geologists, and geohydrologists.

As it became apparent that new and safer facilities for the disposal of LLW were needed, the Nuclear Regulatory Commission and other agencies responsible for these new facilities naturally turned to the body of professionals doing waste remediation work. Because of their training and experience in subsurface work, these professionals tended to recommend subsurface disposal. Our history of disposing of waste by burial and the arid nature of the western United States, where attention was initially focused for radioactive waste disposal, also contributed to this tendency to think first of subsurface disposal.

For these reasons, along with the superficial attractiveness of getting the waste in the ground and out of sight, until now most of the designs proposed for the disposal of LLW involve either belowground disposal or earth-mounded structures.

Although subsurface disposal is an attractive alternative in locations with arid climates and suitable soil types, it has serious disadvantages for areas that have substantial rainfall, freezing temperatures, high water tables, and glaciated soil causing complex geohydrologic characteristics. These conditions prevail in Maine and are common in several other northern states.

CONCEPTUAL DESIGN

Disadvantages of Earth Covered Facilities

Because of the rainfall, high water tables, and complex geohydrologic characteristics of Maine soils, designs below the natural ground surface were ruled out as undesirable early in the study. This left some form of earth-mounded design as the only remaining conventional approach for Maine's facility. Several variations of earth mounded designs were proposed for consideration and were evaluated by the conceptual design group. As the study progressed, these designs became more and more complex as they were modified to address the various failure scenarios proposed by group members and others.

The conceptual design group included engineers with experience in designing and building the impermeable layers, filters, drainage layers, and other features that are crucial to the success of an earth-mounded facility. This firsthand experience with the difficulties in not only designing but actually constructing these features and the multiplicity of failure scenarios led to the conclusion that earth mounding is a much less desirable approach for Maine's conditions than for more arid regions.

Because of these potential difficulties in actually achieving a highly reliable facility (as opposed to achieving a paper design that if perfectly constructed would give high reliability) nonconventional approaches to the disposal of LLW were suggested. Aboveground vaults protected by durable roofing systems instead of soil layers appeared to offer several advantages over earth-mounded structures. Several configurations of roofed facilities were suggested. Each configuration was evaluated for its potential to provide a safe facility under Maine conditions by exploring various failure scenarios.

Conventional Assumptions

The group was aware that aboveground roofed designs had been rejected by others because of one or more of the following assumptions.

1. Prevention of inadvertent human intrusion requires burial

2. Adequate shielding requires a thick earth layer to protect the public

3. Soil is the only material that can provide the required long-term durability with only the minimal custodial maintenance allowed in the regulated design constraints.

However, when examined carefully, these assumptions did not seem to stand up to critical evaluation.

1. Steel and reinforced concrete can provide protection against inadvertent human intrusion and is probably superior to the protection provided by earth covered facilities. Future water well drilling is one example of a likely inadvertent intrusion for any earth-covered facility unless institutional control is continued indefinitely.

2. A computer model, being described in another paper at this conference, was used to show that proper configuration of an aboveground facility and waste placement within the facility, coupled with thicknesses of concrete on the order of two feet, could reduce radiation intensity to well below the levels needed to assure worker and public safety (Breskin 1992).

3. A variety of both natural and manufactured building materials are virtually impervious to degradation in Maine's environment. Some natural stone, 317-type stainless steel, Monel, copper,

lead, and ceramic materials are all promising candidates for use where extreme durability without maintenance is required.

Aboveground Roofed Designs

After evaluating several potential configurations for a roofed facility, two designs appeared to offer the most promise for providing reliable disposal of LLW. Both involve a roofed, reinforced concrete vault designed to reduce radioactivity outside the facility to below required levels and to provide security against inadvertent human intrusion. A second building encloses and shelters the vault from precipitation. Additional safeguards against radionuclides reaching the biosphere would be provided by the design of the soil systems beneath either design. Although there are minor differences in the design of the inner vaults and loading methods, the most significant difference between these two approaches is in the design of the outer building.

The outer buildings in either design would be built to withstand the maximum probable wind, snow, and earthquake loads. The difference between the two designs is in the degree of maintenance required for successful operation. In design 1 (Figure 1) the outer building would employ corrosion-resistant materials to achieve a design life of 400 years beyond the 100-year institutional control period while requiring only custodial maintenance.[a] This design would also incorporate three independent roofing systems for two levels of backup protection against leakage reaching the waste.

Design 2 is similar to design 1 but uses a more conventional steel outer building offering a lower cost design under the assumption that maintenance would be available for periodic repairs. This design involves two independent roofing systems providing one level of backup protection against leakage reaching the waste. Although this design offers safe disposal at lower cost it does not appear to be feasible under the present definitions of allowable maintenance beyond the 100-year institutional control period. For this reason it will not be further described or discussed in this report.

Description of Aboveground Roofed Design

General Description of System

This facility, as shown in Figures 1 through 3, is sized to receive 100,000 cubic feet of LLW with 25% void space, for a total volume of 125,000 cubic feet. This would contain Maine's estimated LLW stream for 10 years. The inner building is a roofed, reinforced concrete vault designed to restrict radioactivity outside the facility to below required levels and to provide security against inadvertent human intrusion. The purpose of the outer building is to enclose the vault and shelter it from the weather. The goal of this conceptual design is to safely contain LLW in an air-dry condition for a 100-year period of active maintenance followed by a 400-year period of only custodial maintenance. The following design features will contribute to this goal.

Concrete Vault

The concrete vault is approximately 85 feet by 125 feet in plan and 20 feet high. The vault will be built as three side-by-side chambers to provide support for the rails of overhead cranes and to reduce the span of the roof slab (see Figure 1). The middle chamber is further divided into three sections, forming an interior chamber for the B- and C-level wastes. This will take advantage of the shielding capability of the inner chamber's concrete walls and keep the B- and C-level wastes a minimum of 45 feet from the outside of the facility.

A roof will be supported on top of the vault (Figure 2) to provide secondary protection in the event of a leak in the primary roof (on the outer building). This secondary roof will use a highly durable material such

a. As defined by Nuclear Regulatory Commission (NRC) and Maine Department of Environmental Protection (MDEP) regulations (United States 1987 and Maine 1988).

as copper, stainless steel, lead, or vitrified clay. Below the secondary roof, the top of the vault will be sloped to allow the top of the concrete to act as a tertiary roof for any water that penetrates both the primary and secondary roofing systems. The secondary and tertiary roofing systems will be designed to survive the collapse of the roof above.

The vault design will allow airtight sealing with simple gasketed steel doors (Figure 3), except when waste is being loaded. When these doors are closed, the vault will be a sealed chamber. This will minimize the possibility of condensation of water vapor within the vault by minimizing the entry of air bringing in moisture. The absence of moisture and light deactivates most potential corrosion mechanisms.

Outer Building

The outer building will enclose the vault and shelter it from the weather. It will be designed to withstand maximum probable wind, earthquake, and snow loads. The 10-foot-wide corridor between the vault and outer building will allow inspection of both structures. The corridor will also provide additional distance between the waste and the exterior of the facility to further reduce radiation levels outside the facility.

The steel frame of this outer building will support the primary roof. As with the secondary roof, the primary roofing system will be a highly durable roofing material. A design using copper shingles fastened to a redwood deck with copper fasteners is one type of system that might be considered.[a] The primary and secondary roofing systems should be different to avoid the possibility of one unanticipated failure mechanism leading to the failure of both systems.

The walls of the outer building may be of either lightweight material or of reinforced concrete. If lightweight material is used, the cladding will be of durable materials similar to those used for the roof. Reinforced concrete walls would have the advantage of providing additional radiation shielding, and, if made of high-durability concrete, should provide a long service life in this mild exposure condition. For maximum durability, the concrete walls could be clad with durable material such as granite.

Loading the Vault

Waste will be loaded into the vault with an overhead crane system (Figures 2 and 3) through a set of baffles to provide shielding during loading (Figure 1). One 15-ton capacity and two 5-ton capacity overhead cranes will provide a precise and flexible method of loading waste. Cranes will be remotely controlled from outside the vault and carry lights and video cameras to provide the operator a clear view while placing the waste. Although all of the crane system except the rails can be serviced outside the shielding baffles, the cranes should be designed for extreme reliability. Tethers on the cranes could provide emergency retrieval in case of malfunction. Automatic controls to guide the waste past the two concrete baffles could easily be incorporated into the designs or simple disconnect switches could be used to make it impossible to hit the baffles or any of the walls. An additional advantage of this configuration is the capability of placing waste without exposing the interior of the facility and the waste to rain and snow. This will allow loading in any season, an issue that will become especially important during loading of the decommissioning waste.

B- and C-level wastes will be placed in the inner chamber within the vault. This will keep these wastes a minimum of 45 feet from the exterior of the outside building. Additionally, when fully loaded, the A-level

---

a. Known material loss rates for copper are very slow for environmental conditions similar to those in Maine. These loss rates indicate a thickness loss of less than 1/100th of an inch in 500 years and less than 1/30th of an inch for 500 years in industrial environments (Baboian 1978). Shingles could be sized to reduce stress or wear from thermal expansion and contraction to insignificant levels. Fastening the shingles to wood sheathing would avoid contact with a dissimilar metal and eliminate a potential corrosion mechanism. Common commercial woods do not deteriorate significantly when protected by a roof. Rot resistant species could be used for further assurance. Redwood has, for instance, been know to resist degradation for hundreds of years even when exposed to weather similar to Maine's.

waste surrounding the inner chamber will provide a minimum of 35 feet of additional shielding between the more radioactive B- and C-level wastes and the outside.

Monitoring of Waste

Not only will the overhead cranes provide a highly reliable and precise means for placing the waste, they could also provide remote visual inspection of the waste in the vault and the condition of the vault itself. In addition to the video cameras and lights mentioned above, a video camera with lights could be lowered for close-up inspection of the containers or structure. Additionally, the crane system could be used to easily retrieve any of the waste if that becomes necessary or desirable.

Several types of sensors could be used to detect unanticipated changes within the vault and activate local or remote alarms. The primary concern should be the detection of water because there should be no liquid water in the vault during its service life. Besides permanently placed sensors, instruments mounted on the overhead cranes could measure moisture, radiation levels, or air quality within the vault at any time in the future. If some of the permanently placed sensors failed or better types became available, the overhead cranes could be used to replace the original sensors.

Drainage and Underlying Soil

The floor of the corridor between the vault and the outer building will be sloped to the outside to direct any water leaking through the primary roof, and being shed by either the secondary or tertiary roofing systems, to the outside of the facility without reaching the waste. The floor inside the vault will be sloped to drains located at the perimeter of the building. The drains will carry any leakage away from the facility for monitoring and possible treatment during the 100-year active maintenance period.

If, in fact, active maintenance ends after 100 years, any water that might penetrate all three independent roofing systems will be directed into the backup system beneath the facility. This system will consist of layers of engineered soils designed to accept the flow of water that might result from total roof failure and adsorb the radionuclides.

Site Requirements

This repository design is adaptable to a wide variety of sites because it depends primarily on the integrity of roofing systems instead of the integrity of subsurface barriers and collection systems. Comments in NRC's report on aboveground vaults seem to agree: ". . . the aboveground vault does not rely as much on site characteristics as other disposal methods to meet the performance objectives." (NRC 1985) It would be suitable for any site that the siting process selects, and for many which that process will reject.

Summary of Advantages

The recommended aboveground roofed designs offer the following advantages.

1. Less dependence on site conditions
2. Waste remains in air dry condition
3. Visual inspection of the interior of the facility and the waste containers throughout the life of the facility
4. Detection of leaks before water reaches the waste
5. Straightforward diagnosis and repair of any future failures
6. Easy retrieval of some or all of the waste

7. Capability of the facility to be modified to take advantage of newly developed materials or procedures during the 100-year institutional control period.

The net effect of these advantages is to provide both a high degree of knowledge about the future performance of the facility and control over that performance by practical remedial action if necessary. This contrasts sharply with conventional belowground or earth-mounded designs as follows.

1. Failures are difficult to detect until after leaks occur

2. Indications of malfunction are difficult to evaluate and diagnose since no direct observation is possible

3. Correction of malfunctions are difficult without major disruption to the facility

4. Once the earthen cap is in place little can be done to modify or improve the facility to take advantage of new developments during the 100-year period of institutional control.

Objections to Roofed Facilities

Although the advantages outlined above seem to heavily favor aboveground roofed designs, two objections have been raised to this type of approach that deserve additional comment.

Concrete Durability

The most common concern for the long-term durability of roofed facilities centers on the durability of concrete in the presence of freezing and thawing. These designs address this concern by keeping the concrete inner vault in air dry condition. Depriving concrete of water effectively deactivates the common deterioration mechanisms responsible for the deterioration of concrete in cold climates. A strong argument can be made that air dry concrete subjected to freezing temperatures is likely to be more durable than concrete buried beneath the frostline in damp soil (MLLRWA 1992).

Concept of "Disposal"

Another objection to the roofed type of design is based on the idea that any facility that isn't protected by a thick layer of soil is simply "storage" instead of "disposal." The official concept of disposal seems to be that if future retrieval is still a practical option, the waste is only "stored." Disposal also seems to require that after the first 100 years the waste must be contained forever with no further attention needed from future generations. If no long-term maintenance can be expected, the assumption that it is possible to achieve this level of facility immortality with soil structures, and only with soil structures, is questionable. Soil is one of our most complex and difficult-to-manage engineering materials. Assuming that it is the best primary material for LLW disposal facilities may not be justified.

The whole question of "disposal" (as opposed to "long-term storage") of LLW is based on the apparent assumption that our descendants will be incapable of doing routine maintenance on a waste facility. This reveals a degree of arrogance about our assumed superiority over future generations that is embarrassing. A more reasonable assumption is that these future people will be at least as intelligent, knowledgeable, and able as we are and will probably develop better ways of handling LLW in the next century or two.

However, the question about the future is irrelevant as far as the disposal of LLW is concerned. If future generations turn out to be intelligent and capable, minor maintenance on a LLW disposal facility until it has decayed to a nonthreatening level will be easily accomplished. If on the other hand, future generations are unable to maintain at least minimal governments, and thus minimum capability to maintain a civilization, life will indeed be, as Thomas Hobbes predicted, "solitary, poor, nasty, brutish and short" (Hobbes 1651). With the continual fear of violent death, the tiny threat of a slight increase in the cancer rate will be of small importance.

It will be one or the other, either future generations will be able to do minimal maintenance on a waste facility or if they can't, society will have deteriorated to a state where other dangers will be overwhelming and a modest increase in exposure to radiation will be totally insignificant. Yugoslavia, Somalia, Ethiopia, and other places where government has degenerated provide current examples where radiation exposure doesn't make it onto anybody's list of major concerns.

Public Reaction

What we fear most is the unknown and things over which we have no control. The unknown potential dangers posed by belowground or earth-mounded disposal and our perceived lack of future control is exactly what is feared most by a skeptical public. This should be expected, since this same public has been repeatedly disappointed by past efforts to dispose of radioactive and other waste by burial.

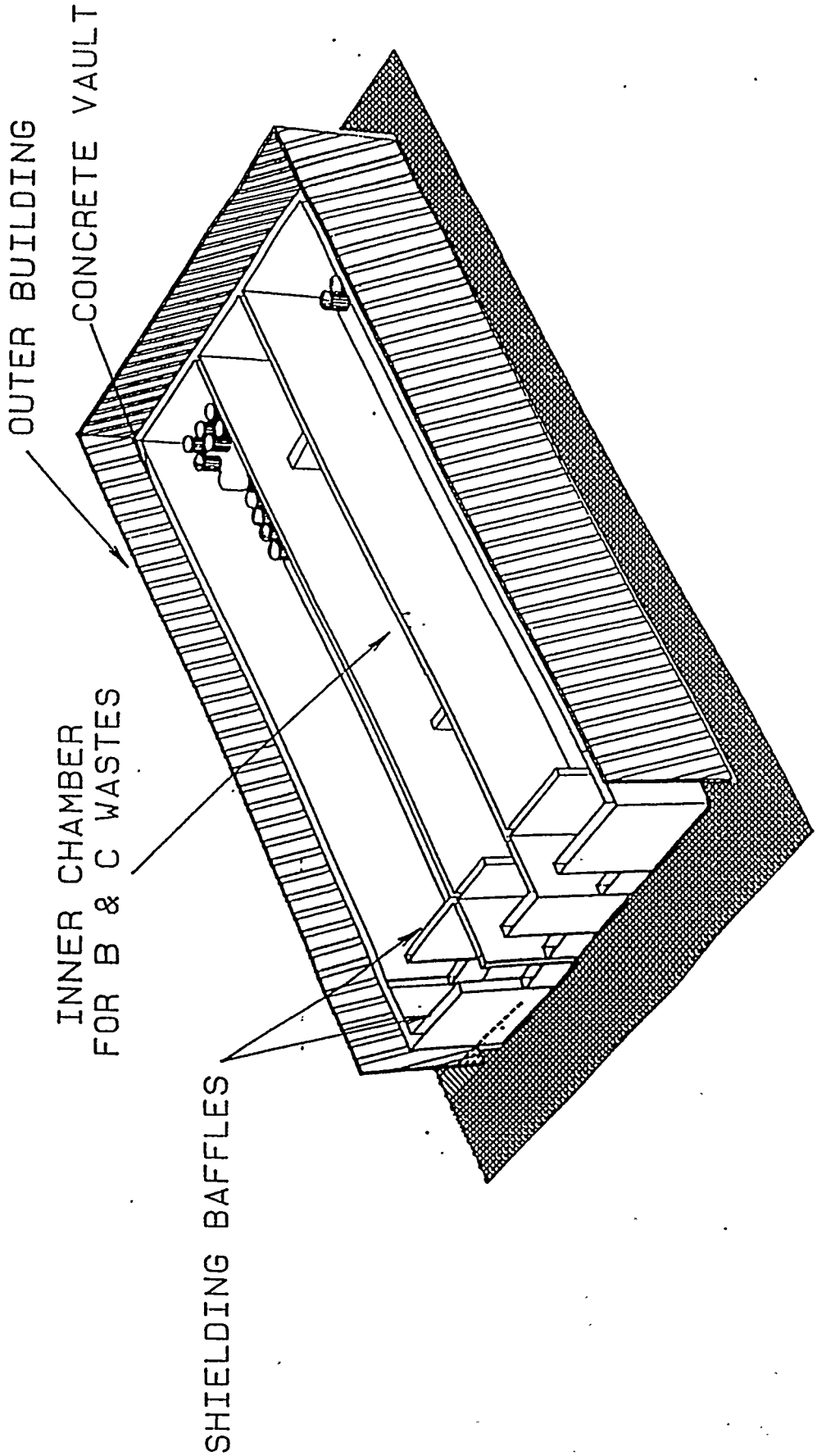
The knowledge and control over future performance promised by the roofed designs have helped to reduce some of the doubts and fears of Maine citizens about the technical feasibility of safely disposing of low-level radioactive waste. For these reasons, the recommended designs have proven attractive to both the Maine Authority and Maine's outspoken citizen's advisory group. Both bodies have endorsed these conceptual designs as the most promising approach for Maine. This approach may be equally appealing to concerned citizens in other states.

CONCLUSIONS

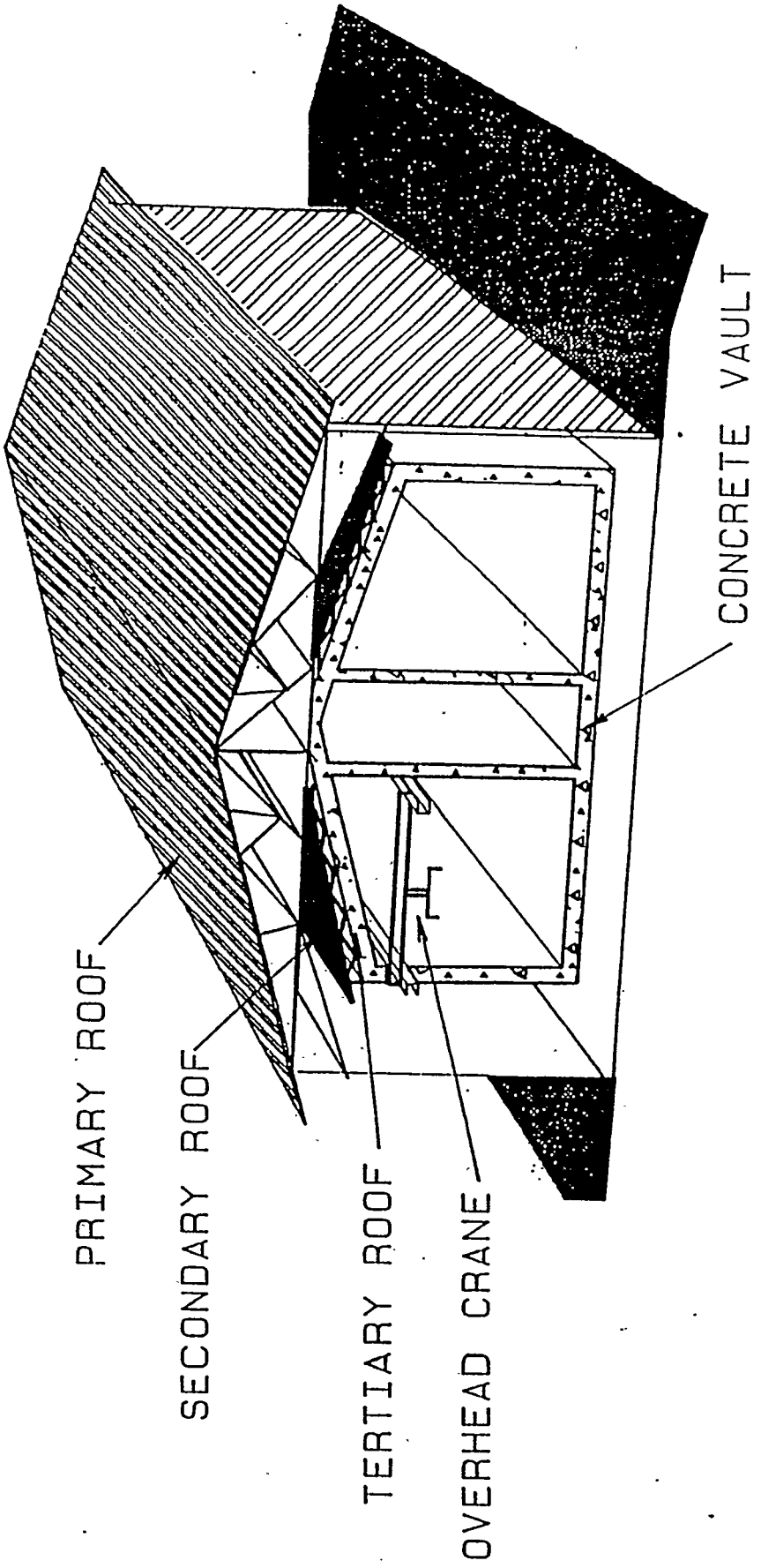
The aboveground, roofed designs are obviously a nonconventional approach to the disposal of LLW, and the recommendation of this type of design must rest on a favorable comparison of its advantages and disadvantages to those of earth mounded designs. A detailed comparison of the advantages and disadvantages of aboveground roofed designs and conventional earth-mounded designs is given in our report to the Maine Low-Level Radioactive Waste Authority (1992).

The aboveground, roofed facilities offer substantial advantages and few disadvantages when compared to a belowground or earth-mounded facilities. These advantages include disposal of waste in an air-dry condition, ease of inspection, leak detection before water reaches the waste, ease of maintenance or repair, ease of retrieving waste, and less dependence upon site requirements. Disadvantages include higher visibility, less protection against massive impacts, and the unconventional nature of this approach which may hinder regulatory approval. Because the advantages seem to heavily outweigh the disadvantages, we concluded that a roofed design would offer greater long-term reliability and safety than a belowground or earth-mounded system in Maine's difficult climatic and geological conditions and strongly recommended that the Authority adopt one of the aboveground, roofed, designs as the starting point for the design of Maine's facility.

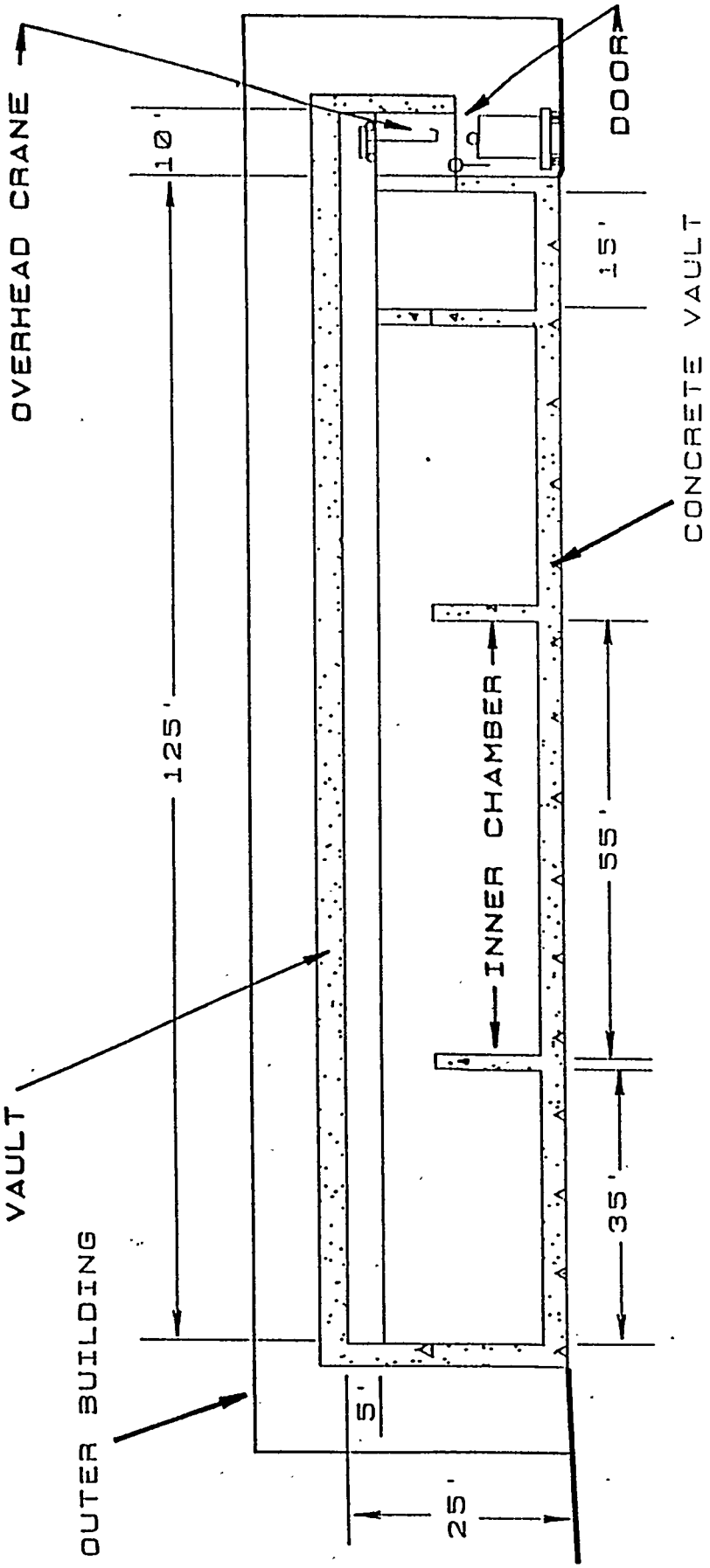
The option of visually inspecting and controlling the LLW provided by an aboveground, roofed design seems to be an attractive concept to that portion of the public most concerned about the future safety of LLW disposal. There may be potential for similar public support in other states where fear of below ground disposal, and the resulting political opposition, is hindering the design and siting of LLW disposal facilities.



CONCEPTUAL DESIGN 1 WITHOUT ROOF SYSTEM
FIGURE 1



CUTAWAY VIEW
CONCEPTUAL DESIGN 1
FIGURE 2



SECTION THROUGH CENTER OF FACILITY
CONCEPTUAL DESIGN 1
FIGURE 3

REFERENCES

Nuclear Regulatory Commission, 1985, *Alternative Methods for Disposal of Low-Level Radioactive Wastes*, Task 2b: Technical Requirements for Aboveground Vault Disposal of Low-Level Radioactive Wastes, NUREG/CR-3774, Vol. 3, 1985, p. 19.

Baboian, R., Haynes G., and Sexton, P., 1978, "Atmospheric Corrosion of Laminar Composites Consisting of Copper on Stainless Steel," *Atmospheric factors Affecting the Corrosion of Engineering Metals*, ASTM STP 646, S.K. Coburn, Ed., American Society for Testing Materials, 1978, pp. 185-203.

Breskin, K. L., Tims, H. V., and Hess, C. T., 1992, "Discrete Source Computer Model for Radiation Exposure Outside A Low-Level Radioactive waste Facility," *Department of Energy Low-Level Radioactive Waste Management Conference, Phoenix, Arizona. Nov. 18-20, 1992.*

Maine Low-Level Radioactive Waste Authority, 1992, *Conceptual Design for Low-Level Radioactive Waste Disposal in Maine*, Revision 1, April 1992.

Hobbes, Thomas, 1651, *Leviathan*, Part 1, Chapter 13, 1651.

Maine Department of Environmental Protection, 1988, "Code of Regulations for Low-Level Radioactive Waste Storage, Disposal and Facility Siting," 1988.

Code of Federal Regulations, 10 CFR 61, "Licensing Requirements for Land Disposal of Radioactive Waste," Office of the Federal Register, January 1992.

Use of Engineered Soils Beneath Low-Level Radioactive Waste Disposal Facilities

Thomas C. Sandford
Dana N. Humphrey
Frank A. DeMascio
Department of Civil Engineering
University of Maine
105 Boardman Hall
Orono, ME 04469

INTRODUCTION

Current regulations (NRC 1992) are oriented toward locating low-level radioactive waste disposal facilities on sites that have a substantial natural soil barrier and are above the groundwater table. In some of the northern states, like Maine, the overburden soils are glacially derived and in most places provide a thin cover over bedrock with a high groundwater table. Thus, the orientation of current regulations (MDEP 1988) can severely limit the availability of suitable sites.

A common characteristic of many locations in glaciated regions is the rapid change of soil types that may occur and the heterogeneity within a given soil type. In addition, the bedrock may be fractured, providing avenues for water movement. A reliable characterization of these sites can be difficult, even with a detailed subsurface exploration program. Moreover, fluctuating groundwater and frost as well as the natural deposition processes have introduced macro features such as cracks, fissures, sand and silt seams, and root holes. The significant effect that these macro features have on the permeability and adsorptive capacity of a large mass is often ignored or poorly accounted for in the analyses.

PURPOSE

This paper will examine an alternate approach, which is to use engineered soils as a substitute for some or all of the natural soil and to treat the fractures in the underlying bedrock. The site selection would no longer be primarily determined by the natural soil and rock and could even be placed in locations with no existing soils. Engineered soils can be used for below- or aboveground facilities (Alexander et al. 1992).

The engineered soil could be designed to have the desired permeability and radionuclide adsorptive characteristics. It would be thoroughly mixed from locally available soils with the addition of imported soil and special adsorptive materials as needed. It would be placed in thin layers using standard construction equipment with careful monitoring of properties. The engineered soils have the potential to contain radionuclide releases with a higher degree of reliability because of their greater homogeneity and the addition of materials with high radionuclide adsorptive characteristics. There would be greater assurance that the entire soil mass has the desired characteristics, since the placement of each layer could be closely monitored.

If necessary, the underlying bedrock could be exposed and the individual fractures treated at the surface by low-permeability grout. This would let the bedrock act as a barrier instead of allowing the bedrock to remain as a conductive medium beneath the facility.

The paper covers the methods of construction and the monitoring for this approach. Advantages and problems associated with the use of engineered soils are discussed.

BACKGROUND

The design and construction of earth embankments for specific uses is not a recent introduction. Not only were earth embankments built many years ago, but many have endured through the ages. Typically the

Roman and Greek ramparts or aqueducts come to mind as examples of ancient embankments still being used today. Burial mounds, protective mounds, and platform mounds are some of the visual remnants of the prehistoric eras in North America (Sowers 1981). The platform mounds evolved in Central America into the earth-stone pyramids. The largest of these at 231 feet high was constructed between 350 A. D. and 600 A. D. and exists today near Mexico City. With less knowledge of soil mechanics and with more primitive tools than we have today, the Incas built terraces, canals, roads, and other structures that are still evident today. Although the time record of these constructed soils are a fraction of the time record of a natural deposit, their survival indicates the potential for long-term success of this type of construction. They would be expected to survive since the type of materials used in engineered fills have been the same natural materials that occur in situ; thus, the deterioration rate should not be different.

The use of earth embankments is not a novelty, and it can almost be said that they have been essential for the development of the modern world. The rural and urban roads and streets in the United States totalled 3,874,026 miles in 1987 (FHWA 1988). Although many of them do not have the thickness of embankment that many engineers would consider adequate for a proper design, most of this length depends upon engineered embankments for strength and drainage. If one considers that there are also railroads, airport runways, parking lots, landfill liners and building foundations with compacted earth, then we realize that the technology is in place to deliver this mode of engineered construction. One of the outcomes of the National Dam Inspection Act (Public Law 92-367) enacted in 1972 was to require an inventory of dams more than 25 feet in height or which impound more than 50 acre-feet of water. The inventory data for the United States showed that 45,459 earth or rock fill dams exist with 1072 over 100 feet high (Miles 1977). These are embankments engineered for the purposes of controlling seepage and many are larger than that anticipated for an engineered embankment for the disposal zone of LLW above bedrock. The problem of adsorption in LLW disposal is a new facet of the use of engineered soils. Peat has been most recently used for treatment of landfill leachates (McLellan and Rock 1986).

The desirability of utilizing soil as a building material stems from its general availability, its range of properties, its durability, and its comparatively low cost.

SOIL DEPOSIT FORMATION OF IN SITU VERSUS EMBANKMENT

The deposit formation process will determine many properties, their variability, and the nature of the boundaries between deposits. Knowledge, or lack of specific knowledge, of the subsurface is related to the reliability of the barrier. Natural deposits are formed by a variety of processes that do not necessarily result in materials with properties best suited for a particular objective, such as disposal of low-level radioactive waste. In Maine, the heterogeneous till and the weak and compressible marine deposit, which has been uplifted above sea level by rebounding bedrock, are the two major naturally occurring deposits that are being investigated for use in isolation of the low-level radioactive waste facility from the biosphere. Embankment deposits are formed primarily from existing natural deposits that have been selected for having particular properties. These properties may be enhanced by further mechanical processing. The properties of an embankment material can be related to construction quality.

Formation of Maine's Glacial Materials

Many of the surficial materials in Maine and other northern states were deposited between 14,000 and 10,000 years ago during the recession of the Wisconsinan glaciation, and we now must explore the subsurface to discover the specific materials at a particular location. Some of the materials, like till, are quite erratic, as expected by the formation process. The precursor of till, which covers much of the state, was generated by the scraping and grinding of the glacier moving over bedrock. Till was typically deposited directly below an actively moving glacier. Unstratified, unsorted mixtures of boulders, sand, gravel, and clay depict the elements of till and give it its heterogeneous nature. In some locations, the till was sorted by the flowing waters of the melting glacier, forming other types of sedimentary deposits that may adjoin the till. The coarser sand and gravel were left behind in the form of long winding eskers, kames, deltas, and other outwash deposits at unknown boundaries. The finer sands, silts, and clay size particles were carried into lakes or into the marine

waters where they settled out to form marine deposits (Tucker and Marvinney 1989a, 1989b). The relative percentage of these components depended upon the water velocity, which varied seasonally as well as by location and climatic episodes. In the near surface, the biota, including animals, insects and plant roots, affects a natural deposit by introducing passageways. The action of freeze/thaw cycles and desiccation over time introduces cracks and fissures especially into the upper 10 feet of a deposit. In other states, different processes, such as in situ weathering of bedrock, can also give complex profiles at natural soil sites.

Groundwater Conditions

A low-level radioactive waste disposal facility is required in Maine to be above the groundwater table, but this restriction severely limits the number of possible natural sites in states like Maine. Due to the precipitation amounts of around 40 inches per year, a cool mean annual temperature, and the shallow overburden, the groundwater in Maine is relatively close to the surface. This is evident by the many bogs, lakes, streams, and rivers in the state. Due to the uneven land surface, bedrock surface, and topography of deposits, and the different hydraulic conductivities of each, groundwater can flow in complex ways (Caswell 1987).

Engineered Soils

Engineered soils for the most part will be composed of natural soils blended for the particular quality desired, such as high adsorbent capacity or low hydraulic conductivity, and then placed to give strength and support capabilities.

The formation of engineered soils uses the same processes (Table 1) that nature uses in forming natural deposits. However, the energy that nature has expended in producing soils is on a different scale than we could expect to expend. Therefore our major activity in engineering soils has been to find and select natural deposits with properties that we require for a particular objective and bring these to the site. For many uses we can find natural deposits, such as granular fill, satisfying our needs at a reasonable distance from a site. Sometimes this is not possible and then bedrock or soil must be further processed to obtain suitable material. The cost of the soil increases as the amount of processing increases and as the distance to the site increases.

Most states, especially more populous ones with depleted surface gravels, produce aggregate from quarries. Selected bedrock is blasted in a quarry, broken down in a crusher and screened to form a strong, durable, free-draining aggregate for airport runways, highways or railroads. The screening process usually removes fines and oversize materials, and multiple screens are used to develop a particular aggregate size.

Large-scale mixing has been done for many construction projects with an onsite mill or plant and allows the introduction of soil admixtures. Some additives like bentonite, which is not available in Maine, can be shipped from places like Wyoming and incorporated locally at the plant. Asphalt is a typical large-scale example where asphalt cement is mixed with a combination of several different aggregate sizes. Roller compacted concrete is another example where an engineered soil can be created onsite by mixing cement and soil components (Hansen and Reinhardt 1991). A plant or mill mixing operation could also be established to produce engineered soils. Currently, central plant mixers capable of producing 1000 cubic yards per day are commercially available that are specifically designed for bentonite/soil admixtures (Goldman 1988). The distinct advantage obtained by mixing is that the quantity of water, soils, and bentonite can be regulated. Mixing can also be performed when the soil material is in place. An example would be the addition of lime to promote stabilization. Mixing is accomplished by a combination of motor graders; large-scale versions of farm implements, such as disks and harrows; and specially designed in-place mixing machines. However, the latter is more efficient and results in a more uniform mix. Incomplete mixing and poorer additive and water control are often problems with in-place mixing. In-place mixing is inferior to plant mixing but is justified for small jobs where the cost of a plant is too much.

The size of particles permitted in the engineered soil can be controlled by screening. Particles of certain sizes, which may inhibit performance or hinder construction, can be removed. Particle size restrictions are specified in many types of construction, especially for drainage. Gravel under roads and airfields, filters in

earthen dams, and concrete aggregates all have to meet certain particle size criteria. It is easier to screen at the larger sizes (> 1/4 inch) due to the requirements of screen strength. As the size of screening gets smaller then the rate of material being screened is reduced with an increasing unit cost. Screening cannot be accomplished below sand sizes.

An engineered soil barrier would be created by placing and compacting thin lifts of soil in successive layers to develop a final elevation and shape. Transport and deposition with large earth-moving equipment, such as trucks and scrapers, and densification by compaction using heavy rolling compactors can be accomplished on engineered soil. The repetitive nature of constructing in layers and the significant area encompassed by an engineered soil barrier would produce economy of scale. Similar situations exist in the construction of landfill liners, earthen dams and roadway embankments. Properly placed and compacted, the resulting soil mass has strength and support capabilities sufficient for most uses as well as permeability or adsorption properties. It is possible to develop surfaces between layers, especially with clays or silts, if the surface is not roughened between lifts. These surfaces usually do not affect strength but may give a higher permeability in the lateral direction. With some materials, segregation, especially of gravel size particles, can occur during unloading and spreading. This can become a problem at the edges of lifts, but can be corrected by removal or remixing. A segregated zone will provide preferred seepage paths.

If necessary, the underlying bedrock could be exposed and the individual fractures treated at the surface by low-permeability grout (Fetzer et al. 1988). Grouting of the rock surface is an important aspect for the safety of dams, since this contact surface to the overlying core could potentially be a water-conducting zone under the full head of the reservoir. In most of the rocks in Maine, the hydraulic conductivity of the intact rock is orders of magnitude less than any natural clay. A number of techniques have evolved to seal the fractures and to coat the surface. Cement grouts with bentonite are usually used, but other grouts are available for special uses. Plugging the fractures would allow the bedrock to act as a barrier beneath the facility instead of a conductive medium as in a natural soil site in Maine.

CHARACTERIZATION OF IN SITU VERSUS EMBANKMENT MATERIALS

The process to characterize an in situ site requires a different approach from that taken for an embankment site. For a natural site one is obligated to discover the material properties and the location of boundaries that have been established by nature in an unknown manner to great depths below the surface. While for an embankment, the desired property limits are established before construction, and thus the duty becomes to ensure that these limits are obtained in the construction process. This difference has several implications. One implication is that the design of the facility on a natural soil site will have to be adapted to the characteristics of the natural soil. In some cases, such as in the use of highly compressible marine clay in Maine, much unwanted settlement may occur at the facility. For the embankment, the unwanted settlement is eliminated before construction by establishing the required soil properties. Another implication is that the embankment material properties have the potential to have a more reliable characterization due to better monitoring. A more reliable characterization is especially important if behavior of the facility turns out to be somewhat different from expected. A third implication for an embankment material is that construction quality must be monitored at all levels to obtain the required properties.

In Situ Soil

The intent of the site investigation is to define the specific subsurface conditions and their physical characteristics with a high degree of confidence. Currently there are no regulatory guides that apply to the geotechnical engineering aspects for a low-level radioactive waste disposal facility (NRC 1988). Guides for nuclear power plants (NRC 1979, NRC 1978) have been suggested as general guides to use in the site investigation of a LLW disposal facility (NRC 1988). However, the required level of detail and the extent of investigation and analyses would vary on a case-by-case basis. Thus for a particular site it is difficult to determine what is the appropriate level of exploration and testing to adequately characterize the site.

As a typical exploration criterion, the following recommendations are given. For favorable, uniform geologic conditions, where continuity of subsurface strata is found, the spacing of borings recommended by

Regulatory Guide 1.132 is one boring per 10,000 square feet (approximately a 100-foot spacing) for containment buildings. Where variable conditions are found Regulatory Guide 1.132 recommends the spacing should be smaller, as needed, to obtain a clear picture of soil or rock properties and their variability. Regulatory Guide 1.132 states: "Sampling of soils should include, as a minimum, recovery of samples for all principal borings at regular intervals and at changes in strata." Suggested sampling frequency ranges from continuous in at least one boring and up to five foot intervals in the other borings.

Since the exploration is a discovery process at a natural site, and there are inevitable variabilities in the subsurface, there are risks in characterizing the subsurface. The NRC has confirmed that these risks sometime lead to inadequate characterization. NRC (1986) states, "One problem experienced at several existing low-level radioactive waste disposal facilities has been the identification of site conditions during site operations which were not adequately investigated and evaluated during the site characterization programs. In several instances, the additional information has raised questions related to the ability to adequately model and monitor the potential migration of radionuclides in the site ground-water systems." Thus it seems that the level of exploration at some natural sites has not been sufficient.

The NRC (1985) has further noted some of the sources of the problems of characterizing natural sites. Problems exist in obtaining undisturbed soil samples and conducting the proper and sufficient laboratory tests to establish material properties. "Lastly, the ability to measure the necessary site characteristics is much more complex and less reliable for geologically complex sites. It may be impossible to get adequate, reliable data from sites underlain by fractured rock. Even sophisticated, expensive site investigations sample only a small fraction of the subsurface, so extrapolation over wide areas at highly variable sites is unreliable." Extensive explorations may not be justified on highly variable sites, as evidenced by Terzaghi and Leps (1958) who found that only several borings were needed on the highly variable glaciated foundation for Vermillion Dam in the Sierra Nevada Mountains since a further number did not give additional useful information. Rather their approach was to accommodate all eventualities into the design relating to the foundation variability. A design approach such as this would be difficult for a LLW disposal facility.

Engineered Soil

An adequate program of construction monitoring and quality control testing is crucial to the successful performance of an engineered soil barrier. Each phase or component of construction can be visually inspected, tested, or verified. Construction quality control provides greater assurance that the entire soil mass would have the desired characteristics, since the placement and composition of each layer could be closely monitored. The records maintained in the future will be available for possible future analyses.

The process of visually inspecting, testing, and controlling begins in the borrow area or at the source. For borrow areas containing nonuniform materials, it may be necessary for construction personnel to guide excavating equipment to avoid or segregate substandard material as it is excavated. Inspection personnel can observe segregation operations carefully and continuously to ensure that only suitable material is retained for construction (Goldman 1988). If nonsoil additives are utilized, quality assurance statements could be provided by the suppliers. If a mixing plant is used, then the quantity of water, soil types and additives can be computer controlled and the components continuously monitored. Normally the placement of each soil layer is visually inspected, criteria for construction methodology are maintained, and testing is conducted. Visual inspection includes checks on thickness of the soil layer, extraneous materials, and lapses in field mixing or compaction. All of these are backed by test methods. The testing normally includes density and moisture content but it may also include permeability testing or other testing.

A test fill can be used to verify the adequacy of the materials, design, equipment, and construction procedures proposed for the engineered soil barrier. Constructing a test fill before full-scale facility construction can minimize the potential dangers and expense of constructing an unacceptable soil barrier. In addition, the test fill is a convenient tool for evaluating the performance of the compacted soil mass and for determining whether the intended compaction equipment can achieve the intended results on the specified soil (Northiem and Truesdale 1986).

Table 2 is a summary of information on current construction quality control practices obtained during interviews with design engineers active in designing and controlling the construction quality of clay liners for waste management facilities and from government agencies (Goldman 1988). Table 3 lists recommendations for construction documentation published by the Wisconsin Department of Natural Resources personnel. Upon review of the data, the average minimum frequency of in-place moisture or density test appears to be one test per 6800 square feet or every 500 cubic yards of compacted material (assuming a 6-in. lift of soil). Thus the frequency of testing even at placement is more than 5 times the amount that would be considered for a uniform natural site. Density and moisture testing can be automated so that almost continuous profiles across layers are obtained.

Additive Materials

Additives have been utilized in numerous engineered soil applications to improve the properties of the soil. The most common additives are asphalt and cement to form their respective concretes. Each is produced in mixing plants, and this technology is adaptable for other additives. In some parts of the country, the addition of lime to soils is common. However, for soils beneath low-level radioactive disposal facilities, permeability and adsorption characteristics with a long life are important, and thus clays are an important additive. In each area of the country, local soils are used as additives.

Bentonite

Bentonite is a colloidal clay composed chiefly of the clay mineral montmorillonite. Two major varieties of bentonite that have commercial application are: sodium bentonite and calcium bentonite. The sodium bentonite is more reactive than the calcium bentonite. Both have been used in relatively small percentages (<5) by weight in slurry walls to control lateral movement of water and liquid wastes (D'Appolonia 1980). Polymer-modified bentonites have been developed, which reportedly improved resistance to salt contamination and to other contaminants aggressive to bentonites (Haxo et al. 1985). Bentonite clays are attractive candidate materials in adsorbing leachates (Cecille 1991). For this reason, it has been used as a sealant or lining material for landfills (Haxo et al. 1985). Also, bentonite can adsorb certain radionuclides (Freeman and Jones 1988).

Zeolites

In addition to bentonite, other clay minerals hold promise in the disposal of low-level radioactive waste. One mineral group in particular, natural zeolites, has received considerable attention (Freeman and Jones 1988). Mumpton (1981) describes the history and use of zeolitic tuffs. The materials have been used as building materials for centuries, but have now been found to apply to the removal of radioactive Cs-137 from nuclear wastewaters. One type of zeolite, clinoptilolite, has been used at Hanford for the removal of radioactive cesium and strontium from low-level waste streams of nuclear installations. Natural zeolites also apply to Sr-90, Co-60, Ca-45, and Cr-51 and thus have a major role in LLW facility design.

Other Clays

A number of other natural clays, including ones containing vermiculite and halloysite, may have properties of interest. Certain clays, such as Mexico City Clay, have unique properties and some of these may apply strongly to this application. In warm climates, iron-rich clays are produced that could be important for certain radioactive minerals.

Other Materials

Other materials could be considered for additives because they are used now for adsorber materials. These include peat, activated carbon, and ion-exchange resins. Questions about their durability make them less attractive than clays.

In the last 20 years peat has been used in environmental pollution control. Peat has been demonstrated effective in the removal of heavy metals and trace organics in a variety of situations (McLellan and Rock 1986). Peat has good potential for use as both an adsorption and ion-exchange medium. The range of pollutants that peat has been demonstrated to remove from wastewaters is growing and may apply to certain radioactive minerals. Peat would likely have to be placed below permanent water for long life of the organic material.

Carbon has been known throughout history as an adsorbent, its usage dating back before Christ. It was used in England in the mid-19th century with the treatment of drinking waters for removal of odors and tastes. Water and wastewater treatment with carbon has become widespread in municipal and industrial processes, including wineries and breweries, paper and pulp, pharmaceutical, food, petroleum and petrochemical, and other establishments of water usage (Cheremisinoff and Ellerbusch 1980). More recently, activated carbon has been investigated as a sorbent material used to prevent the migration of radionuclides from low-level radioactive waste leachate. Activated carbon's greatest strength is in the adsorption of cobalt (Freeman and Jones 1988). An issue to be addressed is its long-term durability and effectiveness.

One of the uses of chemically modified polymers is in the form of synthetic ion-exchange resins. Their main advantages are high chemical and mechanical stability, high ion-exchange capacity, and high exchange rate. An additional advantage is the possibility of selecting the fixed ionogenic groups and the degree of crosslinking of the matrix according to the intended applications (Biswas and Packirisamy 1984). Sodium titanate and sodium titanate resins have been investigated as ion-exchangers to remove Sr-90 and actinides from the large volume of defense waste stored at the Hanford Site in Washington (Kenna 1986).

Performance

Engineered and compacted embankments, in general, behave more predictably and with fewer problems than natural soils. Natural soils may or may not have large settlements under the load of a LLW facility or have problems of foundation stability due to inadequate strength. This variability is the major problem of natural soils. For example, some of the highly precompressed tills have more resistance to movement under load than any compacted soil. However, there are natural clays, such as the marine clay found in Maine, which have more than five feet of settlement for a 60-foot-thick deposit with only a loading of 30 feet of embankment fill. In comparison, the settlement of most properly compacted soils is insignificant for the type of loads that will be found in a LLW facility. The same considerations apply to strength, i.e., it is adequate for compacted soils and may or may not be adequate for natural soils.

Embankment dams, which are engineered embankments built in many cases over natural soils, appear to be able to be designed for earthquake loads by present methods. Sherard (1967) stated, "We are confident that embankment dams which would be safe against strong earthquake shaking can be built at most sites with suitable foundations and that it is reasonable and prudent to do so." Seed (1979) stated that, "Virtually any well-built dam on a firm foundation can withstand moderate earthquake shaking, say with peak accelerations of about 0.2g, with no detrimental effects." Thus there is a confidence that embankments can be designed to withstand earthquake forces but the foundation must itself be strong enough.

Failures of dams and other earth structures have occurred in the natural soils and in the embankments also. Some of the failures in engineered embankments have occurred with early designs such as with uncompacted hydraulic fills dams built around the turn of the century. Much damage in the Loma Prieta earthquake in the San Francisco area was related to hydraulic fills (Seed et al. 1990). However, failure can occur in engineered embankments if poor quality construction is done. The risks in engineered soils appear to be more controllable than those in natural soils.

SUMMARY AND CONCLUSIONS

Properly designed earth fills have the potential for a long life, since they are composed of durable soil constituents. A number of temples and mounds, which were built before recorded history, survive to the present day. Some aqueducts and roads built with embankments in the early Roman times are still being used

today. Canals, dams, and roads built in the last several hundred years form a vital part of our infrastructure, and the extension to use engineered soils below low-level radioactive waste facilities seems to be a natural evolution.

Natural soil additives that can enhance the adsorption of radionuclides or alter other properties are available for all facilities. These include bentonite and zeolite but may include local soils as well. Soils with special properties, such as iron-rich or carbonate soils, are available from certain locales. There are also different soils like Mexico City Clay, which is of volcanic origin and has unique behavior, that deserve to be more thoroughly investigated for possible applications to low-level radioactive waste facilities.

The technology and the skills are available to efficiently and cost effectively manufacture designed soils. This technology includes selection, crushing, screening, washing, mixing, and compacting.

To characterize natural soils, the boundaries and properties must be discovered through subsurface investigations. No matter how thorough the investigation, only a small portion of the subsurface is examined or tested. The possible gaps and natural variability increase the risk that the natural soil deviates in its characterization from that found in the investigation.

In contrast, engineered soils can be monitored extensively to produce a high quality product that is homogeneous, well defined, and meets a particular objective. The quality of the engineered soils depends upon the quality of the construction, and thus monitoring is an integral part of the production. Engineered soils are normally independently monitored at several different locations including at the source, during processing, and during placement. Visual inspection with confirming tests that can be automated with computer control in the processing plant can give thorough monitoring for better characterization and future documentation.

Engineered soils will be used to some extent in any disposal facility that will be designed and constructed. Engineered soil covers, filters, and soil drains will likely be part of any facility in addition to the natural barrier. Engineered soils could be used more extensively to enhance a site whose characteristics are insufficient to effectively isolate the radioactive waste. Use of engineered soils increases the range of sites that may be used for the disposal of LLW, since sites with little or no overburden may be considered for the facility.

Although failures have occurred in both engineered soils and natural soils, the engineered soils are, in general, more consistent and reliable. The resulting engineered soils have the potential to contain radionunclide releases with a higher degree of reliability because of their greater homogeneity and the addition of materials with specific qualities. Engineered soils will cost more compared to natural soils, so decisions must balance the extra costs versus the reduced risks.

Table 1. Formation processes for engineered fill.

Process	Equipment	Usage	Products
SELECTION	Drill Rig Testing	Control type, composition and source of soil material used in an engineered fill.	Sand, gravel, clay and silt
TRANSPORTATION	Truck Rail Barge	Import materials not available locally.	Bentonite, zeolites, clay
COMPACTION	Roller	Control density, permeability and strength of fill.	Embankments, foundations, liners
SCREENING AND SORTING	Screen	Select size to be incorporated or removed from soil.	Filters, gravel, sand, aggregates
WASHING	Washer	Utilize water to sort or remove soil particles.	Sand for concrete, masonry
CRUSHING	Crusher	Mechanically breaking down mass rock into usable fragments.	Aggregates for concrete, asphalt, gravel
ADMIXING	Pugmill Mixer Tiller	Combining different materials together to create a material with desired characteristics.	Soil/Bentonite for liners, asphalt for pavement, lime for stabilization

Table 2. Current quality assurance practices for clay liner construction.

Source of Information	Minimum frequency of in-place moisture or density test	Permeability testing
A	1 per 1,000 c.y. of fill	Occasional lab test
B	Moisture tests only (used with permeability tests and compactive effort to control compaction)	Triaxial and some field tests
C	Frequency per unit volume of fill based on experience	Lab tests
D	1 per 2,500 s.f. of lift	Triaxial -1 per 3 acre feet with minimum of 1 per acre
E	Frequency, per unit volume of fill, based on experience and liner material homogeneity	Modified triaxial, fixed-wall and consolidation lab tests - per unit volume of fill, based on experience
F	Statistical approach	Lab tests - 5 to 6 per acre
G	9 per acre of lift	Falling head field test at density test location - 1 per acre of lift
H	1 per 2,000 s.f. or at least 1 per lift	Lab test - 1 per 10,000 to 20,000 s.f. or every third lift
I	1 per 2,500 s.f. minimum of 4 per lift or 1 per day - more as needed	Lab test - 1 per 2,000 c.y. or 2 per lift - occasional field test
J	1 per 10,000 s.f. or 1 per lift	Lab and field
K	Site specific, based on experience	Lab triaxial
L	1 per 1,000 c.y. or 1 per day	Lab constant head - 1 per 25,000 c.y. or 1 per week
M	1 per 1,000 c.y. or 1 per day	Lab falling head - 1 per 25,000 c.y.
N	1 per 1,000 c.y. - 1 per 200 c.y. if hand tamped	Not indicated
O	1 per 500 to 1,000 c.y.	Not indicated

Source A through M were design and geotechnical engineers with clay liner construction experience.

Source N, U.S. Bureau of Reclamation, 1974.

Source O, U.S. Department of the Navy, 1982.

Table adapted from Goldman, 1988.

Table 3. Recommendations for construction of clay-lined landfills.

Item	Testing	Frequency
Clay borrow source testing	Grain size	1,000 c.y.
	Moisture content	1,000 c.y.
	Atterberg limits (liquid limit and plasticity index)	5,000 c.y.
	Moisture-density curve	5,000 c.y. and all changes in material
	Lab permeability (remolded samples)	10,000 c.y.
Clay liner testing during construction	Density (nuclear or sand cone)	5 tests/acre/lift (250 c.y.)
	Moisture content	5 tests/acre/lift (250 c.y.)
	Undisturbed permeability	1 test/acre/lift (1,500 c.y.)
	Dry density (undisturbed sample)	1 test/acre/lift (1,500 c.y.)
	Moisture content (undisturbed sample)	1 test/acre/lift (1,500 c.y.)
	Atterberg limits (liquid limit and plasticity index)	1 test/acre/lift (1,500 c.y.)
	Grain size (to the 2-micron particle size	1 test/acre/lift (1,500 c.y.)
	Moisture-density curve as per clay borrow requirements	5,000 c.y. and all changes in material

Source: Wisconsin Department of Natural Resources (Gordon et al., 1984).

REFERENCES

Alexander, J. A., Anderson, C. A., Breskin, K. L., Brutsaert, W. F., Eash, M. L., Elgaaly, M., Fernandez, I. J., Hess, C. T., Humphrey, D. N., Norton, S. A., Rock, C. A. and Sandford, T. C., 1992, "Conceptual Design for Low-Level Radioactive Waste Disposal in Maine," Maine Low-Level Radioactive Waste Authority, Augusta, Maine., April 1992, pp. 18-21.

Biswas, M. and Packirisamy, S., 1984, *Advances in Polymer Science*, Springer-Verlag Publishers, Vol. 70, pp. 73-93.

Caswell, W. B., 1987, *Ground Water Handbook for the State of Maine*, Maine Geological Survey, Augusta, Maine, 1987, 135 pp.

Cecille, L., 1990, *Radioactive Waste Management and Disposal*, Commission of the European Communities, Elsevier Science Publishers Ltd., 1990 London, pp. 365.

Cheremisinoff, P. N. and Ellerbusch, F., 1980, *Carbon Adsorption Handbook*, Ann Arbor Science Publishers Inc., 1980, pp. 1-54.

D'Appolonia, D. J., 1980, "Soil-Bentonite Slurry Trench Cutoffs," *J Geotechnical Engineering Division*, American Society of Civil Engineers, V. 106, No. GT4, April 1980, pp. 399 - 417.

Fetzer, C. A., Kramer. R. W., and Swiger, W. F., 1988, "Earthfill Dam Construction and Foundation Treatment," Chapter 10 in *Advanced Dam Engineering for Design, Construction, and Rehabilitation*, ed by Robert B. Jansen, Van Nostrand Reinhold, New York, 1988, pp. 321 - 353.

Federal Highway Administration, 1988, Highway Statistics 1987, Report No. FHWA-PI-88-008, Washington, D. C., 1988, p. 109.

Freeman, H. D. and Jones, E. O., 1988, "Design of Engineered Sorbent Barriers", *10th Annual DOE Low-Level Waste Management Conference, August 30-September 1, 1988, Denver, Colorado,* pp. 40-45.

Goldman, L. J., 1988, *Design, Construction, and Evaluation of Clay Liners for Waste Management Facilities*, U.S. Environmental Protection Agency, EPA/530/SW-86/007F, 1988, pp. 5-89.

Gordon, M. E., Huebner, P. M. and Kmet, P., 1984, "An Evaluation of the Performance of Four Clay-Lined Landfills in Wisconsin," *Seventh Annual Madison Waste Conference, University of Wisconsin, Madison, Wisconsin, 1984.*

Hansen, K. D. and Reinhardt, W. G., 1991, *Roller Compacted Concrete Dams,* McGraw-Hill, Inc., New York, 1991, pp. 1-62.

Haxo, H. E. Jr., Haxo, R. S., Nelson, N. A., Haxo, P. D., White, R. M., Dakessian, S. and Fong, M.A., 1985, *Liner Materials for Hazardous and Toxic Wastes and Municipal Solid Waste Leachate*, Pollution Technology Review No.124, Noyes Publications, Park Ridge, N. J., 1985, pp. 48-49.

Kenna, B. T., 1986, *Radiation Stability of Sodium Titanate Ion-Exchange Materials,* Sandia Laboratories, Albuquerque, N.M., February 1986, pp. 1-5.

Maine Department of Environmental Protection, 1988, "Code of Regulations for Low-Level Radioactive Waste storage, Disposal and Facility Siting," Approved September 28, 1988.

McLellan, J. K. and Rock, C. A., 1986, "The Application of Peat in Environmental Pollution Control: A Review," *International Peat Journal, 1*, 1986, pp.1-14.

Miles, S. H., 1977, "Status Report on Public Law 92-367," The Evaluation of Dam Safety, American Society of Engineers, New York, 1977, pp. 3-19.

Mumpton, F. A., 1981, *Mineralogy and Geology of Natural Zeolites*, Vol. 4, Mineralogical Society of America, Washington D.C., 1981, pp. 177-9.

Northiem, C. M. and Truesdale, R. S., 1986, *Construction Quality Assurance for Hazardous Waste Land Disposal Facilities*, U.S. Environmental Protection Agency, EPA/530-SW-86-031, 1986, pp. 19, 25, 55-66.

Code of Federal Regulations, 10 CFR 61, "Licensing Requirements for Land Disposal of Radioactive Waste," Office of the Federal Register, January 1, 1992.

Nuclear Regulatory Commission, 1988, *Standard Review Plan for the Review of a License Application for a Low-Level Radioactive Waste Disposal Facility,* Office of Nuclear Material Safety and Safeguards, NUREG-1200, Rev. 1, 1988.

Nuclear Regulatory Commission, 1986, *Site Suitability, Selection and Characterization*, Branch Technical Position-Low-Level Waste Licensing Branch, Office of Nuclear Materials Safety and Safeguards, NUREG-0902, 1986.

Nuclear Regulatory Commission, 1985, *Alternative Methods for Disposal of Low-Level Radioactive Wastes*, Vol. 3, "Technical Requirements for Aboveground Vault Disposal of Low-Level Radioactive Waste," Office of Nuclear Materials Safety and Safeguards, NUREG/CR-3774, 1985.

Nuclear Regulatory Commission, 1979, "Site Investigation for Foundations of Nuclear Power Plants," Office of Standards Development, Regulatory Guide 1.132, 1979.

Nuclear Regulatory Commission, 1978, "Laboratory Investigations of Soils for Enginering Analysis and Design of Nuclear Power Plants," Office of Standards Development, Regulatory Guide 1.138, 1978.

Seed, H. B., 1979, "Considerations in the Earthquake-Resistant Design of Earth and Rockfill Dams," *Geotechnique, V. 29, No. 3*, 1979, pp. 215-263.

Seed, R. B., Dickenson, S. E., Riemer, M. F., Bray, J. D., Sitar, N., Mitchell, J. K., Idriss, I. M., Kayen, R. E., Kropp, A., Harder, Jr. L. F., and Poer, M. S., 1990, *Preliminary Report on the Principal Geotechnical Aspects of the October 17, 1989 Loma Prieta Earthquake*, Report No. UCB/EERC-90/05, University of California at Berkeley, 1990, pp. 73-76.

Sherard, J. L., 1967, "Earthquake Design Considerations," *J Soil Mechanics and Foundations Division*, American Society of Civil Engineers, July 1967, pp. 377 - 402.

Sowers, G. F., 1981, "There Were Giants in Those Days," *J Soil Mechanics and Foundations Division*, American Society of Civil Engineers, April 1981, pp. 383 - 420.

Terzaghi, K. and Leps, T. M., 1958, "Design and Performance of Vermilion Dam," *J Soil Mechanics and Foundations Division*, American Society of Civil Engineers, August 1958, V. 84, No. SM4, 30 pp.

Tucker, R. D., and Marvinney, R. G., 1989a, *Studies in Maine Geology*, Volume 5, "Quaternary Geology," Maine Geological Survey, Augusta, Maine, 1989, 176 pp.

Tucker, R. D., and Marvinney, R. G. 1989b, *Studies in Maine Geology*, Volume 6, "Quaternary Geology," Maine Geological Survey, Augusta, Maine, 1989, 142 pp.

Mechanisms of Contaminant Migration from Grouted Waste

Swen O. Magnuson
Idaho National Engineering Laboratory[a]
EG&G Idaho, Inc.
Idaho Falls, ID 83415

Andrew D. Yu
Westinghouse Savannah River Company

INTRODUCTION

Low-level radioactive decontaminated salt solution is generated at the Savannah River Site (SRS) from the In-Tank Precipitation process. The solution is mixed with cement, slag, and fly ash to form a grout, termed "saltstone," that will be disposed of in concrete vaults at the Saltstone Disposal Facility (SDF).[1] Of the contaminants in the saltstone, the greatest concern to SRS is the potential release of nitrate to the groundwater because of the high initial nitrate concentration (0.25 g/cm^3) in the saltstone and the low Safe Drinking Water Act (SDWA) maximum contaminant level (MCL) of 44 mg/L. The SDF is designed to allow a slow, controlled release over thousands of years. The release is limited or controlled by the low saltstone hydraulic conductivity and low diffusivity. The facility performance objective is to comply with the SDWA MCL of 10 mg/L of $NaNO_3$ as nitrogen,[2] or 44 mg/L as $NaNO_3$, in the groundwater at the SDF boundary.

This paper addresses a modeling study of nitrate migration from intact, nondegraded concrete vaults in the unsaturated zone for the radiological performance assessment (PA) of the SRS Saltstone Disposal Facility.[3] The PA addresses the performance requirements mandated by DOE Order 5820.2A.[4] Simulations of degraded concrete vaults were also performed but are not part of this paper.

THE SALTSTONE DISPOSAL FACILITY

The SDF will consist of 15 concrete vaults. The first vault, completed in 1990, is 100 feet wide by 600 feet long by 25 feet high. The other 14 vaults will be twice as wide. The bottom of the vault is at ground level, which is at least 20 feet above the historical high water table. The vault sides are 1.5 feet thick and the vault floor is 2 feet thick. The vault will be filled with 24 feet of contaminated grout, and one foot of uncontaminated grout is placed on top. A sloped concrete roof approximately 3 feet thick at the center and 2 feet thick at the edge will complete the vault.

After the vaults are filled, the SDF will undergo closure. Although the closure plan has not been completed, the current closure concept includes backfilling around the vault; backfilling two more feet above the vault; and then placing two feet of clay, one foot of gravel, three feet of soil, and two feet of top soil above the backfill. The purpose of the closure is to reduce infiltration, reduce the likelihood of exposure to an inadvertent intruder, and minimize the probability of waste exposure by erosion. A schematic diagram of the SDF is shown in Figure 1.

a. This work was sponsored by the U.S. Department of Energy, Office of Environmental Restoration and Waste Management, under DOE Savannah River Field Office Contract No. DE-AC09-89SR18035.

CONCEPTUAL MODEL

Modeling Domain

A two-dimensional vertical cross-section of a saltstone vault was modeled (Figure 2). The top of the simulation domain was the backfill soil below the clay cap. The closure cap was excluded to reduce the model complexity. However, the effect of the closure cap was represented by a reduced infiltration rate at the upper boundary. The bottom of the simulation domain was the water table. Only half of a vault was simulated to take advantage of symmetry. The saltstone grout monolith was placed at the upper left portion of the model and was surrounded by the concrete vault. The vault design included a sloping concrete roof; however, this was not included in the simulation and can be considered conservative since in increases the amount of perched water on the roof.

Initial and Boundary Conditions

An initial nitrate pore water concentration of 0.25 g/cm^3 was calculated based on the inventories to be disposed of and the grouting process. There was assumed to be no nitrate in the pore fluid of the concrete vault or in the backfill soil. The concrete vault and the saltstone were assumed to be at 100% water saturation. The backfill soil water saturation was calculated from the soil characteristics (relative conductivity and capillary pressure) with a 40 cm/yr infiltration, the accepted rate at SRS based on lysimeter tests and water balance studies.

The boundary conditions used for the simulation were: (a) constant water influx of 2 cm/yr at the top of the domain which accounts for the effect of the closure cap, (b) the bottom of the simulation domain was represented by the water table, which was modeled with a prescribed head of zero cm, (c) a zero nitrate concentration was assigned to the top and the bottom boundaries assuming nitrate was quickly removed at the aquifer, and (d) no convective or diffusive flux was allowed at the vertical boundaries due to symmetry. One vertical boundary represented the centerline of a vault while the other boundary was midway between vaults.

Transport Mechanism

The dominant mechanisms for nitrate release from the saltstone were convection and diffusion. Convection results as a small amount of perched water flows through the vault and leaches nitrate from the saltstone. Diffusion occurs as a result of the concentration gradient between the saltstone and the model boundaries. Because of these two processes, simultaneous transient flow and transport were simulated. This option was more realistic than using a steady-state flow assumption because it took approximately 2000 years for the flow field to reach steady state.

The relative importance between convection and diffusion was governed by the flow and transport properties of the porous media. It was assumed that the properties of the materials remained unchanged during the entire period modeled. The hydraulic conductivities and the diffusivities for saltstone, concrete, and the backfill used in this study were:

Material	Conductivity (cm/sec)	Diffusivity (cm^2/sec)
Saltstone	1.0×10^{-11}	5.0×10^{-9}
Concrete Vault	1.0×10^{-10}	1.0×10^{-8}
Backfill Soil	1.0×10^{-5}	5.0×10^{-6}

The saltstone diffusivity has been measured extensively in leaching tests.[5] The measured slag-formulated saltstone conductivity data ranges between 1×10^{-12} and 1×10^{-8} cm/sec. Further validation tests to better determine the saltstone conductivity are under way.

Other mechanisms that typically affect contaminant transport are adsorption, decay, chemical reactions, and solubility limits. These were unimportant in this study because nitrate is nonsorbing, nondecaying, nonreactive and highly soluble.

MODELING METHODOLOGY

The PORFLOW 2.40 simulation code[6] was used for the study. A 56 x 97 computational grid that was nonuniformly spaced was used for the simulation and is shown in Figure 3. The vertical grid dimensions were optimized by one-dimensional modeling. Small grid blocks at the material interfaces were used to minimize numerical dispersion. Harmonic averages of flow and transport properties were used for the calculation.

Because of the huge contrast in conductivity and diffusivity between the backfill and the cementitious materials, most of the infiltrating water was diverted through the backfill. Only a small fraction of water penetrated the vault. Since all the nitrate was initially in the saltstone, the amount of water penetration was crucial to nitrate release. It was found that a double-precision code was necessary to account for the minute changes in water penetration.

A valuable lesson learned from this study was to use small time steps and a large number of iterations, especially in the beginning of the run. Earlier runs using relatively large time steps resulted in a mass balance error of more than 100%. A run with a starting time step of 0.0001 year, which gradually increased to 1 year by 10,000 years, reduced the mass balance error to less than 0.01%. Using small time steps also reduced the number of iterations per time step.

The alternate direction implicit (ADI) solver was used for this application. Because the problem was basically vertical flow, three vertical (y-direction) sweeps were followed by one horizontal (x-direction) sweep. An abrupt change was imposed on the system when the vault was superimposed and the infiltration was reduced from 40 to 2 cm/yr. These impulses resulted in a significant mass balance error even when very small time steps were used. A solution to the mass balance problem was to solve only the pressure equation for the first year and then solve for pressure and mass simultaneously. The pressure solution was discontinued once steady-state conditions prevailed, which occurred by 2000 years.

RESULTS

Based on conservative assumptions and the best available data, a base run (Run 1) was conducted to predict nitrate release from the saltstone vault. The resulting steady-state water saturations and pressure heads are shown in Figures 4 and 5. Due to the small pore structure of the concrete and saltstone, both of these were completely saturated. The 2 cm/yr infiltration rate resulted in water perching above the vault and being diverted around the side of the vault through the backfill. The area beneath the vault was relatively dry and had the highest capillary pressure. Figure 6 shows the flow streamlines for steady-state conditions with arrowheads to indicate travel times. Due to the dramatic differences in water velocities in separate regions of the simulation, three different time interval markers were used to illustrate water movement. Above and beside the vault, the travel time markers indicate 10 years. Below the vaults, the time markers indicate 5000 years. Within the saltstone itself, the travel time between arrowheads is 50,000 years.

Nitrate could either migrate upward against infiltration or downward to the aquifer. With 2 cm/yr infiltration, the amount of nitrate that diffused through the top boundary was negligible. More than 99.99% of the released nitrate discharged to the aquifer. The rate of nitrate discharge was obtained by integrating the product of concentration and flow rate across the bottom of the simulation domain to obtain a release rate in grams per year for the modeling domain. Since the modeling domain was a prototype for the SDF, the release rate was divided by the initial inventory to obtain the fractional yearly release. This predicted fractional yearly release for the Base Run is shown in Figure 7. This release history was then used as a key input to the saturated zone model. The saturated zone model consisted of a three-dimensional steady-state flow field and transient contaminant migration. The predicted peak concentration at the site boundary resulting from the intact vault simulation was 8 mg/L, about 1/5 of the SDWA MCL. This saturated transport simulation is outside the scope of this paper.

DISCUSSION

The bottleneck to nitrate release was diffusion and convection in the saltstone and concrete. Once nitrate was released into the soil, it was transported to the water table by convection at the top and side of the vault and mainly by diffusion under the vault. Two hypothetical cases were tested to verify the relative importance of the transport mechanisms. In Run 2, the conductivity of the vault was assumed to be zero. In Run 3, the diffusivity of the vault was assumed to be zero. The fractional release curves for Runs 2 and 3 are compared to that of the base run in Figure 8. Under the assumptions used for the runs, diffusion and convection appear to be about equally important. The peak fractional release of 3.0×10^{-6}/yr for the base run was slightly lower than 3.4×10^{-6}/yr, the combined peak releases from Runs 2 and 3. This probably resulted from an offset of upward diffusion by downward convection at the top of the vault.

Three more runs were conducted to verify the key mechanisms. In Run 4, the conductivities of both saltstone and concrete were increased by a factor of 10 while the diffusivities were kept the same as the base run. In Run 5, the conductivities were the same as the base run, whereas the diffusivities were increased by a factor of 10. In Run 6, both conductivities and diffusivities were increased by a factor of 10. The peak fractional releases increased to 1.7×10^{-5}/yr for Run 4, 2.0×10^{-5}/yr for Run 5, and 2.6×10^{-5}/yr for Run 6, compared to 3.0×10^{-6}/yr for the base run (Figure 9).

From a mass transport point of view, the saltstone and the concrete were in series. Low convective flux was obtained when either or both of the saltstone and the concrete conductivities were low. Low diffusive flux was obtained when either or both of the diffusivities were low. The effect of secondary parameters such as dispersivity, infiltration rate and soil characteristics were also modeled but will not be covered in this paper.

CONCLUSIONS

There are two primary conclusions resulting from this simulation study. They are:

- The flow and transport phenomena in the unsaturated zone for the intact SDF were successfully modeled by PORFLOW.
- Modeling results indicated that the intact SDF will meet DOE Order 5820.2A performance objectives.

REFERENCES

1. C. A. Langton, S. B. Oblath, D. W. Pepper, and E. L. Wilhite, "Waste Salt Disposal at the Savannah River Plant," *Chem. Eng. Comm.*, 1988, Vol. 66, pp. 189-199.

2. U.S. Environmental Protection Agency, "National Interim Primary Drinking Water Regulations," EPA-570/9-76-003.

3. Westinghouse Savannah River Company, *Radiological Performance Assessment for the Z-Area Saltstone Disposal Facility*, prepared for Westinghouse Savannah River Company by Martin Marietta Energy Systems, Inc., EG&G Idaho, Inc., and Westinghouse Hanford Company, August 1992.

4. U.S. Department of Energy, "Radioactive Waste Management," DOE Order 5820.2A, September 26, 1988.

5. E. G. Orebaugh, *DWPF Saltstone Study: Effects of Thermal History on Leaching Index and Physical Integrity - Part II Final Report*, WSRC-RP-92-568, April 10, 1992.

6. Akshai K. Runchal and Budhi Sagar, "*PORFLOW, A Model for Fluid Flow, Heat and Mass Transport in Multifluid, Multiphase Fractured or Porous Media*, User Manual, Version 2.40, January 2, 1992.

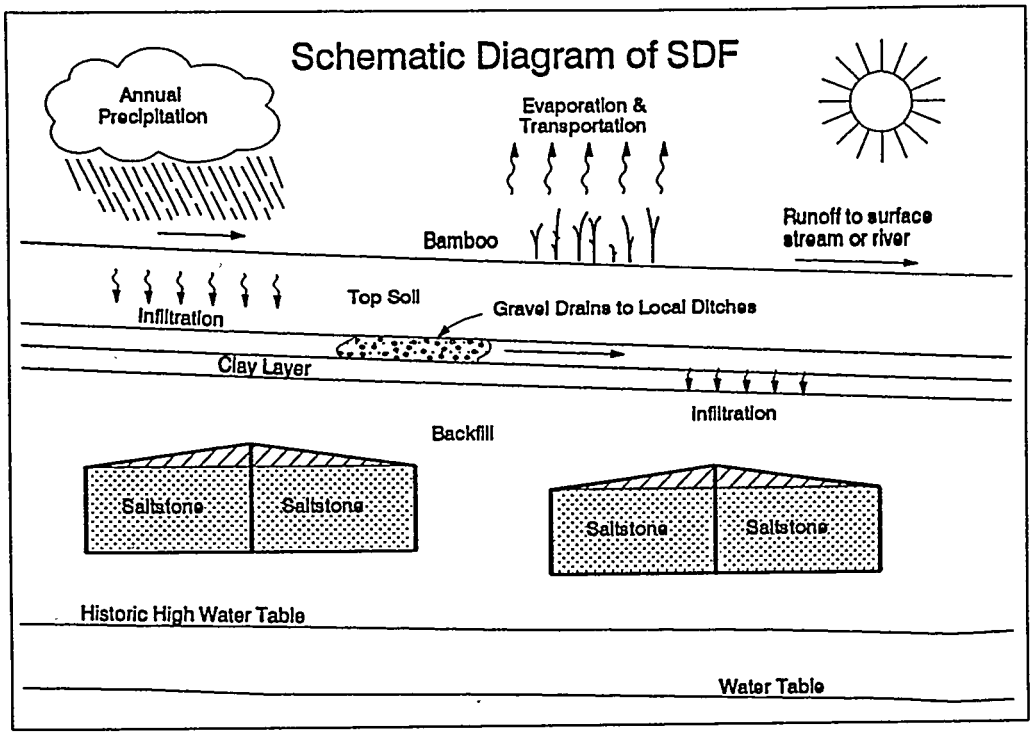


Figure 1

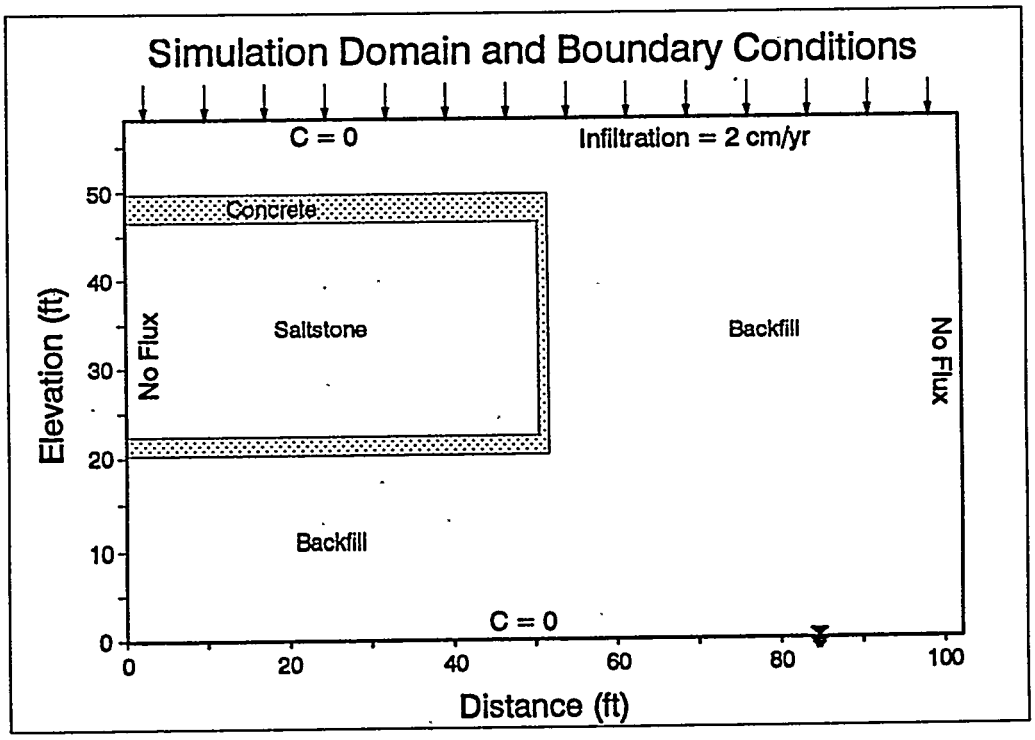


Figure 2

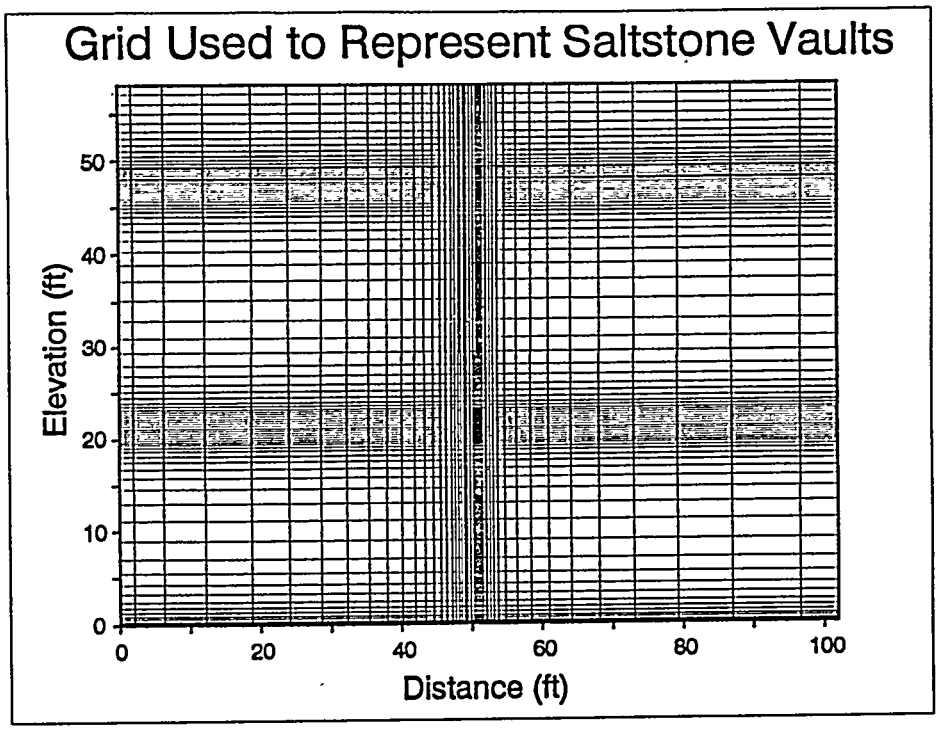


Figure 3

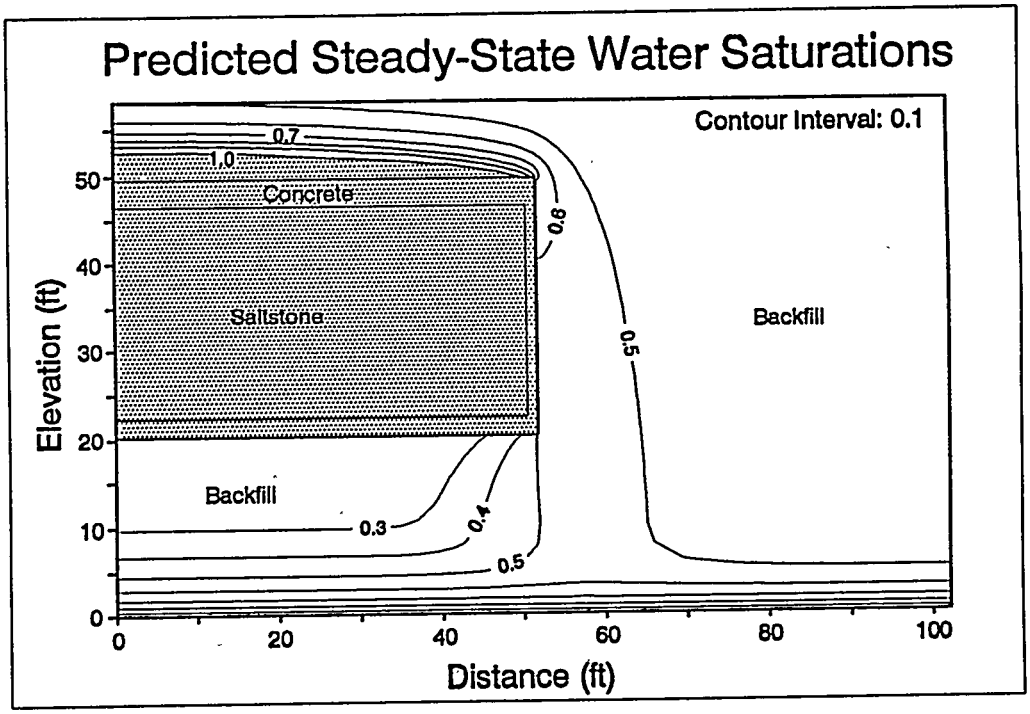


Figure 4

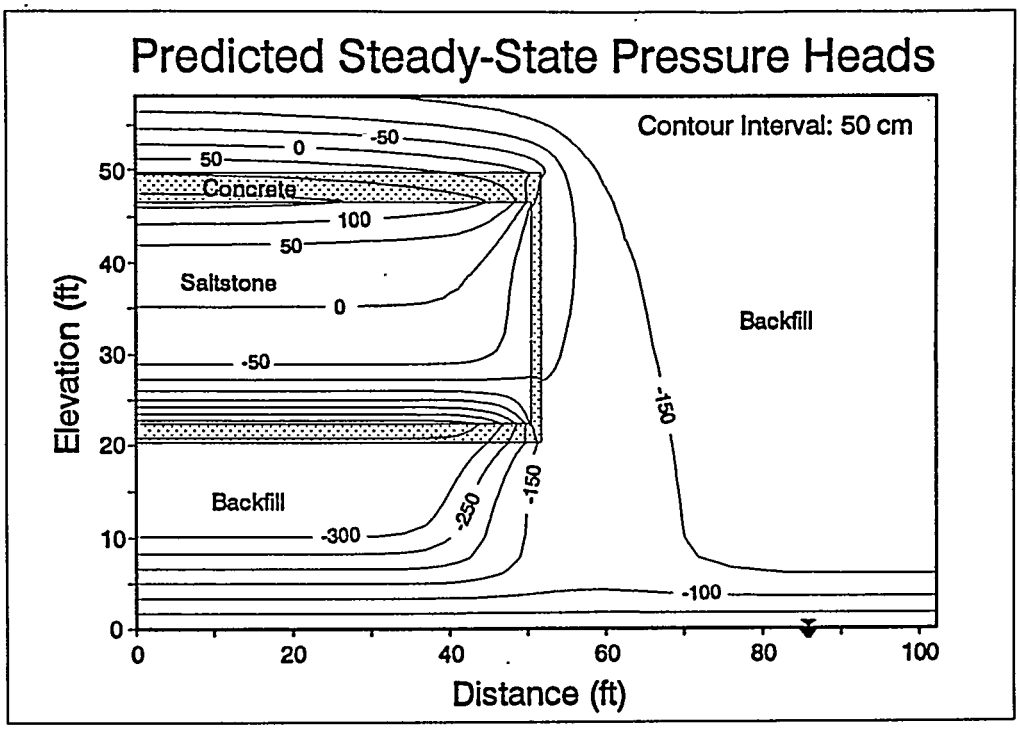


Figure 5

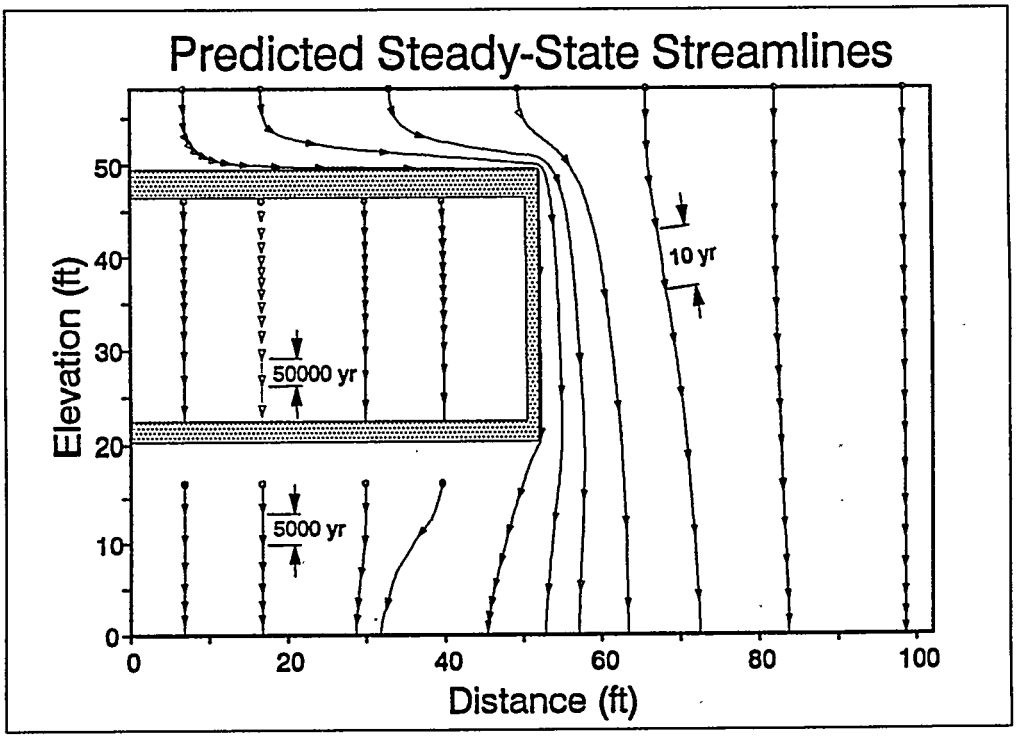


Figure 6

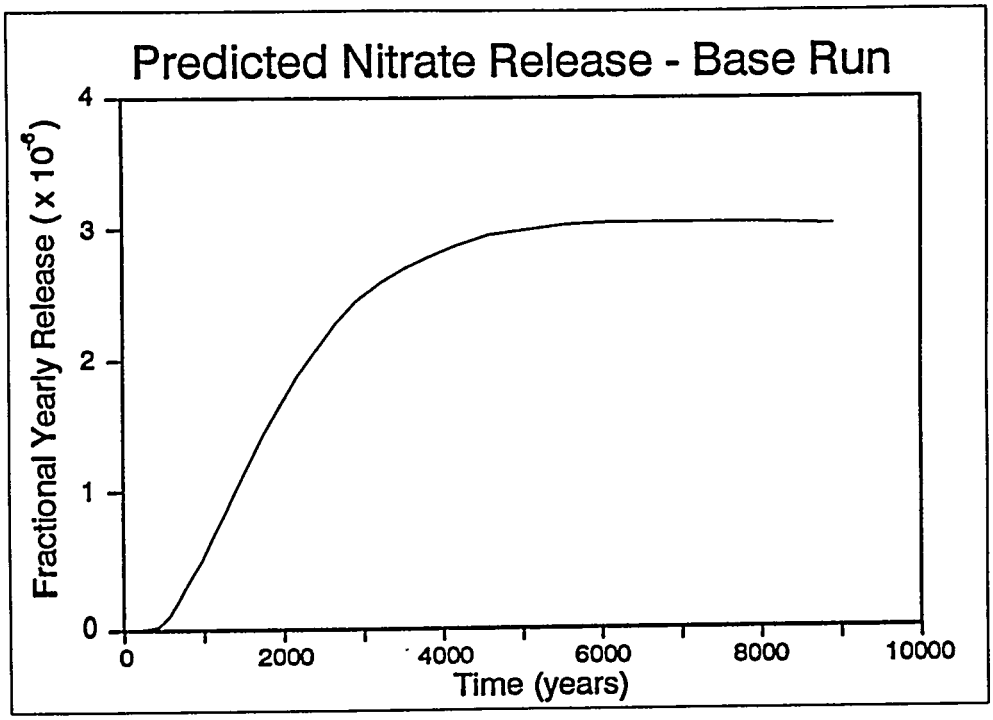


Figure 7

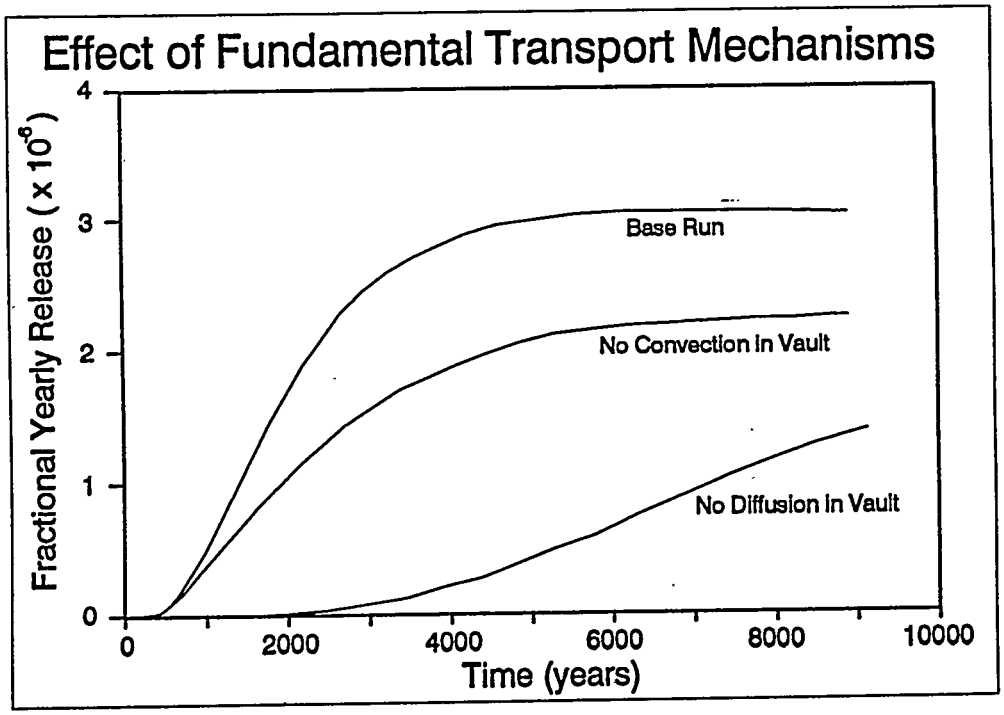


Figure 8

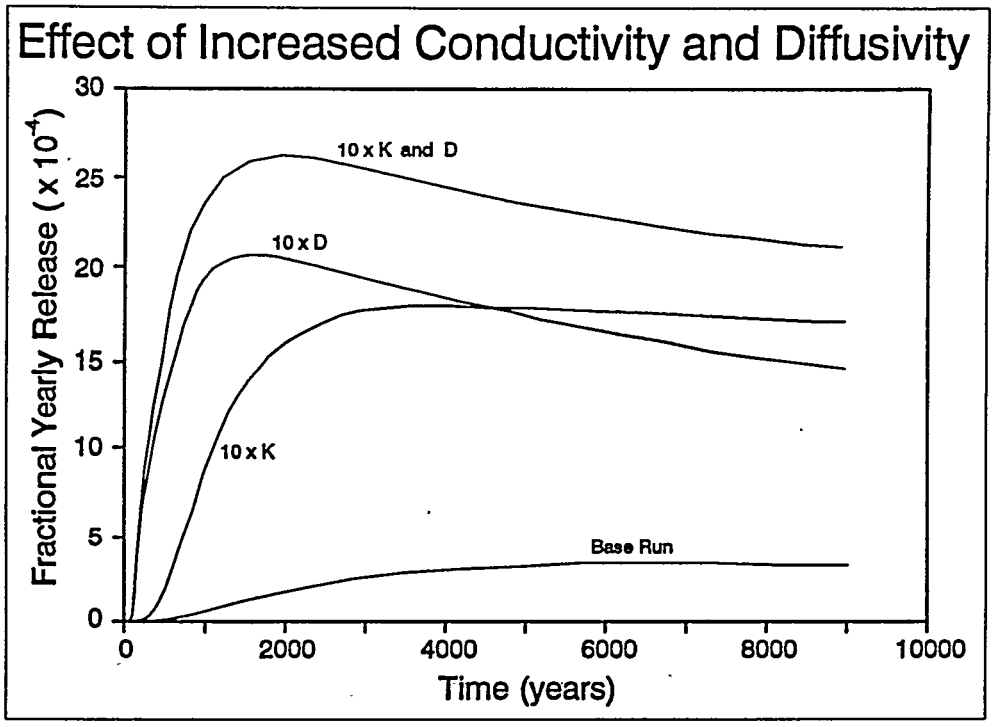

Effect of Increased Conductivity and Diffusivity
Fractional Yearly Release (x 10⁻⁴)
30
25
20
15
10
5
0
10 x K and D
10 x D
10 x K
Base Run
0
2000
4000
6000
8000
10000
Time (years)

Figure 9

Performance Assessment Techniques for Groundwater Recovery and Treatment Systems

Gerald L. Kirkpatrick, P.G.
Environmental Resources Management, Inc.
855 Springdale Drive
Exton, PA 19341

ABSTRACT

Groundwater recovery and treatment ("pump and treat" systems) continue to be the most commonly selected remedial technology for groundwater restoration and protection programs at hazardous waste sites and RCRA facilities nationwide. Implementing a typical groundwater recovery and treatment system includes the initial assessment of groundwater quality, characterizing aquifer hydrodynamics, recovery system design, system installation, testing, permitting, and operation and maintenance. This paper focuses on methods used to assess the long-term efficiency of a pump and treat system. Regulatory agencies and industry alike are sensitive to the need for accurate assessment of the performance and success of groundwater recovery systems for contaminant plume abatement and aquifer restoration. Several assessment methods are available to measure the long-term performance of a groundwater recovery system.

This paper presents six assessment techniques: degree of compliance with regulatory agency agreement (Consent Order or Record of Decision), hydraulic demonstration of system performance, contaminant mass recovery calculation, system design and performance comparison, statistical evaluation of groundwater quality and preferably, integration of the assessment methods.

Applying specific recovery system assessment methods depends upon the type, amount, and quality of data available. Use of an integrated approach is encouraged to evaluate the success of a groundwater recovery and treatment system. The methods presented in this paper are for engineers and corporate management to use when discussing the effectiveness of groundwater remediation systems with their environmental consultant. In addition, an independent (third party) system evaluation is recommended to be sure that a recovery system operates efficiently and with minimum expense.

INTRODUCTION

The most widely used technology for contaminated aquifer restoration and control programs at hazardous waste sites is groundwater recovery and treatment ("pump and treat"). Although pump and treat systems receive wide and varied criticism for their inability to satisfy remedial goals, many of these programs are currently operating. The method will continue to be a selected remedy at hazardous waste sites nationwide, at least in the near future, even though current technologies hold great potential.

Performance assessment of these systems is necessary to prove that adequate protection of human health and the environment is being achieved through efficient operation of the system. In addition, system owners and operators need to provide supporting data that effective use of operating capital is being realized through proper operation and maintenance of equipment. If necessary, the assessment results are useful in modifying the recovery system such that original performance goals are met.

This paper encourages the use of integrating assessment methods and independent third-party evaluation of pump and treat systems to improve performance of aquifer restoration systems.

No single assessment method provides a comprehensive evaluation of the overall success of a groundwater recovery and treatment system. Groundwater quality data will provide an indication of the degree to which protection to human health and the environment is achieved (the key objective), yet the recovery system equipment may be operating ineffectively and inefficiently, consuming an operator's invested capital.

The degree to which a regulatory agreement is being followed may provide legal evidence of system success; however, long-term operation of the recovery system may show that the system, as originally designed, is inadequate or over-designed. In such cases, recommending changes to improve system performance is appropriate.

PRELIMINARY ASSESSMENT STRATEGY

Collecting proper groundwater remediation system assessment data is done only after developing measurable remedial goals and identifying a data collection strategy. These data are used to assess the degree to which remedial goals are satisfied. The primary goal of a groundwater remediation program is to restore the affected aquifer to a condition protective of human health and the environment. For plume containment, for example, the primary goal of operating a groundwater recovery system is to limit the expansion and migration of a contaminant plume and to provide protection of nearby receptors. Achieving remediation goals using pump and treat systems is assessed in several ways (Table 1):

- Compliance with regulatory agreement Frequently, administrative orders require meeting certain performance criteria. These criteria are usually expressed in terms of compliance with water quality goals (ARARs, MCLs etc.);

- Demonstration of system hydraulic contaminant control Recovery system design is usually based on a straightforward extension of well hydraulic concepts that are useful as an assessment criterion. This assessment criterion depends on the acquisition of reliable field data and a reasonable interpretation of the data acquired. Included in this method would be demonstrating favorable temporal plume geometry changes.

- Contaminant mass recovery The ratio between estimated contaminant mass within the affected groundwater regime and expected mass recovery can be calculated. Determining such a ratio relies on initial contaminant mass estimates and accurate recovery system mass removal records.

- System design and performance comparison Using the initial groundwater recovery and treatment system design may also be useful as a "benchmark" for comparison with actual operation statistics. Using such an assessment method is appropriate for groundwater volumes (comparing design recovery volumes to actual recovery volumes) or contaminant mass recovery data (comparing design contaminant mass removal rates to actual mass removal rates).

- Statistical evaluation of groundwater quality Statistical assessment of long-term groundwater quality trends (which consider natural compound fluctuations) also provides an indication of recovery system success. Using time-dependent statistical techniques, it is possible to quantify improving or degrading groundwater quality trends.

- Integration of above-described techniques Rather than depend on a single approach for assessing recovery system performance, consider integrating several of these methods into a comprehensive evaluation.

COMPLIANCE WITH REGULATORY AGREEMENT

Records of Decision, Consent Orders, best demonstrated available technology standards and certain regional permits may require that the recovery system operate until attaining specific maximum concentration limits (MCLs) or health-based risk standards. These standards must be maintained in the groundwater regime on a permanent basis. Evaluating system performance by comparing existing groundwater quality to ultimate groundwater quality goals is a common assessment method.

The data required to assess recovery system performance using this criterion is readily available for nearly all projects. Accurate analytical data from carefully designed groundwater monitoring well networks can be used to compare specific groundwater quality performance standards to existing groundwater quality

conditions. These monitoring well networks may (and probably should) evolve as more information and understanding are attained, despite increased practical and administrative difficulties.

Using a quarterly summary comparison of groundwater quality data about required cleanup standards is one way to assess the success or failure of the system. Develop a table (Table 2) which identifies the regulated compound(s) used to determine groundwater quality, the initial concentration in the well, the observed compound concentration, the agreed-upon quality standard, and the degree to which the goal has been attained. Validated analytical data and carefully placed monitoring wells are required to use this approach successfully.

Compliance with regulatory agreement is a useful assessment tool when system performance requirements are clear and well defined. Only by identifying quantitative performance standards can this method be valuable. Thus, ambiguous phrases such as "until aquifer quality has been restored to useful benefit" will result in confusing and excessive interpretive flexibility in determining if the system is working as planned. In these cases, it is the consultants' responsibility to assess system effectiveness while representing the client's interest.

DEMONSTRATION OF SYSTEM HYDRAULIC CONTROLS

An important and effective method available to identify successful recovery system performance, particularly at project sites where groundwater quality is of concern, is the assessment of hydraulic manipulation of the groundwater regime by a network of injection/recovery wells. This method of assessment is interpretive and therefore somewhat subjective. However, it is possible to obtain a general agreement on an interpretation, because system design and operation is usually a straightforward extension of well hydraulic concepts. These concepts are based on assumptions and limitations used in developing a conceptual model for the physical system.

This approach requires locating monitoring wells in positions most favorable to map the potentiometric surface for definition of plume hydraulic control (definable overlapping cones of depression). It is noteworthy that installing monitoring wells to assess groundwater quality changes may not assess the hydraulic effects a recovery system operation will have on groundwater flow. Frequently, such hydraulic effects are difficult to identify. Uncertainties include unpredictable nearby pumping centers, measurement and instrument error, mechanical equipment failure, and complex geology complicate interpretations. In addition, it is important to monitor changes in area groundwater use (new users, increased use, or discontinued use) and account for these changes in data interpretation.

Assessments of this type are usually completed once or twice at a site; once during the early stages of system testing and design (pump testing) and a second time during the initial full-scale operation of the system. Unfortunately, aquifer uses change. In addition, reduced well production capacities during the groundwater recovery program are not uncommon. For this reason, an operator should consider a synoptic water level monitoring test once every five years to assess what affect changes in the aquifer system (additional groundwater use or long-term production affects) have on the efficiency of the recovery system.

In addition, using these methods will identify plume geometry changes such that system success or failure will become apparent after a relatively short (several quarterly sampling events) time.

In general, this assessment method is reliable in those cases in which an adequate monitoring well network exists such that one can identify the hydraulic effects of the recovery system. The method is a preferred choice when plume containment is a primary recovery system goal. However, the method may not be useful when hydraulic data are of suspect quality, such as few measurement points or when historical records are inadequate to compare prepumping to pumping conditions.

CONTAMINANT MASS RECOVERY

Groundwater recovery and contaminant treatment systems include pretreatment influent sampling as part of system operation. Results of this sampling are useful to estimate contaminant mass removal from an aquifer as a result of system operation. For a dissolved phase plume, the total mass recovered would be expressed in terms of pounds or kilograms. Estimated values of total contaminant mass are made by converting average treatment system influent concentrations and recovered water volumes to gallons (liters) of influent contaminant recovered. Using the weight per unit volume, an operator can calculate an estimate of total system mass removal. Generally, such estimates should be made on a monthly basis.

For nonaqueous phase liquids (petroleum hydrocarbons, for example) a reasonable estimate can be made about the expected recoverable product volume. In some cases, a simple calculation identifying the percentage of recoverable product removed may be enough to assess system success or failure. An initial agreement with the regulating agency regarding the expected volume of recoverable free-phase hydrocarbons provides an excellent measure of system success. Recovered dissolved phase petroleum hydrocarbon components would be monitored in a manner consistent with that discussed above.

This assessment technique is particularly useful at sites requiring frequent influent/effluent sampling. Most remediation projects are subject to RCRA or National Pollution Discharge Elimination System sampling and reporting protocol. When monitoring a large suite of compounds at the treatment unit, it is possible to report impressive contaminant mass removals. The technique is less valuable when monitoring only a few compounds.

SYSTEM DESIGN AND PERFORMANCE COMPARISON

Basing the final design of a groundwater recovery and treatment system on technical information available before system operation is common practice. However, even the most carefully collected hydraulic, geologic and engineering data will be insufficient to predict, with certainty, the result of long-term groundwater withdrawal programs.

Predictive limitations aside, it is helpful to use the initial groundwater recovery mechanical system design as a benchmark against which actual operating statistics are compared. In order for this comparison to be of value, it is important to develop and implement a data collection program before the time of system startup.

Table 3 illustrates a common monthly system reporting form useful when recording the performance of recovery system mechanical equipment. Monthly reports are preferable to quarterly reports in that operators can correct problems more quickly should they arise.

Each recovery well is identified in column one. In column two, the time of actual operation for the 30-day reporting period is recorded. In column three, the total volume of water pumped (in gallons) for the month is identified. Column four identifies the average monthly pumping rate, and column five identifies the originally designed recovery rate for the well. A simple calculation provides a measure of the degree to which the original design rate was achieved during the monthly reporting period (column six). Use of this form, which can be adapted to any one of several spreadsheet software programs, will enable the system operator to detect both long-term and short-term problems with the recovery system equipment.

In addition to quantitative assessment of recovery volumes, the form includes failure codes to identify the source of significant operating and maintenance difficulties. This particular form has six categories of system difficulties:

- Electrical problems—These problems are those specifically associated with electrical circuitry. In addition, this category includes power surges or failures.
- Well-specific mechanical—This category includes such problems as pump failures, pumping lift, changing groundwater conditions, and motor burnout.

- Delivery system mechanical problems—These problems include the delivery line (the line from the well-head to the treatment system) ruptures, or other damage or blockage.

- Biological fouling—This category identifies iron manganese and sulfate bacterial problems resulting in loss of well yield and formation plugging.

- Well maintenance—Recovery systems require periodic well and recovery system maintenance to assure proper operation and long-term mechanical reliability, this category identifies "down time" in well operation as a result of these activities.

- Other—This category includes vandalism, lightning strikes, vehicular damage and other types of difficulties not accounted for in the categories noted above.

By analyzing the monthly summary reports, the operator can identify which wells have recurring problems, what type of problems they are, and how to correct them. Annual compilation of the data into narrative reports includes graphic presentation of monthly (Figure 1) and cumulative (Figure 2) production trends for each well in the recovery system.

By collecting these data, trends may be identifiable that indicate gradual production rate decline (possibly indicating a slow deterioration of well performance). An operator can evaluate the cause of the decline and take corrective measures as appropriate.

This assessment technique is one frequently ignored by environmental engineers. The degradation of equipment performance is only identifiable if careful, complete operating records are maintained from the first day of operation. An engineer may note a reduction in well performance or increase in operating costs long after such conditions are reperable.

An operator can avoid or eliminate catastrophic failures by developing operating system manuals, equipment performance reports, and strict maintenance schedules.

STATISTICAL EVALUATION OF GROUNDWATER QUALITY

Several statistical approaches (based on type of monitoring and the nature of the data) have been developed to assess temporal groundwater quality changes in an aquifer. One of the most common is the approach developed by EPA as presented in the 1986 RCRA Technical Enforcement Document.[1] In addition, operators frequently reference the EPA's guidance document on statistical analysis of groundwater monitoring data.[2]

Though not as well known, comprehensive statistical software packages have been developed. Using water quality statistical approaches for temporal groundwater quality data analysis will detect trends in water quality parameters for a specific monitoring point, rather than comparing data to arbitrarily selected background wells. For recovery systems operating in aquifers in which background cannot be easily defined (very low hydraulic gradient, or tidally influenced aquifers for example), such an approach may be more useful.

Assuming proper data collection and analysis, statistical programs can identify, to some degree of quantitative precision, whether a suspected trend in groundwater quality is actually present. The quantification of data trends can be used to assess the effectiveness of the recovery system. Key groundwater monitoring wells and several indicator parameters are selected for analysis. An operator can interpret the resulting output to identify improving, degrading or stabilized groundwater quality conditions.

An example of a groundwater quality trend for benzene, toluene, ethylbenzene and total xylene (BTEX) compounds at a gasoline service station is shown in Figure 3 (a simple time series plot) and Table 4 (trend identification output). The time series plot is a simple X-Y plot of the parameter measured (in this case BTEX concentrations in $\frac{1}{4}$g/L; parts per billion) against time (on a quarterly basis). Table 4 lists statistical

data output for the time series data shown in Figure 3 using one of several commercially available statistical packages (WQSTAT II).[3,4] The example shown illustrates a case in which groundwater quality data, with respect to BTEX, is improving. There is a statistically identifiable decrease in compound concentrations over the past five years.

Using a statistical assessment of groundwater quality data is most reliable when a few years of quarterly data exist. It is a preferred assessment technique because it is one of the best ways to quantitatively demonstrate environmental improvement and protection of human health and environment. In some cases, regulatory personnel may require some education to achieve enough comfort in the resulting interpretation, but rarely is this assessment method unacceptable.

ASSESSMENT TECHNIQUE INTEGRATION

Experience at various project sites has resulted in the application of a multi-assessment (integrated) approach. This approach requires the use of available data and results in a comprehensive analysis of the systems operating success or failure. In addition, formulating specific recommendations about the potential improvement of the system can be presented to the operator for implementation.

An independent review by qualified personnel of the recovery system operating history is encouraged to provide an objective opinion on the efficiency of system operation and the potential need for improvement. The independent review process eliminates potential conflict of interest concerns and results in an unbiased evaluation. Below is a summary of the independent evaluation process using the multi-assessment approach.

IMPLEMENTATION OF INDEPENDENT SYSTEM EVALUATION USING A MULTI-ASSESSMENT APPROACH

The independent system evaluation process (Figure 4) begins by conducting a preliminary data assessment. This assessment determines the amount, type, and quality of data available for evaluation. The ideal data base for such an evaluation includes

- The original groundwater recovery system design specifications
- Initial recovery well hydraulic data
- Quarterly groundwater quality data
- Quarterly groundwater level elevation data
- Monthly groundwater production and treatment volumes
- Well documented system problems on a well-by-well basis
- Monthly treatment system influent concentration data.

Rarely are all the data listed above available. If a system has been operating for years with only limited record keeping, it may be important to have the equipment manufacturer's specifications available (the data would identify how a particular piece of equipment should work). In addition, if a system has been operating for a limited time, with limited groundwater quality data, it would be important to include contaminant mass recovery and hydraulic control information in the assessment process. In these and other cases, developing an assessment proposal that identifies the rationale for the selection or omission of certain system information becomes important.

After review of the assessment proposal, data collection reduction and analysis are performed. Frequent contact with the operator may be necessary to clarify specific aspects of recovery system operation and

maintenance. The time required to conduct an assessment will vary with system complexity. Generally, the assessment can be completed within 60 days of project authorization.

A final report is prepared for the owner or operator that provides a summary of the recovery system assessment. In addition, as part of the conclusions, an attempt is made to address the following key issues:

- Is the owner or operator complying with the agency order (or agreement)?
- Is the recovery system equipment operating as it was originally designed?
- Is the recovery system improving and attaining health-based groundwater quality standards or goals?
- Do recovery system operating procedures or equipment require modification?

Answering these four questions is the goal of a groundwater recovery system assessment project. These questions can be most reliably answered by analyzing several categories of data in an integrated fashion and not relying exclusively on a single technique.

CONCLUSIONS AND RECOMMENDATIONS

The probable selection and continued operation of groundwater recovery and treatment systems for aquifer restoration in the future requires that they operate as efficiently as possible.

Proper operation of a recovery system is necessary because owners or operators expend large amounts of capital for operation and maintenance of these systems, and allocating these funds in the most appropriate manner possible is important. It is therefore important to note that efficient operation of a recovery system is best achieved not only by appropriate pilot testing and experimental design but also by periodic monitoring and assessment as well.

To assess properly the success of a recovery system, consider developing a simple monthly reporting form that presents data useful for each of the techniques described, and keep these forms on file with the owner or operator. Such a monthly reporting form would combine appropriate elements of Tables 2 and 3, and Figures 1, 2, and 3 as well. Based on the business objectives of the client, and regulatory requirements of the agency, it is the consultant's task to select which of the methods noted above is most useful. Combining these monthly reports into annual assessments of recovery system performance by an independent third-party reviewer is an important step in the evaluation process.

REFERENCES

1. U.S. Environmental Protection Agency, *RCRA Groundwater Monitoring Technical Enforcement Guidance Document*, September 1986.

2. U.S. Environmental Protection Agency, *Statistical Analysis of Groundwater Monitoring Data at RCRA Facilities-Interim Final Guidance*, February 1989.

3. Phillips, R. D., Hotto, H. P., and Loftis, J. C., *WQSTAT II- A Water Quality Statistics Program User's Manual*, Colorado State University, 1989.

4. Loftis, J. C., Phillips, R. D., Ward, R. C., and Taylor, C. H., "WQSTAT II: A Water Quality Statistics Package," *Groundwater 27 (6)*, 1989, pp. 866-873.

Table 1- Assessment Techniques and Data Requirements

Assessment Technique	Data Required
Compliance with Regulatory Agreement	ROD/AO Objectives.
Demonstration of System Hydraulic Control	Synoptic round water level data.
Contaminant Mass Recovery	Treatment system influent concentrations.
System Design/Performance Comparison	Monthly performance records.
Statistical Evaluation	Quarterly ground water quality data.
Plume Geometry Evaluation	Quarterly ground water quality data.
Integration of Above Techniques	Combination of the above.

Table 2- Sample Quarterly Reporting Form
Comparing Compliance Goals to Current Ground Water Quality

Monitoring Well	Benzene Concentration				Percent of Objective
	Inital	Current	ROD Goal		
MW-1	121	100	5		18%
MW-2	100	65	5		37%
MW-3	107	88	5		19%
MW-4	115	102	5		12%
MW-5	90	87	5		4%
MW-6	8.5	9	5		-
MW-7	2.7	2.5	5		NA
MW-8	<0.5	<0.5	5		NA
MW-9	<0.5	<0.5	5		NA
MW-10	40	37	5		9%

Table 3- Sample Monthly Reporting Form for Recovery System Operation Documentation

Project: _____ **Reported By:** _____

Location: _____ **Checked By:** _____

Date of Report: _____

Time Period: 1 November-31 November 1991

Recovery Well	Operating Time (Minutes)	Recovered Ground Water (Gallons)	Average Rate (GPM)	Original Design (GPM)	Percent Original Design	Failure Codes
RW-1	40,300	443,520	11	25	44%	(3) See Note
RW-2	40,185	1,245,735	31	30	103%	
RW-3	32,800	524,800	16	25	64%	(1) See Note
RW-4	40,300	725,400	18	20	90%	
RW-5	37,500	2,700,000	72	70	103%	
RW-6	22,500	900,000	40	40	100%	

Operating Notes:

RW-1 Plugged Delivery pipe increasing back-pressure. Line to be replaced next month.

Rw-3 Experienced recurring electronic failure in down-hole wiring. After examination of system it was determined that pump wires were shorting out. Wires were replaced and normal operation has resumed.

Failure Codes

(1) -Electrical system Failure
(2)- Mechanical Problems
(3)- Delivery System Mechanical Problems
(4)- Biological Fouling
(5)- Well Maintenance
(6)- Other

Table 4 *Example of WQSTATII Output for BTEX Data Shown in Figure 3*

Trend Tests

Kendall Tau Test
Test Statistic = -3.769

Confidence Level	Test	Significance
95%	-3.769<-1.960	SIGNIFICANT
90%	-3.769<-1.645	SIGNIFICANT
80%	-3.769<-1.282	SIGNIFICANT

Seasonal Kendall Test
Test Statistic = -3.258

Confidence Level	Test	Significance
95%	-3.258<-1.960	SIGNIFICANT
90%	-3.258<-1.645	SIGNIFICANT
80%	-3.258<1.282	SIGNIFICANT

Seasonal Kendall Sen Slope Estimate: Slope = -10.00000 units/year
Summary Statistics

Kruskal-Wallis test for Seasonality
Test Statistic = 0.07

Confidence Level	Test	Significance
95%	0.07<7.81	NOT significant
90%	0.07<6.25	NOT significant
75%	0.07<4.11	NOT significant

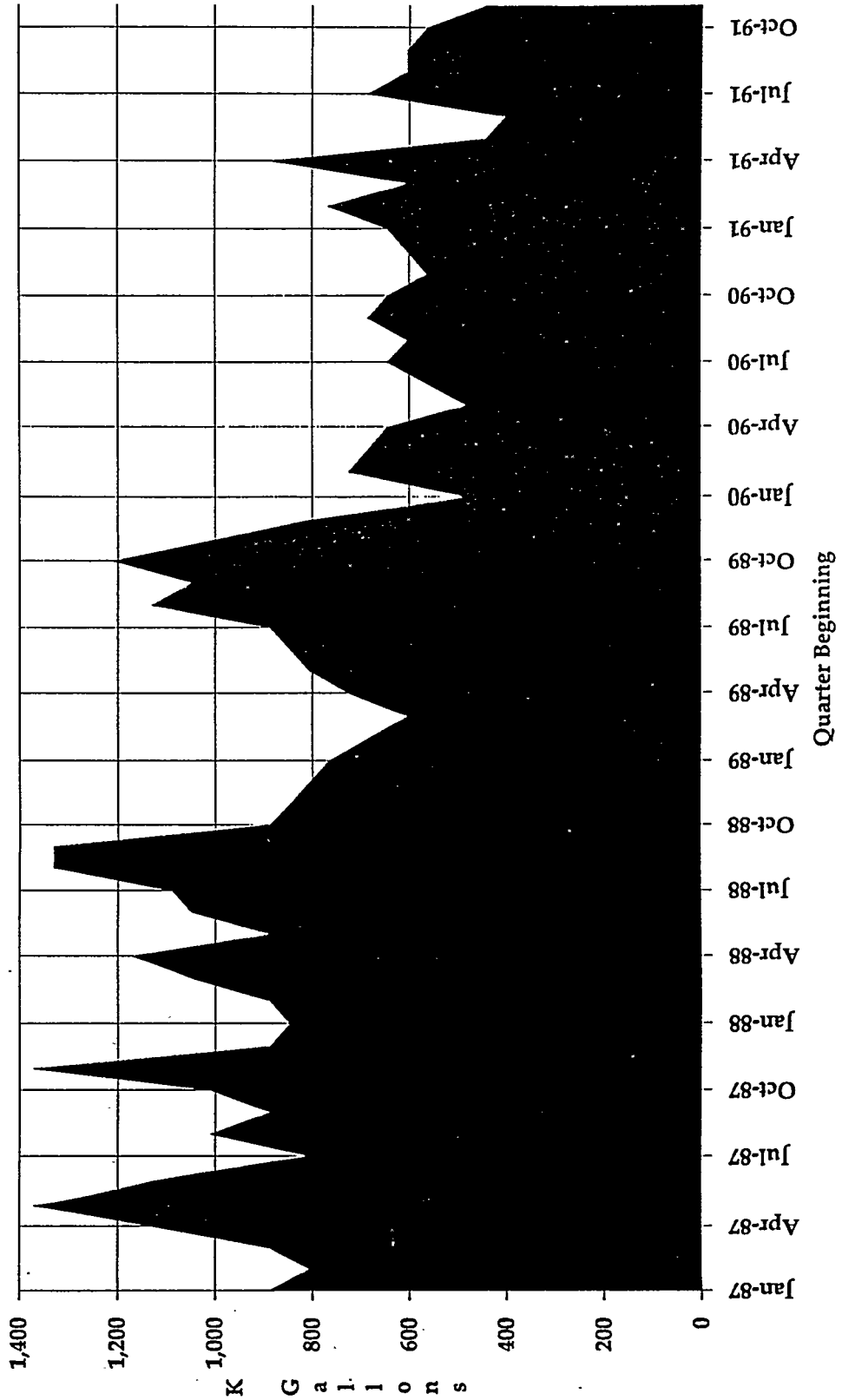


Figure 1- Monthly Ground Water Recovery Volume

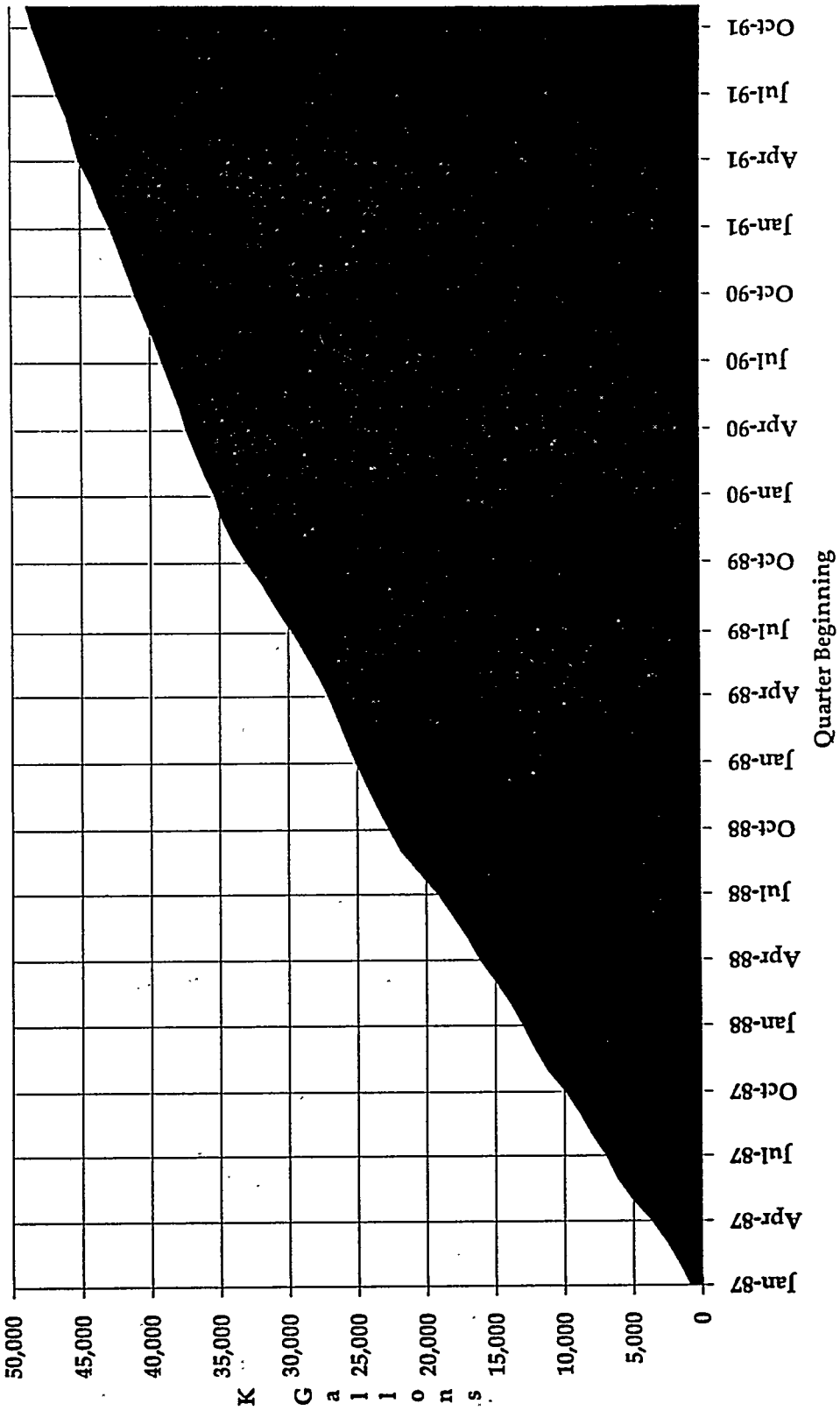


Figure 2- Cumulative Ground Water Recovery Volumes

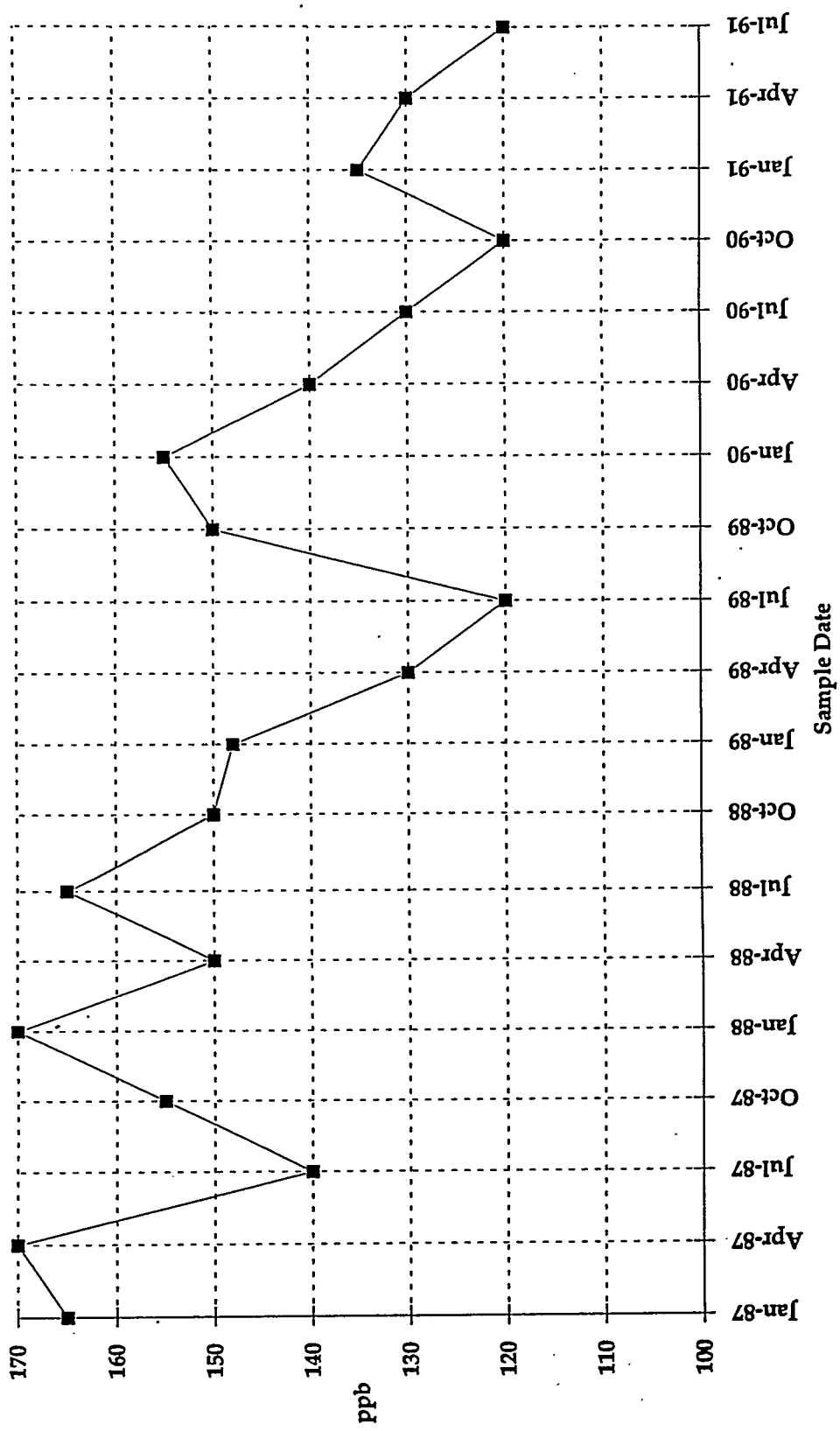
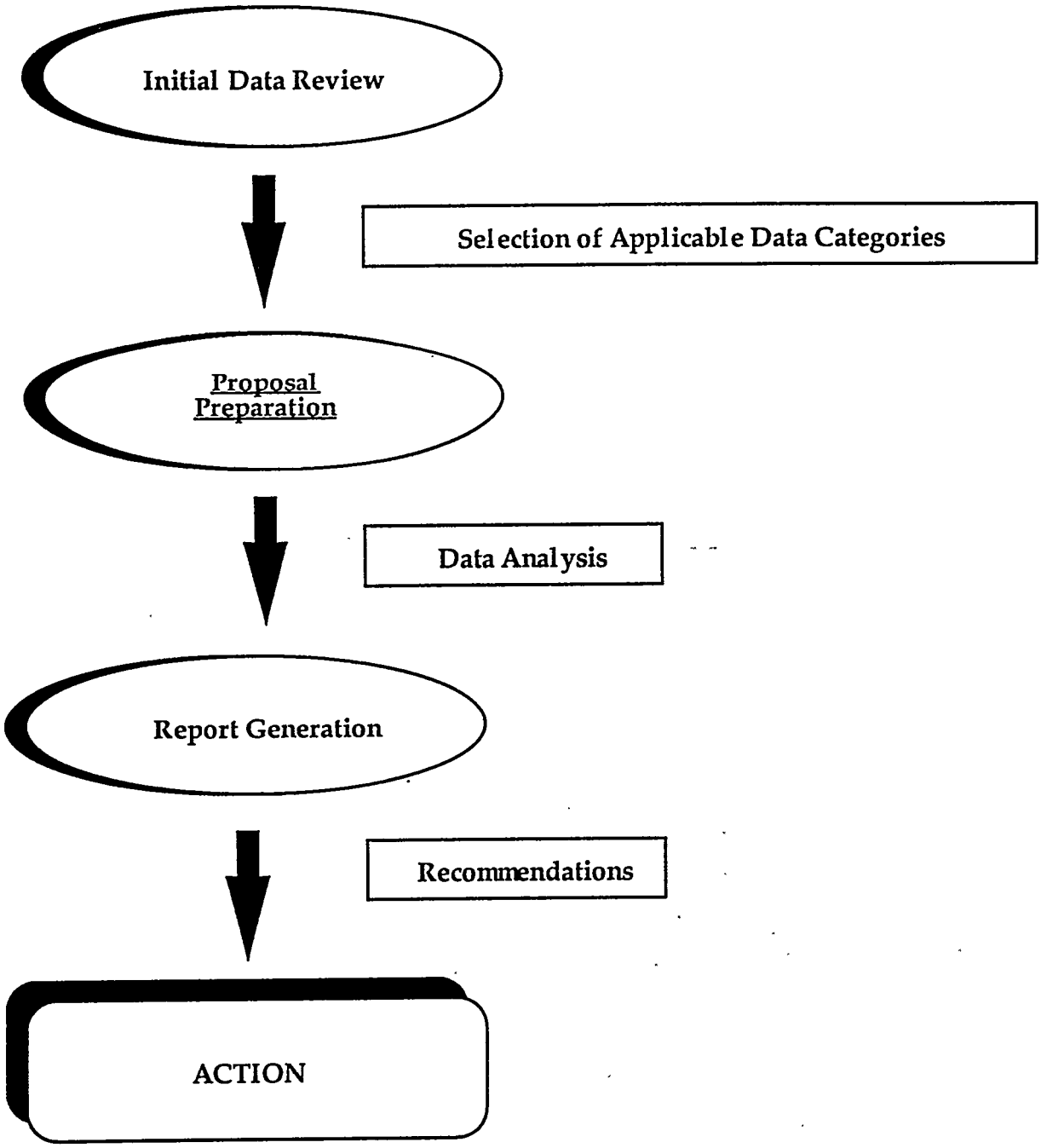


Figure 3- Indicator Compound Concentration

Figure 4- Ground Water Recovery System Assessment Process



Discrete Source Computer Model for Radiation Exposure Outside a Low-Level Radioactive Waste Facility

K. L. Breskin
H. V. Tims
C. T. Hess
Departments of Civil Engineering and Physics
University of Maine
Orono, ME

ABSTRACT

We developed a computer program to answer questions that arose during the design of an aboveground vault (AGV) for storage or disposal of low-level radioactive waste. Results from this model were compared to results from hand calculations on a limited number of cells and a verification was made using measurements taken on LLW in temporary storage.

The program calculates approximate radiation dose at selected points inside, outside, and on the roof of the loaded building. Gamma-ray exposure was used to decide whether a person could safely enter the building during loading operations or perform repairs to the roof should this be needed early in the life of the building. This model was used by a study group from the University of Maine (UM) in developing conceptual designs for an AGV.

The earth surrounding and covering a belowground vault or an earth-mounded structure will provide excellent radiation shielding. These structures can be easily loaded from above with a crane to limit operator exposure. By contrast, the AGV suggested by the UM group would be loaded from inside the building, under the completed roof, using an overhead crane or a fork-lift to move the waste containers. All radiation absorption would be through the concrete walls and roof of the building and through the other waste. Aboveground disposal of LLW could have many advantages, but potential exposure of the public or of facility operators to gamma radiation is an issue that had to be addressed before aboveground storage or disposal buildings could be considered.

The computer model was developed to try to answer some of these questions. Written in Fortran, it will run on an IBM-compatible PC with a math coprocessor chip and limited memory. The model calculates the dose at several points inside and outside an aboveground LLW repository with concrete walls and roof. The model can predict dose inside the building to decide whether facility operators will be able to safely enter the building during loading or waste retrieval. It can also be used to determine the thickness of concrete wall needed to reduce the dose outside the walls to an acceptable level and to predict the dose to a potential inadvertent intruder inside the building or camped against a wall after the period of institutional control has passed. It calculates the dose at both inner and outer roofs of the building to determine whether major repairs could be undertaken if the roof were damaged at any time during or after waste loading. It could also be used to determine the depth of soil backfill that is needed at the top of the cells of a belowground vault so that workers are adequately protected from radiation during construction of a permanent concrete cover, although we have not used it for this purpose.

In practice, dose at any point inside or outside the building will depend on the final composition, concentration, density and placement of the waste inside the building. This type of information is not available early in the design process, but model results based on present information should be sufficiently accurate to use in building design.

METHODS

Model Operation

The conceptual building design for which the model was written is shown in Figure 1. It would have a main vault with concrete walls and roof containing Class A waste. A concrete-walled inner storage area for Class B and C wastes, and any particularly "hot" Class A waste containers would be in the middle of this vault. The vault would be surrounded by an outer building to protect the inner concrete walls and roof from the weather. This outer building is assumed to be made of thin metal, and no absorption or buildup through the metal is considered in the model. When the vault is full, waste will be stored covering the entire floor surface and up to a height of five meters.

Dose is calculated at points one meter above the ground along the long and short axes of the building. Calculation points are at the face of the array of waste cells, on the outside on the vault wall, and at a point a distance away from the vault wall. This point can be set to represent dose between the vault and the outer shell, at the outer building wall, or at any other distance away from the vault. Dose is also calculated on both inner and outer roofs directly above the central storage area wall on the short axis of the building. The points are shown in the figure.

In the model, the space in the building to be used for waste storage is divided into cells having a volume of one cubic meter. A specified activity of each nuclide being considered is modeled as a point source in the center of each cell, representing a concentration of waste at a location in the vault. Class C waste cells had much higher specific activities than the Class A waste cells and were clustered together in the data set to approximate the higher exposure that would result from relatively "hot" containers. Clusters of Class C waste cells in the central storage area were positioned to have maximum impact at the points being monitored outside the vault, and one cluster of Class C waste cells was located in the main part of the vault, outside the central storage area and near a calculation point, to simulate facility operator error.

The model calculates the distances through LLW, concrete wall or roof, and air from each cell to each calculation point around the building. This information, together with the densities the shielding materials and the curies of each gamma-emitting nuclide in the cell, is sent to subroutines that calculate gamma-ray absorption and buildup through each shielding material from the activity of each nuclide in that cell. The resulting exposures from each cell are summed at each calculation point to estimate the total exposure at each location being monitored.

Gamma-emitting nuclides are considered in the model because alpha and beta radiation are adequately absorbed by the waste containers and concrete building walls or roof. There are no fast neutron sources in Maine's LLW.

Assumptions in the Model

As with any computer model, there are many assumptions built into our representation of a disposal vault. We have made assumptions of many parameters for which more accurate information is not available early in the design process.

Waste container weight and steel thickness are not considered separately from the waste. As a simplifying assumption, we have assigned a uniform density based on the combined average weight of waste and container to all cells in the model. The filled B-88 boxes that were used in our verification study had an average unit weight of 32 pcf, although the waste shipped by Maine Yankee Atomic Power generally varies from 35 pcf to a maximum of around 140 pcf (George Pillsbury, ME Yankee Health Physics, p.c.). Most LLW in Maine is produced by the Maine Yankee Atomic Power Plant, and some of the waste containers are packed with sand. It is likely that the real average density of the waste is higher than 32 pcf, and we have assumed that most filled waste containers would not float. We used 32 pcf in the model to project dose in the worst case, and 64 pcf to approximate expected conditions. If most Class A waste containers were heavier than this, exposure outside the building would be lower than that calculated.

Many types of material become LLW during power plant operations. This makes precise determination of a coefficient of mass absorption for this waste a difficult matter. The coefficient we used was chosen for an average equivalent atomic number of 10, based on the constituents likely to be present in much of the waste, in concrete aggregates, and in the sand used in packing containers.

We have assumed in our data set that radionuclides will be evenly distributed across the waste stream. Activities in a cell determine whether the cell is classified as Class A or Class B/C waste, but the same set of radionuclides appears in each cell. This is a reasonable assumption for power plant operations waste and was true of the containers used in our verification, but may not be acceptable for decommissioning wastes. The model does not require an even distribution of nuclides although this simplifies the construction of data sets.

Based on information from the Maine LLW Authority, we have assumed that 90% of the LLW activity will be contained in Class B and C wastes occupying only 3% of the storage volume in the building. This allowed us to fill the remaining 97% of the storage volume in the model with very low activity Class A wastes, which provided additional shielding.

Gamma Absorption and Buildup

Gamma rays consist of photons that interact with matter such that a single event will remove the gamma ray from the incident path. The intensity of the beam will decrease exponentially:

$$N = N_o e^{-\mu x} \quad . \qquad \text{Eq. (1)}$$

- N = intensity of the beam (subscript, o, denotes initial intensity)
- μ = the absorption coefficient (cm^{-1})
- x = distance traveled by the particle.

The absorption coefficient may also be expressed

$$\mu_m = \mu/\rho = ns/\rho = N_A s/M_A \quad . \qquad \text{Eq. (2)}$$

- μ_m = mass absorption coefficient (g/cm^2)
- ρ = density of attenuating material (g/cm^3)
- n = number of atoms per unit volume ($atoms/cm^3$)
- s = total cross section (sum of three absorption processes ($J\text{-}cm^3$)
- N_A = Avogadro's number (atoms/mole)
- M_A = atomic mass of attenuating material (g/mole).

There are three absorption processes that compose the total cross section and ultimately the absorption coefficient. Each absorption process is treated as a result of a photon interaction with an electron or an atom. Three possible interactions are:

Photoelectric Effect. A photon interacts with an atom such that the total energy of the photon is absorbed and concentrated on one electron. If the energy absorbed exceeds the binding energy, the electron may be expelled from the atom at a velocity determined by the excess received energy.

Pair Production. When a gamma ray exceeds an energy of 1.02 MeV in the field of a nucleus, a positron and an electron can be created. The energy threshold of 1.02 MeV is equivalent to the rest energies of the two particles.

Compton Effect. When a photon interacts with an atomic electron the gamma ray is not completely absorbed, but merely scattered. The interaction reduces the energy of the photon. To account for the forward-scattered gamma rays a Buildup factor, B(u,x) is used (Enge 1966). Equation 1 becomes

$N = B(u,x)N_o e^{-x}$. Eq. (3)

3Buildup

The University of Maine program uses a Buildup factor based upon the Capo formula.

$B(\mu,x) = E(3\ i = 0)b_i(\mu x)^i$; Eq. (4)
$E(3\ i = 0)b_i = E(4\ j = 0)\ C_{ij}(1/E)^j$.

Capo's formula has a range of distances up to 15 or 20 mfp, and energies of .5 to 10 MeV. Coefficients are available for materials such as water, aluminum, iron, lead, and uranium, as well as ordinary concrete and heavy (magnetite, ferrophosphorous, and barytes) concretes.

The Capo coefficients for concrete were calculated by interpolation from known buildup data for elementary materials on the assumption that the concrete mixture behaves as would an element of atomic number 11, 17, 21, or 27. Due to this approximation, buildup factors from these coefficients must be considered less accurate than the elemental materials. A.B. Chilton has carried out unpublished Monte Carlo calculations based on direct concrete attenuation and has stated that although the buildup is a little high at lower energies, the factors are "valid within perhaps about 20% overall."

Capo's curve-fitting method is a rough calculation. Compared to many of the other buildup methods such as Geometric Progression (GP) and Taylor curve-fitting, it is primitive in a sense. Although the buildup value for any given radionuclide can be as much as 20% different from the GP method, averaged together through at least one foot of concrete the Capo buildup values are very close to that of the GP values. In fact, a ballpark value of 10 can be used for buildup for various methods through up to 3 feet of concrete, for the six gamma-emitters Mn-54, Co-57, Co-58, Co-60, Cs-134, and Cs-137.

Absorption

In the computer algorithm the source activity is converted into equivalent dose measurements using the relation

Dose equivalent = Γ*(Activity), R/hr . Eq. (5)

Γ designates a gamma factor (Radiological Health Handbook, 1970).

The source strength of the equivalent dose measurement is then estimated at a distance, r, from the source.

Source strength= (Dose equivalent)/r^2 . Eq. (6)

The attenuation of the source strength is then calculated using the mass absorption coefficient; μ_m, density; d, and thickness; t, of the material between the source and the point at which the source is measured.

Attenuated source strength= (Source strength) * $B(\mu,x)\exp[-\mu_m pt]$. Eq. (7)

For more than one type of shield the attenuating exponents are summed together to estimate the total attenuation. For n shields the attenuation would be

Total attenuation= $\exp[-\mu_m p(t_1)]*\exp[-\mu_m p(t_2)]*$
$...*\exp[-\mu_m p(t_n)] = \exp[-\mu_m p(t_1)-\mu_m p(t_2) ...-\mu_m p(t_n)]$. Eq. (8)

The attenuated source strength is then summed for each cell with respect to reference points.

The activity in each cell is treated as a point source surrounded by a shield with the thickness, density and mass absorption coefficient of the LLW. Self-absorption through the waste is treated no differently than absorption through any other shield.

Bremsstrahlung

When a beta particle passes near an atom or a nucleus the charged particle is accelerated, and bremsstrahlung x-rays are emitted as a result of the interaction. Bremsstrahlung can be estimated using the following equation (Cember, 1983):

$$f = 3.5 * 10^{-4} ZE \qquad \text{Eq. (9)}$$

f = the fraction of Beta energy converted to photons
Z = atomic number of the shield
E = Beta energy of the source.

Using each beta emitting nuclide in Maine's waste stream with an equivalent atomic number of 10 for the concrete shield, this fraction was calculated to be less than 1% for Maine's LLW in an aboveground LLW vault. Bremsstrahlung was not considered in the model because this number is well within our range of uncertainty.

RESULTS

Testing and Verification

A test of the model was made using data collected on LLW stored in the temporary storage building at the Maine Yankee Atomic Power Plant in Wiscasset, Maine. The lower walls of this building are 1-foot-thick concrete, and although there was other LLW in the building at the time our radiation survey was made, it was a distance away from the waste being used in our test. Measurements were taken around a single stack of B-88 boxes containing LLW, stacked seven boxes long by three boxes high. The locations of the boxes in the storage building are shown in Figure 2.

Dose measurements were made outside the boxes, at a distance of 4 meters from the boxes, and outside the building along the same line. The survey was made using a Ludlum Model 5 Geiger counter, which has five ranges from 0 to 2000 mR/hour, with accuracy $\pm$ 5% on each scale. Some dose from the other waste in the building is expected to appear in these measurements, although the effect should not be great.

As a further examination of the density assumption mentioned above, the model was run with this data using the assumed unit density and also set up as an accurate representation of the conditions in the stack of LLW boxes. In this second trial the waste and the steel box were treated separately. Absorption was calculated through waste, steel, concrete and air. Buildup was calculated through steel and concrete separately. Buildup was not considered through the waste itself because the boxes appeared to contain material such as used coveralls and gloves. This waste weighed only 28 lbs/ft^3 not including the weight of the box.

The activities of gamma-emitting nuclides in these boxes, the weights and volumes of these boxes, and the distances to the points where dose was measured were used in the U of M model. The results of these tests appear in Table 1. In the 1st calculation column, the model assumption of a uniform density including the container was used. In the 2nd calculation the waste and steel were treated separately.

Table 1. Waste building experiment results, August 1992.

Location	Dose in mrem/hour		
	Combined unit weight	Separate waste and box	Measured exposure
Corner of stack	2.7	2.8	4
4 meters from stack	0.4	0.7	1
Outside building (7 meters from stack)	0.02	0.02	0.02

Based on these test results, the assumption of a unit weight that includes the average weights of both waste and container seems to be a reasonable simplification of separate buildup and absorption calculations for the LLW and the container for purposes of building design.

Results using Maine's LLW

The model was used with the known and assumed data from Maine's LLW stream to answer the questions in the introduction: gamma-ray exposure to the public or to facility operators does not appear to pose a problem around a properly designed aboveground LLW facility. The added radiation exposure outside the outer wall of the AGV conceptual design from the UM group should be on the order of 1% of natural background radiation after ten years has elapsed. Most of the shielding of Class B/C wastes would be provided by Class A waste, and Class A waste gamma rays would be absorbed by the concrete walls of the building.

The nuclides present in Maine's LLW stream, the yearly activities of each nuclide to be stored, and the yearly volumes of waste were obtained from the Maine Low Level Radioactive Waste Authority. A building to store 10 years of waste would need storage space for 100,000 cubic feet of waste and an additional 25% for wasted space between containers. This amounted to 3800 cells in the model. Maine must dispose of approximately 700 curies/year as LLW. The 7000 curies that enter the building from 10 years of waste were loaded into the model, with 90% of the activity assigned to 94 cells representing Class B/C waste and 10% of the activity representing the Class A waste in the remaining 3706 cells. The activities placed in each cell are shown in Table 2.

Table 2. Activity per cell in the model of Maine's LLW (curies).

Nuclide	Class A waste	Class B/C waste
Mn-54	0.00064	0.22717
Co-57	0.00002	0.00652
Co-58	0.00039	0.13925
Co-60	0.02416	8.57150
Cs-134	0.00307	1.08798
Cs-137	0.03132	10.78871

To reduce the time needed for a computer run, a waste loading arrangement was used that assumed symmetrical placement of Class A and B/C waste cells about the axes of the building so that only 1900 cells were used for calculation. The resulting exposures were doubled.

Exposure at the face of the array of Class A waste cells remained fairly constant once a depth of four cells was reached, indicating that this thickness of waste at a density of 32 pcf is adequate to absorb the radiation of any added rows of Class A waste cells. When a cluster of Class B/C waste is at least five meters away from the calculation point and this five meter space is filled with Class A waste with a density of at least 62 pcf, radiation exposure is controlled by the Class A waste. Dose at the face of this waste was high enough at approximately 120 mrem/hr to prohibit operator entry into the building. Thickness of the concrete walls surrounding the central Class B/C waste storage area is unimportant because radiation is adequately absorbed

by the Class A waste. For this design we recommend remote loading of the waste by overhead crane with TV monitors to minimize operator exposure.

Exposure at both the inner and outer roofs was adjusted by varying the thickness of the concrete roof. Table 3 shows projected exposure to a worker on the outer roof immediately after final closure of the facility for different thicknesses of concrete. Potential damage to the roof is the greatest risk to an AGV, and so the model was also run with a data set that used activities of the nuclides in the building 10 years after facility closure. These are shown in Table 4. These results clearly indicate that minor roof repairs could take place at any time, and major repairs could be done within a reasonable time after the building was filled and closed.

Table 3. Projected exposure at inner and outer roofs.

Roof thickness	At inner roof	At outer roof
1 ft.	39 mrem/hour	27 mrem/hour
2	0.93	0.69
3	0.020	0.016

Table 4. Projected exposure at roof ten years after closure.

Roof thickness	At inner roof	At outer roof
1 ft.	6.8 mrem/hour	6.7 mrem/hour
2	0.14	0.12
3	0.0027	0.0021

Dose outside the vault in the middle of the long wall of the building was found to be slightly higher than dose outside the short wall, although the difference was not great. Table 5 shows the calculated maximum exposure outside the vault wall. This shows the maximum exposure a person could receive at chest height if he or she were to stand between the vault and the outer shell for the entire year following closure of the vault.

Substantial reduction in exposure is achieved by increasing the thickness of the main vault walls, although, due to the rapid decay of the gamma-emitting nuclides, thicker walls may be more important in increasing the longevity of the vault than in gamma ray absorption.

Table 5. Maximum exposure at the vault wall.

Wall thickness (ft)	Expsoure
1	1.3 mrem/hour
2	0.030
3	0.00065

These results indicate the maximum exposure calculated outside the vault walls. Exposure was slightly lower at the vault wall than a short distance away, due to the shielding effect of the waste and concrete: the radial distance through waste and concrete measured to the inner calculation point is always greater than the distance through waste and concrete to the outer calculation point, although the total distance is longer to the outer point. The difference between dose at the wall and the maximum dose is controlled by the density of the waste but was less than 1 mrem/hour for waste density less than 62 pcf. The exposure curve shown in Figure 3 is based on a waste density of 32 pcf.

This geometric shielding effect is similar to the results of sky-shine (radiation reflection off the atmosphere, for example from a LLW building having thick concrete walls but a thin steel roof), but the increased dose is seen immediately outside the building. Location of this point of maximum exposure varies

with the thickness of shielding. The dose decreases as expected after the point of maximum dose, which is located near 1/2 meter from the vault wall for the LLW activity and distribution we used.

The model was run with the stored activities increased 400% and no other changes to the building. These activities might result from compaction of the waste to reduce stored volume, or from underestimation of the activities to be stored. As would be expected, the exposure increased by a factor of 4 for all wall thicknesses. The model was also run using a waste density of 64 pcf to test the sensitivity of the results to variations in waste density. The calculated exposures were approximately five times lower using the higher waste density.

CONCLUSION

Based on the exposure projected by this model, we specified that an AGV should be loaded using a track-mounted overhead crane with television monitoring. Class C waste in the middle of the vault is adequately shielded by the surrounding Class A waste when the vault is loaded, but the interior concrete wall reduces the dose outside the building while the building is only partly full. Due to the rapid decay of the gamma-emitting nuclides, thickness of the vault walls may be more important for longevity of the concrete than for gamma-ray absorption although thick concrete ensures a safe external dose level while the building is being loaded. Within 50 years, exposure inside the building would permit safe entry into the vault. It appears that an aboveground storage facility for low-level radioactive waste can be designed so that the gamma ray exposure at the walls of the building resulting from stored LLW is at or below the level of background radiation. Ten years after the facility is closed, gamma ray exposure levels at the perimeter of an aboveground building in which the "hotter" waste is surrounded by Class A waste should be difficult to detect above background radiation.

REFERENCES

Bureau of Radiological Health, *Radiological Health Handbook*, 1970, p. 131.

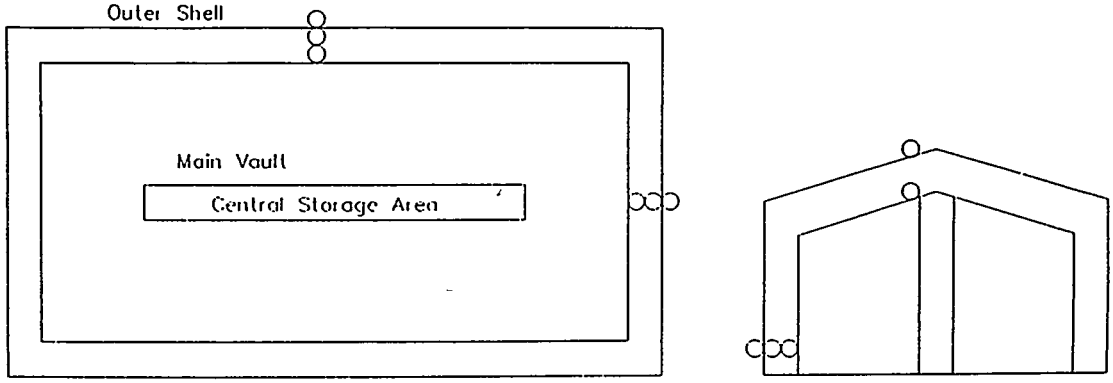
Cember, H., *Introduction to Health Physics*, New York: Pergamon Press, 1983, p. 106.

Enge, Harald, *Introduction to Nuclear Physics*, Addison Wesley, 1966, pp. 195-196.

Jaeger. R.G., *Engineering Compendium on Radiation Shielding*, Chilton, A.B., "Broad Beam Attenuation," Springer-Verlag, 1968.

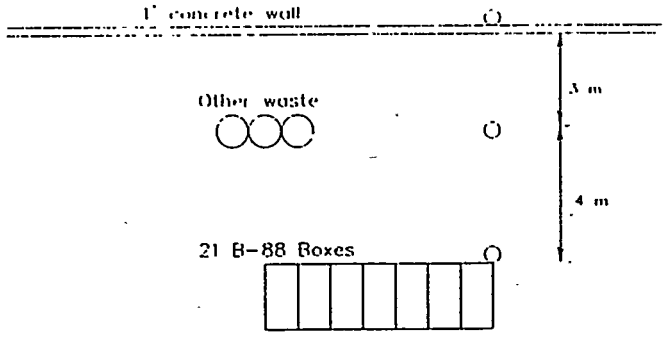
Maine Low-Level Radioactive Waste Authority, *Conceptual Design for Low-Level Radioactive Waste Disposal in Maine*, Revision 1, April 1992.

Figure 1.



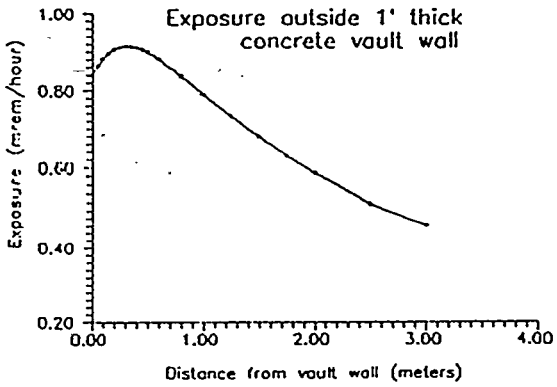
O Calculation Points

Figure 2.



O Calculation points

FIGURE 3.



The Effect of an Engineered Closure Cap on Radon Gas Transport from a Shallow Land Burial Site

F. Tom Lindstrom
David E. Cawlfield
Mary E. Donahue
Dudley F. Emer
Gregory J. Shott
Reynolds Electrical and Engineering Co., Inc.
P.O. Box 98521
Las Vegas, NV 89193-8521

INTRODUCTION

DOE Order 5820.2A requires performance assessment of all new and existing low-level radioactive waste disposal sites. An integral part of performance assessment is estimating the fluxes of radioactive gases such as radon-220 and radon-222. Mathematical models, which in themselves point out data needs and therefore drive site characterization, provide a logical means of performing the required flux estimations. The effects of an engineered closure cap on radon gas transport in a very dry alluvial soil in the southwestern desert are considered in detail in this paper. Our model (Lindstrom et al. 1992 a & b, and Cawlfield et al. 1992 a & b) was constructed in a site-specific fashion because the existing mathematical models are few in number for noble gas transport from the spatial point of origin in the low-level waste repository through the surrounding soil and closure cap with subsequent release to the atmosphere (Nazaroff, 1992).

Our model, called CASCADR9, includes the diffusion and barometric pressure induced advection of an N-chain of radionuclides. The parent material is assumed to be buried somewhere between the soil-atmosphere interface and the water table some 240 meters below the surface. The usual Bateman decay and ingrowth mechanics are included with each radionuclide. Both linear reversible sorption kinetics and linear irreversible sorption kinetics are assumed for each radionuclide.

GAS TRANSPORT MODEL

Figure 1 shows a sketch of a 4-chain of radionuclides being processed in a representative elementary volume (REV) of dry desert alluvium, which is around and under the radioactive waste management site (RWMS) at Area 5 of the Nevada Test Site (NTS). Lindstrom (Lindstrom et al. 1992 a & b) gives all the developmental details for the isothermal mass balance based gas phase radionuclide transport and fate model, CASCADR9. Cawlfield (Cawlfield et al. 1992 a & b) give the details of how the Fortran 77 codes for CASCADR8 and CASCADR9 are constructed together with illustrative realistic scenarios of radon-222 transport in dry NTS alluvium.

Application of the principle of mass balance in the REV leads to the following equations:

$$\frac{\partial C^1}{\partial t} + \frac{1}{\varepsilon\left(1+R^1\right)}\frac{\partial\left(q_{air}\, C^1\right)}{\partial x} + \left(\lambda_1 + \frac{\lambda^1_{irr}\, f_{irr1}\,(1-\varepsilon)}{\varepsilon\left(1+R^1\right)}\right) C^1 =$$

$$\frac{D^1}{1+R^1}\frac{\partial^2 C^1}{\partial x^2} + \frac{(1-\varepsilon)\,\rho_p\, S_0(x) + (1-\varepsilon)\, S_{SP}\,(x,t)\left(\frac{M_1}{M_0}\right)}{\varepsilon\left(1+R^1\right)} \qquad (1)$$

for the first daughter radionuclide and

$$\frac{\partial C^j}{\partial t} + \frac{1}{\varepsilon\left(1+R^j\right)}\frac{\partial\left(q_{air}\, C^j\right)}{\partial x} + \left[\lambda_j + \lambda^j_{irr}\, f_{irrj}\,\frac{(1-\varepsilon)}{\varepsilon\left(1+R^j\right)}\right] C^j =$$

$$\frac{D^j}{1+R^j}\frac{\partial^2 C^j}{\partial x^2} + \lambda_{j-1}\left(\frac{1+R^{j-1}}{1+R^j}\right)\left(\frac{M_j}{M_{j-1}}\right) C^{j-1} \qquad (2)$$

for the jth daughter radionuclide, j = 2, 3... M. The mathematical symbols are defined in Appendix A.

Barometric Pumping

In equations 1 and 2 the effect of barometric pressure induced advection is included via the spatially and temporally varying function q_{air} (x,t).

The details of barometric induced air pumping in the CASCADER concept are given in Lindstrom et al. (1992a). Briefly, the one-dimensional D'arcy air flow on the homogeneous interior of each soil layer is defined as

$$q_{air} = -\frac{\kappa_{air}}{\eta_{air}}\left(\frac{\partial P_{air}}{\partial x} - \rho_{air}\, g\right) \qquad (3)$$

(Lindstrom et al. 1992a). The assumptions are made that (a) the air can be treated as an ideal gas so that

$$\rho_{air} = \frac{M_{air}}{R_g T}\, P_{air} \qquad (4)$$

and (b) isothermal conditions hold. Combining these two definitions (constitutive equations) with the continuity equation (mass balance) in the REV

(5)

$$\frac{\partial(\varepsilon \rho_{air})}{\partial t} + \frac{\partial}{\partial x}(\rho_{air}\, q_{air}) = 0$$

provides us a way of estimating the advective velocity V_{air} (x,t) since

$$q_{air} = \varepsilon V_{air} \quad . \tag{6}$$

Both CASCADR8 the homogeneous porous medium version and CASCADR9 the heterogeneous porous medium version, make use of all of these relationships together with initial and boundary data to estimate the advective velocity of the radionuclides.

Interface Coupling Conditions

In CASCADR9 the requirement of mass balance in conjunction with the classical "Gaussian pill box" concept applied at each contrast or interface in the porous mediums material properties, leads to the requirement of continuity in the normal component of the pressure flux at interface $x = x_{Ik}$ as

$$-\kappa_{air I_k^-}\left(\frac{\partial P_{air}\left(x_{I_k^-},t\right)}{\partial x} - \frac{M_{air}\, g}{R_g\, T_{air}} P_{air}\left(x_{I_k^-},t\right)\right) =$$
$$-\kappa_{air I_k^+}\left(\frac{\partial P_{air}\left(x_{I_k^+},t\right)}{\partial x} - \frac{M_{air}\, g}{R_g\, T_{air}} P_{air}\left(x_{I_k^+},t\right)\right) \quad . \tag{7}$$

With no sources or sinks of air existing along the interface the pressure field is continuous at the interface. That is,

$$P_{air}\left(x_{I_k^-},t\right) = P_{air}\left(x_{I_k^+},t\right) = P_{air}\left(x_{Ik},t\right) \quad . \tag{8}$$

Analogous reasoning on the jth radionuclide gas phase concentration near the interface I_k yields the two coupling conditions

$$-\varepsilon_{I_k^-} D_-^j\left(\frac{\partial C^j}{\partial x}\left(x_{I_k^-},t\right)\right) = -\varepsilon_{I_k^+} D_+^j\left(\frac{\partial C^j}{\partial x}\left(x_{I_k^+},t\right)\right) \tag{9}$$

for the continuity in normal component of the chemical flux field and

$$C^j\left(x_{I_k^-},t\right) = C^j\left(x_{I_k^+},t\right) = C^j\left(x_{IK},t\right) \tag{10}$$

for continuity in the chemical concentration of the jth radionuclide at the interface I_k.

Initial and Boundary Conditions

Since we rarely, if ever, have a complete air pressure profile at time t=0 we choose the initial air pressure distribution in the porous medium to be

$$P_{air}\left(x,0^{+}\right) = P_{air}\left(0\right) e^{\frac{M_{air}\, g\, x}{R_g T}} \quad , \tag{11}$$

for $0 \le x = X_{wt}$.

The boundary condition on the pressure field at the water table $X = X_{wt}$ is

$$\left.\frac{\partial P_{air}}{\partial x}\right|_{x=x_{wt}} = \frac{M_{air}\, g}{R_g T} \left.P_{air}\right|_{x=x_{wt}} \tag{12}$$

while the boundary condition at the atmosphere-soil interface P(0,t) is a prescribed function of time defined via 15 minute National Oceanic and Atmospheric Administration (NOAA) barometric pressure data for Area 5. Figure 2 (on page 2) shows a typical 40-day plot of such pressure data.

The initial condition for the jth radionuclide chemical concentration $C^j\,(x,0^+)$ is obtained from the secular equilibrium conditions in the Bateman chain so that

$$C^j\left(x,0^{+}\right) = \frac{\lambda_{j-1}\left(\frac{1+R^{j-1}}{1+R^j}\right)\left(\frac{M_j}{M_{j-1}}\right) C^{j-1}\left(x,0^{+}\right)}{\lambda_j + \lambda_{irr}^j\, f_{irrj}\left(\frac{1-\varepsilon}{\varepsilon\left(1+R^j\right)}\right)} \quad , \tag{13}$$

$j = 2, 3 \ldots M$. $C^1\,(x,0^+)$ is prescribed in both CASCADR8 AND CASCADR9.

Figures 3 and 4 show respectively the soil-atmospheric boundary layer concept and the soil-water table interface concept, respectively. At the soil-atmosphere interface the boundary condition on the jth radionuclide chemical concentration assumes the form

$$-\varepsilon_{out}\, D^j_{out}(t)\left(\frac{C^j\,(0,t) - C^j_{out}}{\Delta x_{out}\,(t)}\right) = -\varepsilon D^j \left.\frac{\partial C^j}{\partial x}\right|_{x=0} \tag{14}$$

while at the soil-water table interface the boundary condition on the jth radionuclide chemical concentration becomes

$$-\varepsilon D^j \left.\frac{\partial C^j}{\partial x}\right|_{x=x_{wt}} = -\varepsilon_{in}\, D_{in}\left(\frac{C^j_{in} - C^j\,(K_{wt},t)}{\Delta x_{in}}\right) \quad . \tag{15}$$

Numerical Solution Method

Even though the model is linear in air pressure P(x,t) and jth radionuclide chemical concentration $C^j(x,t)$ a closed form solution for the system (combinations of elementary function such as sinusoids, exponentials, logarithms) has not been found, largely due to the induced advection velocity as a function of both space and time t. We therefore use a split operator mixed Euler-Lagrange procedure to effect the solution for the

radionuclides (Lindstrom et al. 1992a). A two time level implicit unconditionally stable backward finite difference approximation is used for the pressure field. The resulting tridiagonal system is solved via the classical Thomas algorithm (a special case of the well known LU decomposition method). The barometric pressure fields in both CASCADR8 (homogeneous porous medium model) and CASCADR9 (heterogeneous porous medium model) are treated in this way. However, in CASCADR9, at each contrast or layer interface, the discretized mass balance transport equation is replaced by discretized mass flux conserving interface condition based upon equations 7 and 8. In CASCADR8 the particle backtracking technique is applied at every internal nodal point while in CASCADR9 the particle backtracking technique is applied at every internal nodal point other than the contrast nodal points. At the contrast nodal points, a three-point approximation of equations 9 and 10 is used, which preserves the mass flux continuity across the interface. The way interface nodal points are handled constitutes the main difference between CASCADR8 AND CASCADR9.

The algorithm for solving the coupled system of equations is very simple. First, we solve the pressure field between time levels t_n and t_{n+1}. Then we use a discrete version (three-point Lagrangian formula, Lindstrom et al. 1992a) of equations 3 and 6—all but the interior contrast nodal points—to estimate the advective velocity field, $V(x_k, t_{n+1})$. Knowledge of $V(x_k, t_n)$ and $V(x_k, t_{n+1})$ allows estimation of the "origin" points $X^*_{K(n)}$ via the particle backtracker. Next, a full Lagrange cubic spline procedure spanning the entire domain is used to estimate (interpolate) the advected jth radionuclide chemical concentration at $X^*_{K(n)}$. Knowing these concentrations at the interior nodal points the Eularian portion of the split operator procedure together with all the fate kinetic processes (ingrowth, decay, sorption, etc.) are allowed to operate between time levels t_n and t_{n+1}. The diffusion portion is also treated implicitly so as to generate a fully implicit unconditionally stable Eularian tridiagonal system of transport and fate equations. However, the particle backtracker is explicit in time and therefore must satisfy courant number conditions for stability in the computation. Since the system of M-equations is cascade in nature we begin with the first daughter j=1 and proceed up until all daughters have been accounted for between time levels t_n and t_{n+1}. Because of the low order accuracy of the two and three point Lagrange approximations to derivatives, the nodal point spacing, especially in the neighborhoods of each contrast and near the edges of the low level waste package region, is kept small.

AN ENGINEERING APPLICATION OF CASCADR9

Figure 5 shows a heterogeneous soil formation consisting of four distinct layers over a fifth very thick homogeneous layer extending to the water table. This "4-layer cake" design is <u>not</u> happenstance. Indeed, this is the current design of the engineered closure cap over the low-level radioactive waste that Reynolds Electrical & Engineering Co., Inc. (REECo) of Las Vegas, Nevada, waste management engineers are studying. Each layer is to be one meter thick. The native soil top layer is to be native soil spread more or less uniformly across the top for revegetation purposes. The second layer is to be made of course builders sand (0.5 mm average particle diameter). The third layer is placed as a capillary barrier and consists of standard clean washed pea gravel. The fourth layer is called the control layer because it is basically the hybrid manmade layer that is engineered for a compromise in gas permeability properties, liquid (water) permeability, and geotechnical (cracking-self sealing) properties. It is to be constructed one meter thick and consists of a mixture of sand, bentonite, silica flour, anhydrous calcium sulfate and anhydrous calcium carbonate and is mixed in a concrete style blender with a fixed amount of water per batch. The exact proportions of each component is currently the goal of an ongoing REECo NV/DOE research program in optimized closure cap design (L. Barker, private communication, 1991). A layer of native soil is usually placed over the top most lying waste packages to bring the filled up waste pit back to grade. The actual cap will have a mounded center with a 5% slope required by RCRA. For one-dimensional modeling purposes with CASCADR9 we use the scheme as shown in Figure 5. We now proceed to characterize the radium-226 source in a typical waste pit at the RWMS in Area 5 of the NTS.

Figure 6 shows a sketch of pit 6 (po6u, old to8u) (W. Morgan, private communication, 1992). The length, width, and depth of pit 6 are 630 feet, 100 feet, and 24 feet, respectively. The waste packages are assumed to be the usual 4 feet by 4 feet by 7 feet treated plywood boxes. The boxes are stacked in tier fashion, four high. A four-inch gap (filled with native soil) is left between each box. A total of three gaps realizes one foot of extra space. Thus, stacking the boxes four high totals 17 feet from top to bottom.

The volume inside pit 6 available for waste storage is computed as follows:

- volume = (100') (17') (600') = 1.02×10^6 ft^3
- each box measures 4' × 4' × 7' = 112 ft^3
- they are then estimate to be $(1.02 \times 10^6$ ft$^3)/(1.12 \times 10^2$ ft^3/box) = 9,107 boxes
- assuming the actual storage rate at 95% implies (9,107 boxes) (0.95) = 8,652 boxes.

The assumption (conservative) is made that each box contains 1×10^6 gm of pure uranium-238 at time t=0. Figure 7 shows the ingrowth of radium-226, the source or parent for our radon-222, the "chemical" of interest. The peak ingrowth of radium-226 occurs about 4 million years (not shown). The peak value for radium-226 is 0.34 gm for the given 1 million gram initial mass of uranium-238. Figure 7 was generated from a table of mass ingrowth data obtained from the chemical mass form of the classical Bateman decay chain of uranium-238. The inner workings of CHAIN1 (REECo, WMD staff) are given in Lindstrom et al. 1992b, Appendix B. Observe in Figure 7 that the ingrowth is a very slowly increasing function of time. For short periods of time, e.g., one to two years, the mass of radium-226 can be treated as a constant with the actual mass value of radium-226 obtained directly from the graph and scaled accordingly, since the classical Bateman decay chain is a linear system of ordinary differential equations. For illustrative purposes only we choose the value of radium-226 at 4 million years (the peak value), which is 0.34 gm of radium-226, to constitute the radium source on a per box basis. Hence,

(8,652 boxes) at (1×10^6 U^{238}/box) = 8.652×10^9 gm U^{238} in pit 6. (16)

Also,

(8,652 boxes) at (0.34 gm Ra^{226}/box) = 2,942 gm Ra^{226} in pit 6. (17)

The volume of the waste is estimated to be 1.02×10^6 ft^3, which is easily converted via 28.3×10^3 (cm^3/ft^3) to a volume of 2.887×10^{10} (cm^3). The source function is then defined by assuming that the 2,942 gm of radium-226 is instantaneously and uniformly mixed into the 2.887×10^{10} cm^3 volume. No credit is taken for the slow decay (corrosion in the case of steel drums) of the waste packages. Were this known, we could modify the release rate accordingly. Therefore, we estimated

$$S_{SP} = \frac{\{0.693\}}{\{1600\text{yr}\}\left(3.15576 \times 10^7 \frac{\text{sec}}{\text{yr}}\right)}\left(\frac{2{,}942\,\text{gm Ra}^{226}}{2.887 \times 10^{10}\,\text{cm}^3}\right) =$$

$$1.39864 \times 10^{-18}\,\frac{\text{gm}}{\text{cm}^3 - \text{sec}} \qquad (18)$$

as the manmade source function.

From the one-dimensional model's point of view, the top of this source resides seven feet (2.134 m) below grade, while the bottom of the source resides 24 ft (7.317 m) below grade.

A seven-foot layer of native soil is therefore placed over the top of the waste to bring everything up to grade. Then the four-layer cake (4 m thick) is placed over this with the geometry as shown in Figure 5. Before running any simulations, we must know the material properties of the various porous materials making up the porous medium extending from the soil-atmosphere interface to the water table. The waste package region is given the same material properties as the native soil, a necessary assumption to make for data is totally lacking otherwise. Table 1 summarizes the material properties assigned to the native soil, builders sand, and pea gravel (D. D. Daffern, private communication, 1992).

Table 1. Material properties of porous medium.

Soil type	Particle density (gm/cm^3)	Air dry porosity (cm^3/cm^3)	Air permeability (cm^2)
native	2.6	0.37	4.0×10^{-8}
builders sand	2.6	0.35	4.0×10^{-7}
pea gravel	2.6	0.30	4.0×10^{-6}

Because the material properties of the control layer are yet to be determined experimentally, an engineering design study of the properties of the control layer is summarized in Table 2. The air permeability is chosen to reflect the intrinsic permeability ranges from well graded silty sand and gravel ($\kappa = 4 \times 10^{-12}$ m^2) to homogeneous clays ($\kappa = 4 \times 10^{-16}$ m^2) as shown in Figure 8. With a chosen κ value we use the Kozeny equation (Nazaroff 1992, and Marshall 1958)

$$\kappa = \frac{\varepsilon^4 d^2}{36(1-\varepsilon)^2} \tag{19}$$

Table 2. Estimated material properties and radon-222 diffusion coefficients.

Permeability (κ) (cm^2)	Porosity (ϵ) (cm^3/cm^3)	D_s / D_o (dimensionless)	D_s (20°C) (cm^2/sec)
4×10^{-8}	0.37	0.225	0.0225
4×10^{-9}	0.23	0.110	0.0110
4×10^{-10}	0.137	0.0507	0.00507
4×10^{-11}	0.0795	0.0224	0.00224
4×10^{-12}	0.0455	0.0097	0.00097

and a nonlinear Newton zero finder (Press et al. 1986) to estimate the porosity ϵ. With the calibration point being the native soil, we obtain $d^2 = 3.05 \times 10^{-5}$ cm^2 which physically implies a mean grain diameter of 5.52×10^{-3} cm. We also need to estimate the effective radon-222 diffusion coefficient in the control layer. From Marshall (1959) we have the simple expression

$$\frac{D_s}{D_0} = fa^{\frac{3}{2}} \tag{20}$$

where $fa = \epsilon$ for our very dry alluvium. D_0 is estimated to be 0.1 cm^2/sec at 20°C in free air (Nazaroff, 1992).

Each of the five sets of 40-day runs made with CASCADR9 (Figures 9-13) used the same barometric pressure function. This function consists of a table lookup definition such as the barometric wave sketched in Figure 2.

Table 3 summarizes the 25 numerical experiments conducted to demonstrate the effect of the two engineering design variables: (a) depth of burial and (b) control layer gas permeability κ_{air}, on the surface flux of radon-222 for the source characterization previously discussed.

Table 3. Numerical experiments using CASCADR9.

depth (meters)	$\kappa_{air}(cm^2)$ 4.0×10^{-8}	4.0×10^{-9}	4.0×10^{-10}	4.0×10^{-11}	4.0×10^{-12}
2.0 4.0 8.0 16.0 32.0	Figure 9	Figure 10	Figure 11	Figure 12	Figure 13

It is clear from the study of Figures 9-13 that both increasing the impedance of the control layer (a decrease in κ_{air}) and an increase in the depth to the top of the waste package zone, decreases the radon-222 flux at the soil-atmosphere interface. Notice in particular that as the control layer gas permeability (κ_{air}) decreases by an order of magnitude we only decrease the surface flux by, about a factor of 10. This seems to agree with the theory discussed in Section 3.2 in Lindstrom et al. (1992b). As the depth of burial increases, the effect on radon-222 surface flux seems to drop off exponentially. More work on this engineering variable is planned since the final design of the closure cap-trench system will have to be a compromise between depth of burial and the engineered closure cap.

RESULTS AND CONCLUSIONS

CASCADR9 is a very useful tool for engineering design work. With respect to isothermal dry vadose zone gas transport it can be used to realistically simulate: (a) the surface flux of low-level gas phase radionuclides, (b) the cumulative (time integrated) surface flux (pCi) over one square meter of surface area of low-level gas phase radionuclide, (c) the gas phase low-level radionuclide concentration distribution over time at up to 10 user selected horizons, (d) barometric pressure distribution over time for up to 10 user-selected horizons, (e) the advective velocity distributions over time for up to 10 user-selected horizons, and (f) the free phase, reversibly bound phase, and irreversibly bound phase radionuclide mass distributions for each radionuclide at up to 10 user-selected horizons. It can be driven by either real atmospheric pressure (table lookup) or by a user-tailored barometric pressure wave consisting up to 15 user supplied frequencies and amplitudes. This paper has demonstrated the use of CASCADR9 in the engineering study mode. The two design parameters, (a) engineered cap gas permeability and (b) the depth of burial, clearly show the utility of CASCADR9.

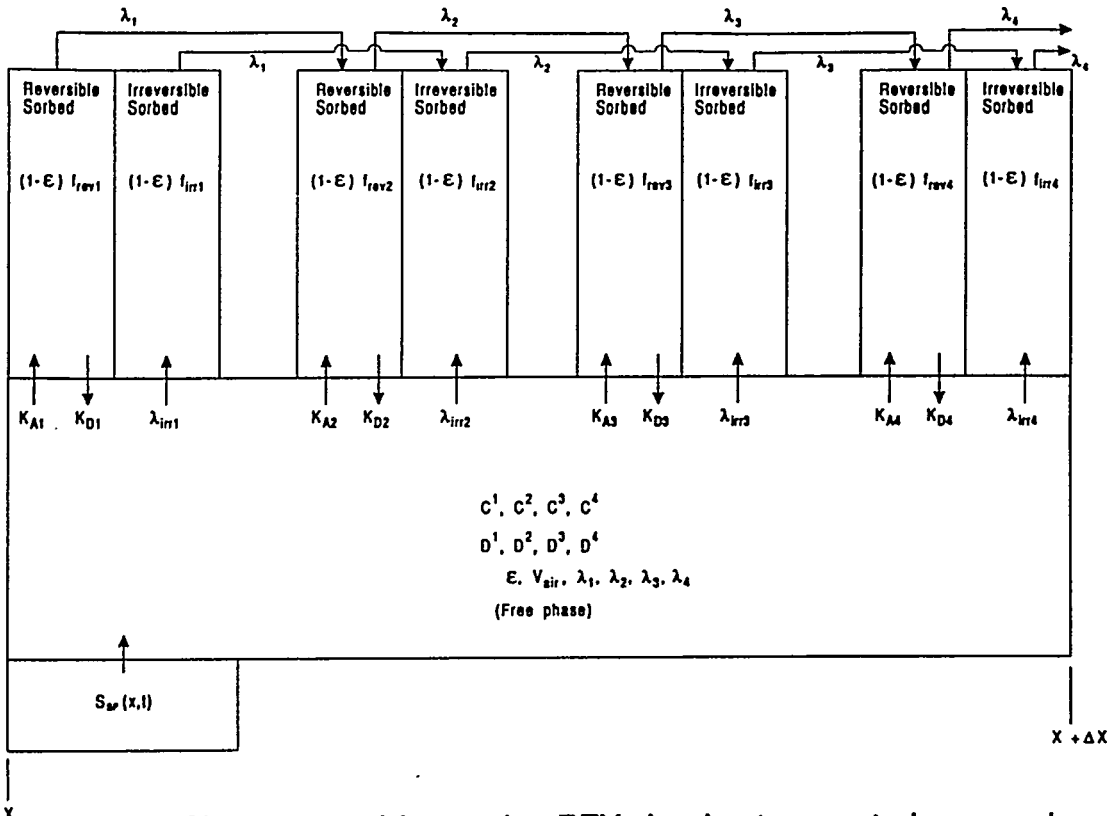


Figure 1. Transport and fate region REV showing transport, decay, and sorption paths.

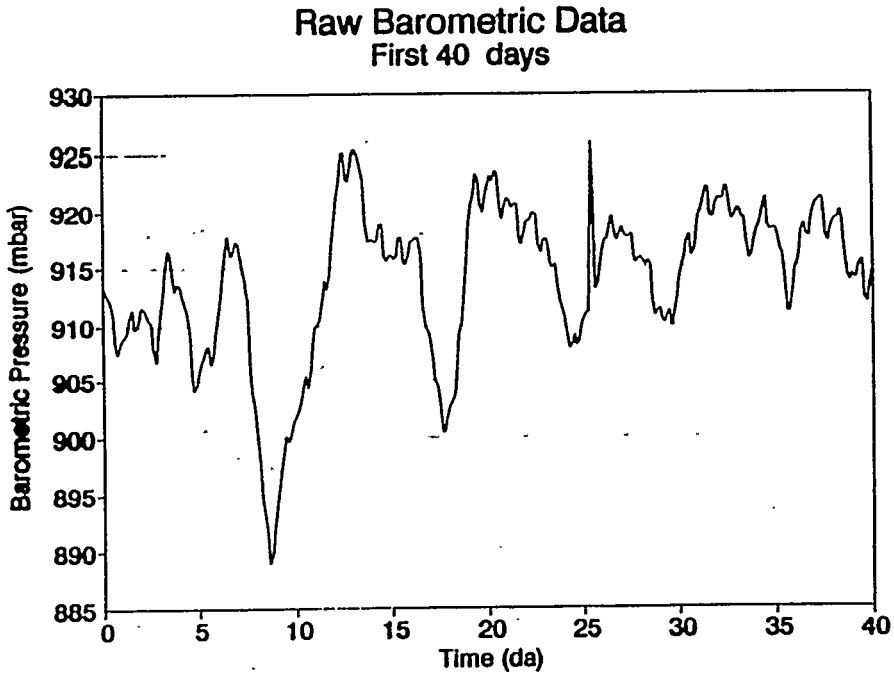


Figure 2. Typical barometric pressure data. Fifteen minute NOAA MET Stn 5, Area 5, Frenchman dry lake, NTS.

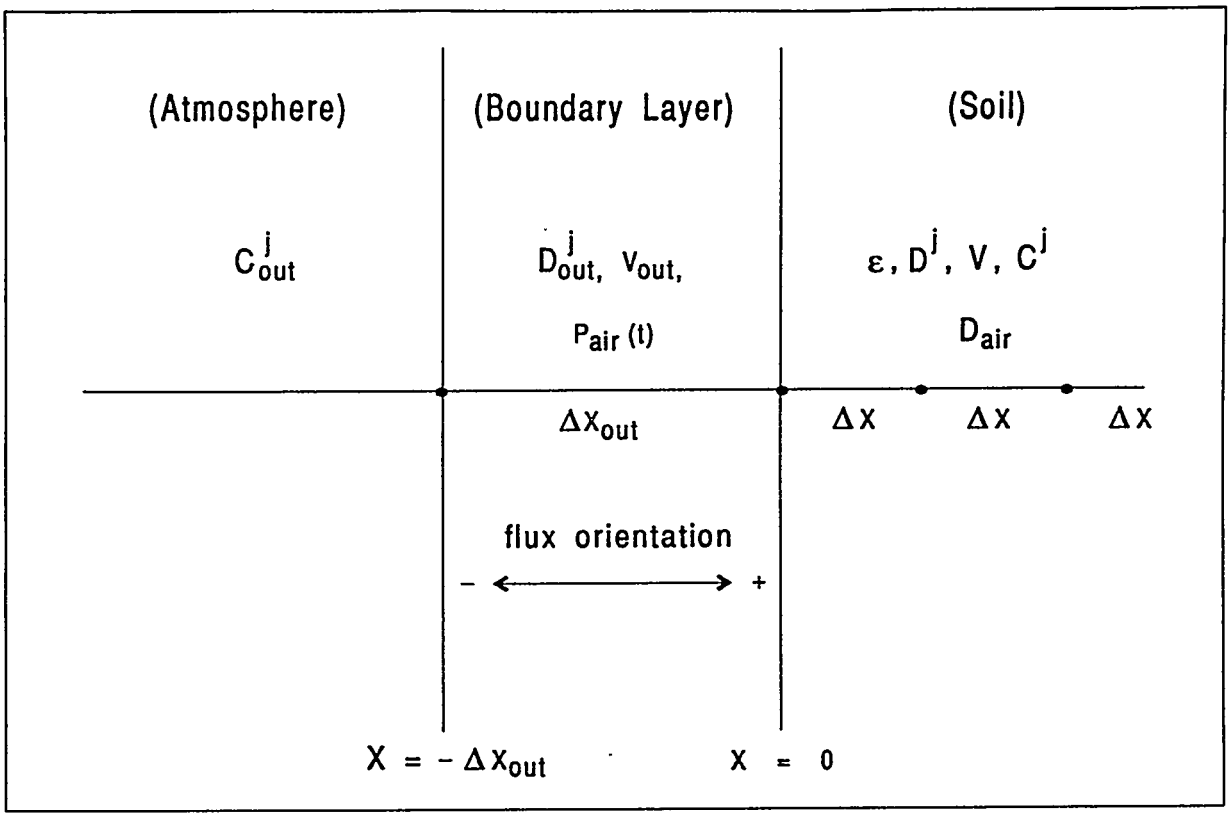


Figure 3. Illustration of the soil-atmosphere boundary layer geometry.

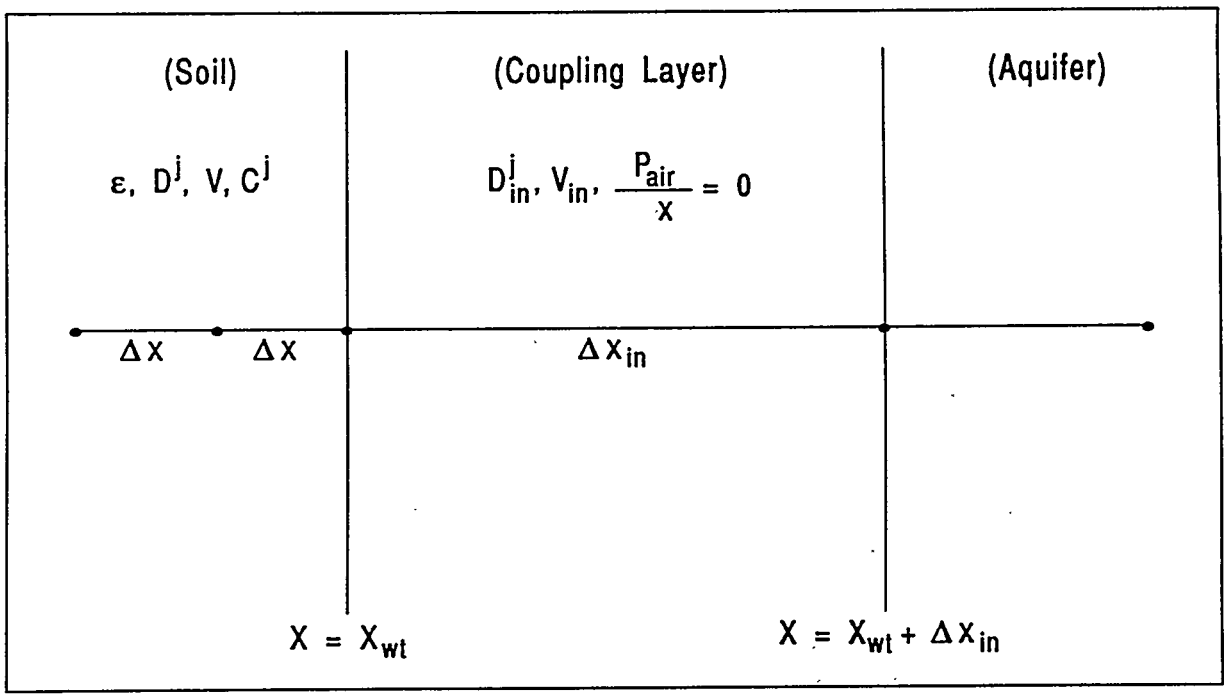


Figure 4. Illustration of the soil-water interface.

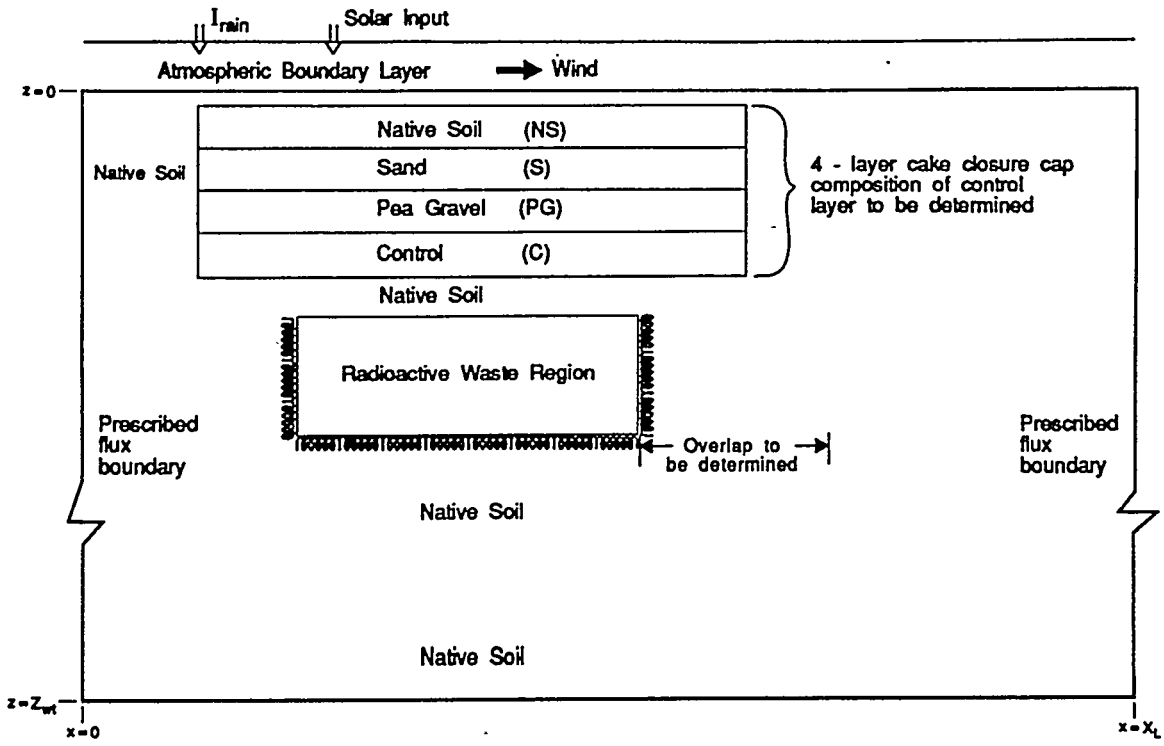


Figure 5. Typical 4-layer cake engineered closure cap REECo design.

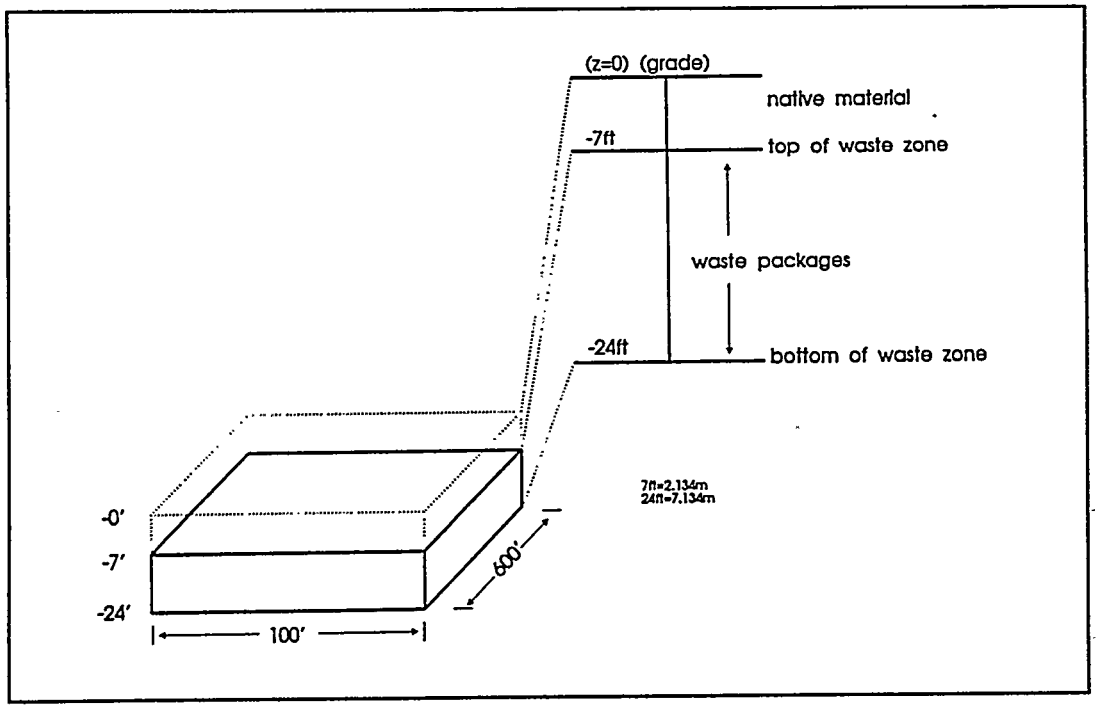


Figure 6. Schematic of typical LLW pit at RWMS in Area 5 of NTS.

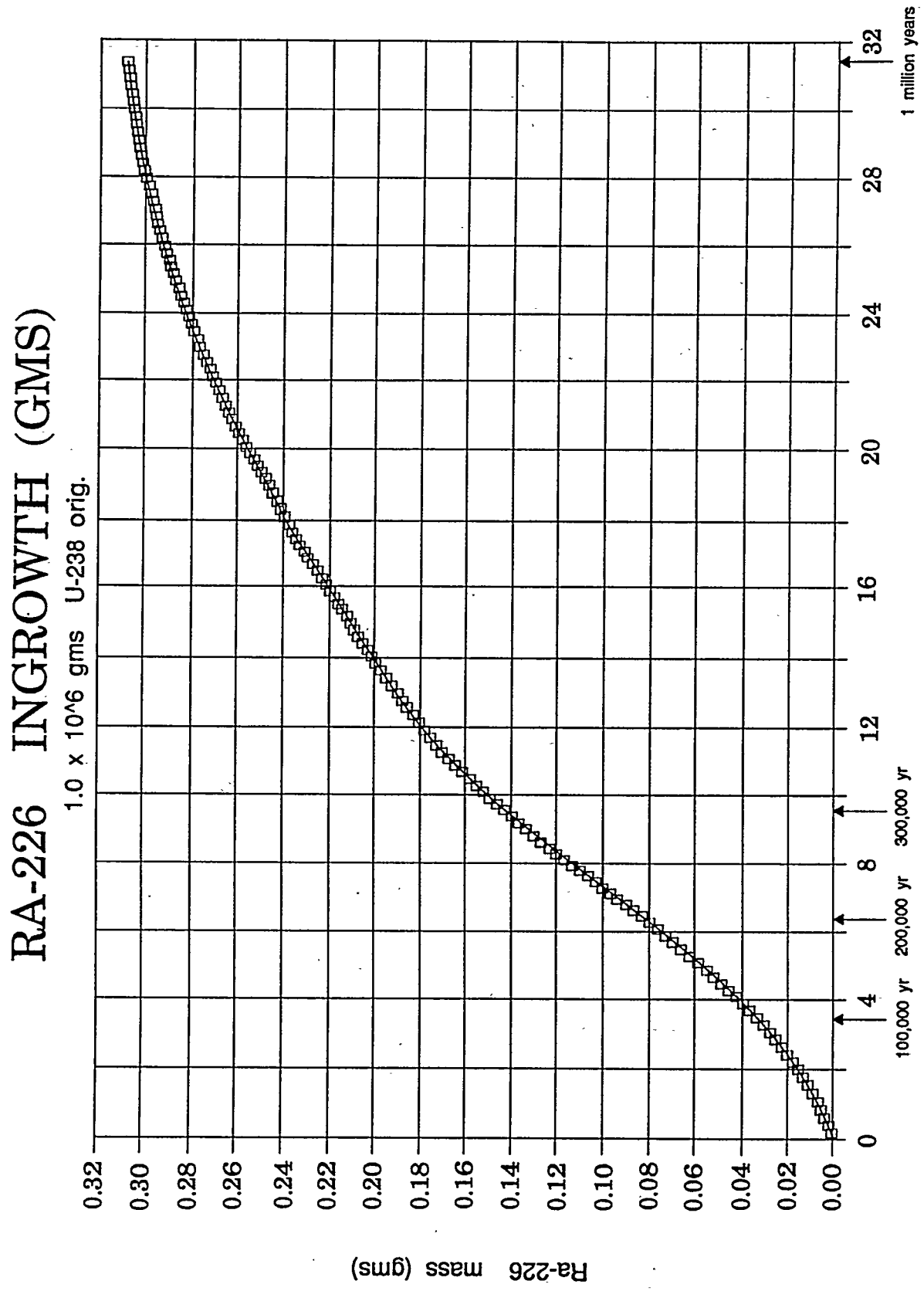


Figure 7. Ingrowth of radium-226 from 1×10^6 gm of pure uranium-238 at time t=0.

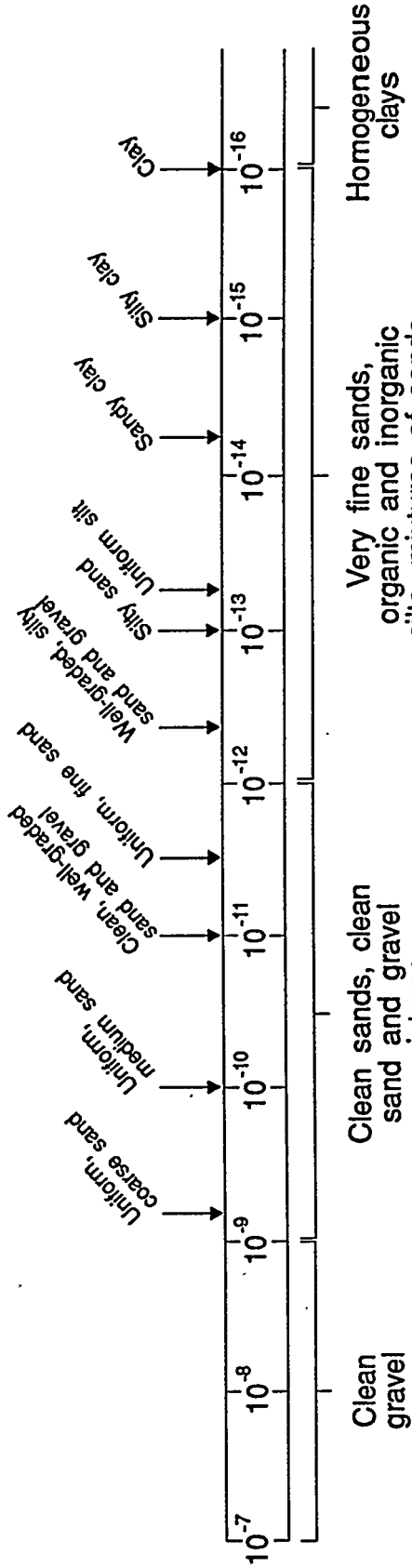


Figure 8. Permeability (m^2) of representative soil textures (lower labels are from Terzaghi and Peck [1976]; upper labels are from Tuma and Abdel-Hady [1973]).

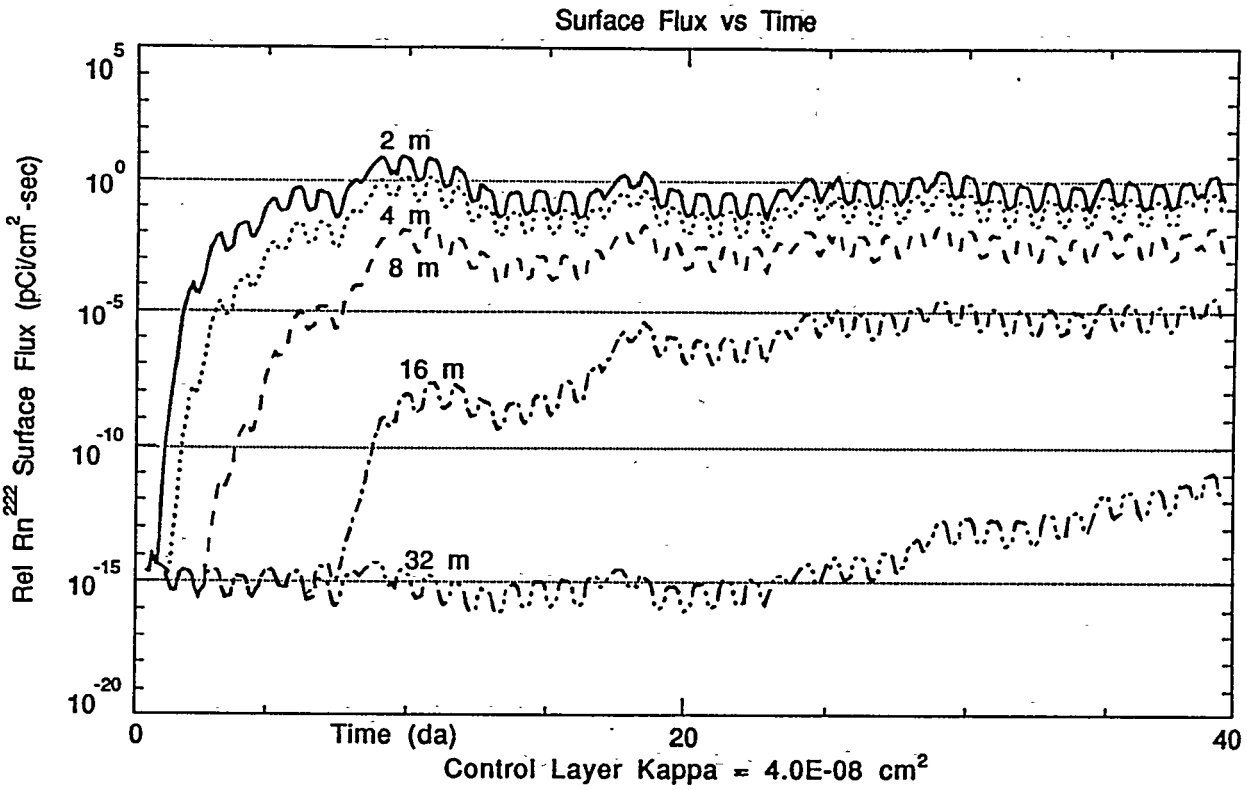


Figure 9. Relative surface flux vs time air perm tests -- $\kappa_{air} = 4.0 \times 10^{-8}$ (cm^2).

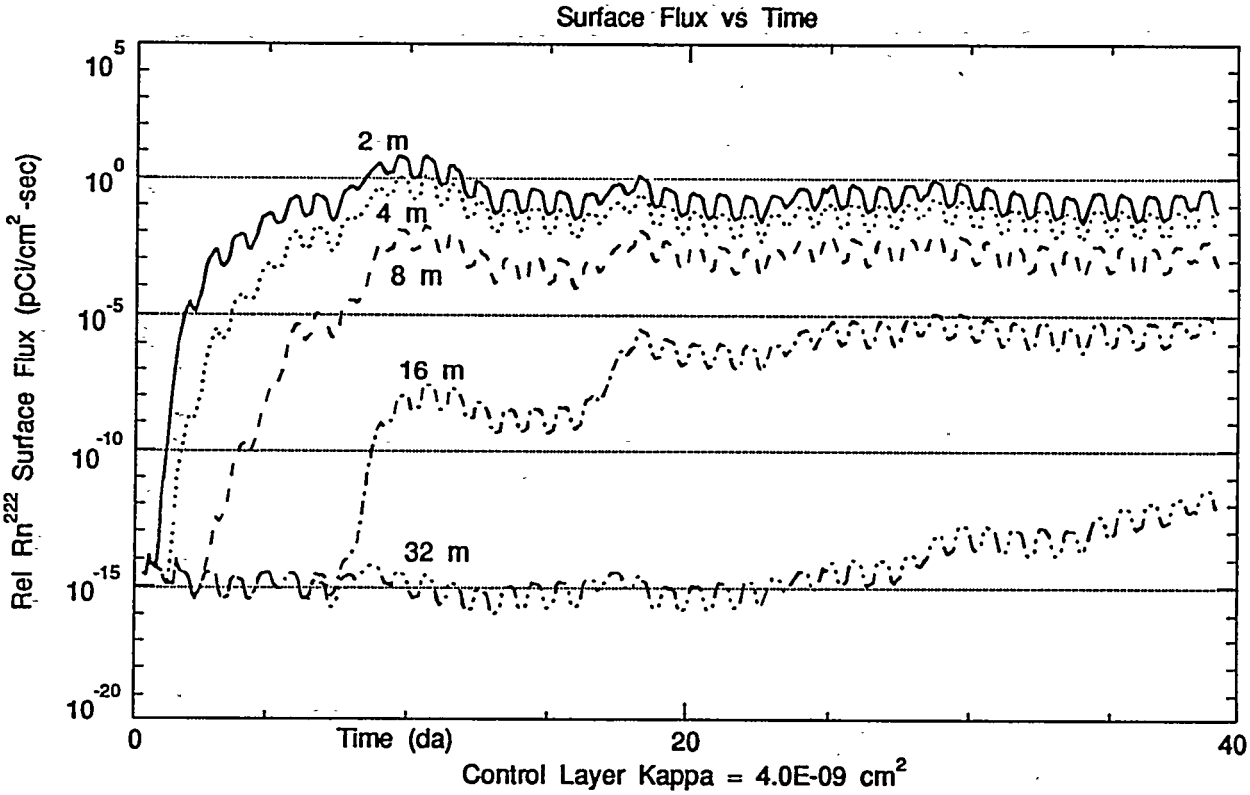


Figure 10. Relative surface flux vs time air perm tests -- $\kappa_{air} = 4.0 \times 10^{-9}$ (cm^2).

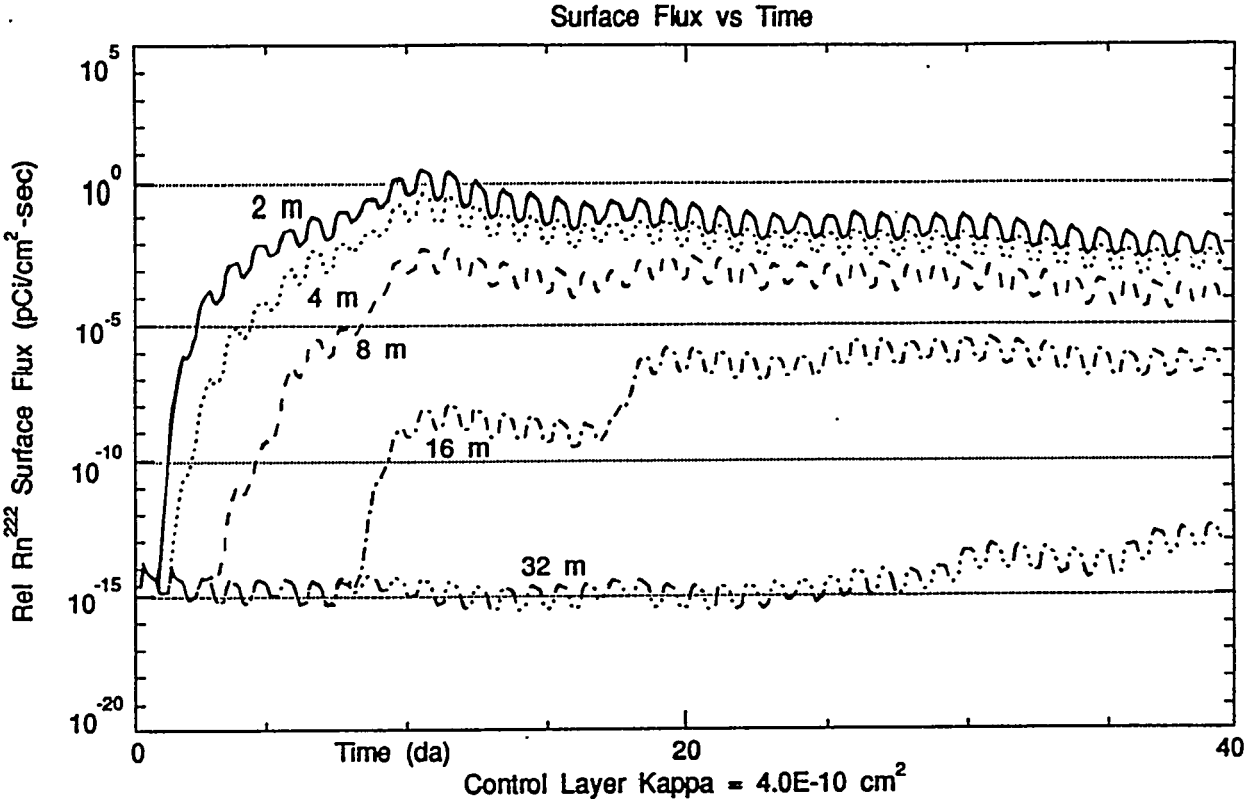


Figure 11. Relative surface flux vs time air perm tests -- $\kappa_{air} = 4.0 \times 10^{-10}$ (cm^2).

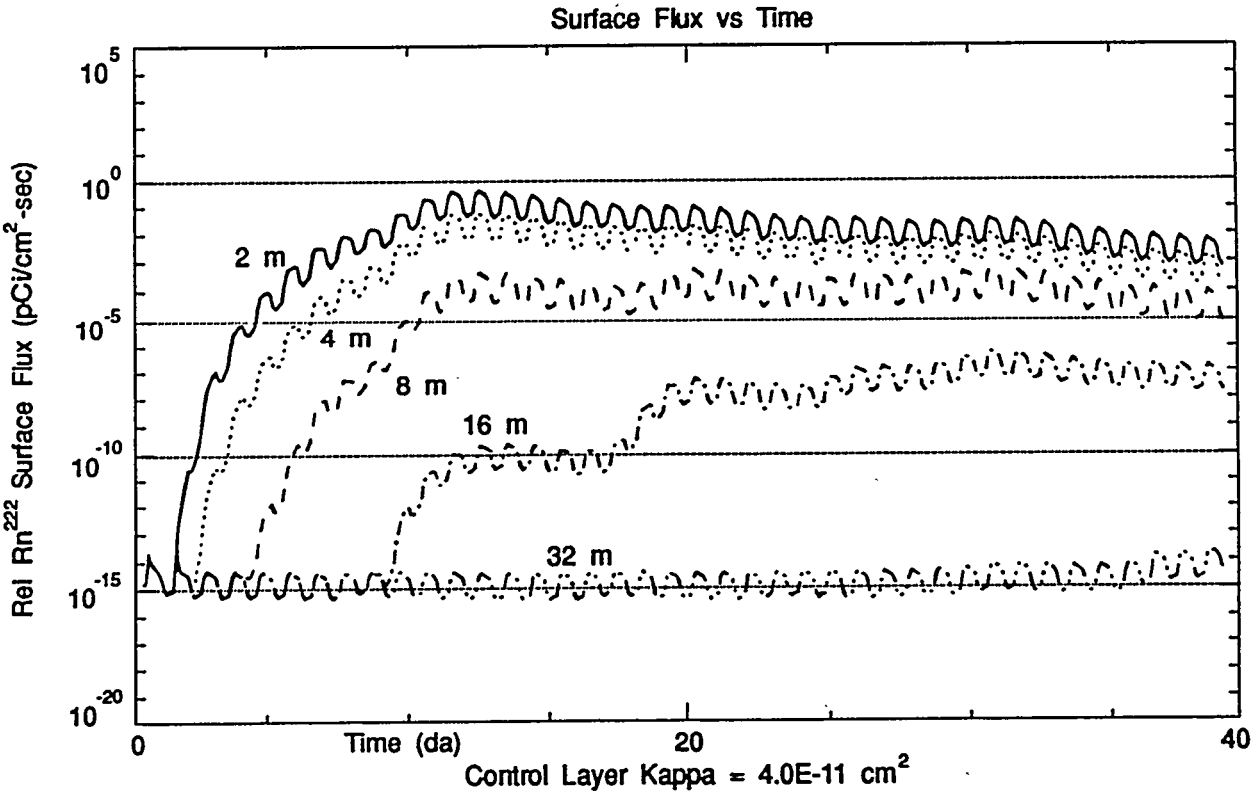


Figure 12. Relative surface flux vs time air perm tests -- $\kappa_{air} = 4.0 \times 10^{-11}$ (cm^2).

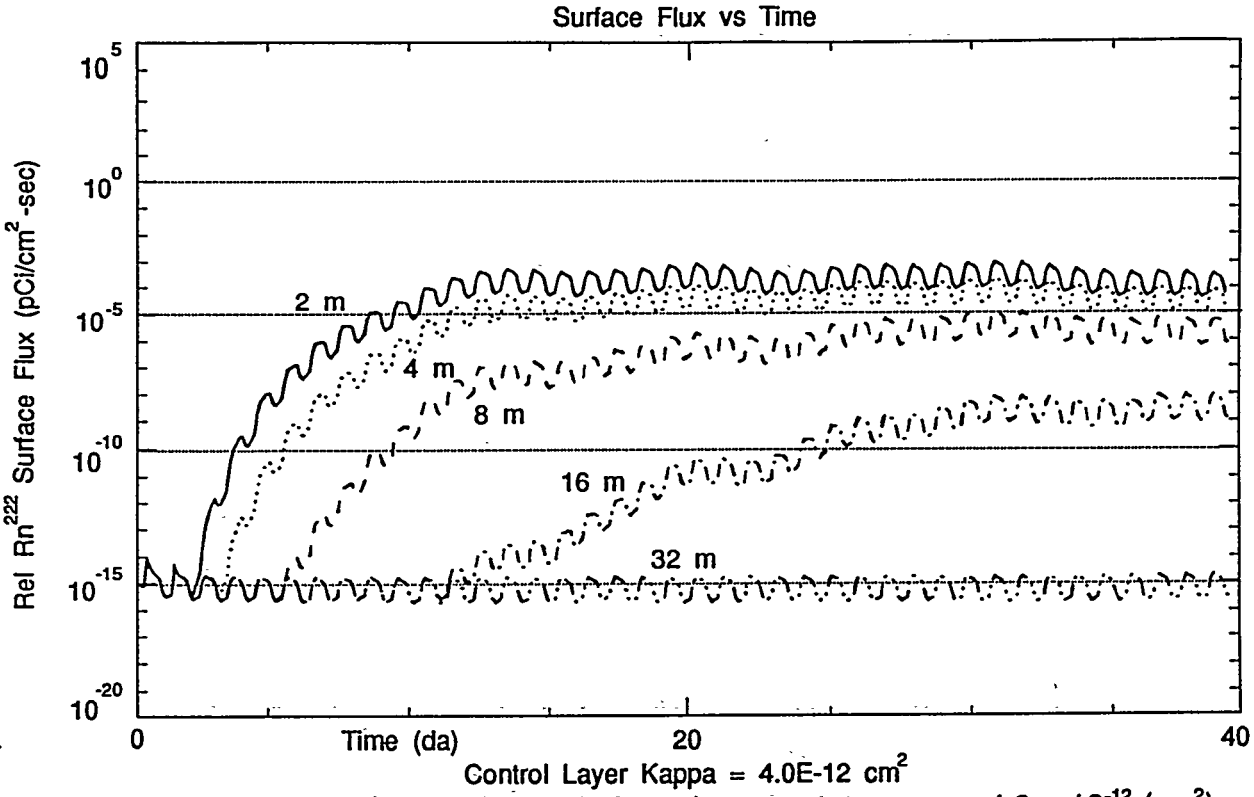


Figure 13. Relative surface flux vs time air perm tests -- $\kappa_{air} = 4.0 \times 10^{-12}$ (cm^2).

REFERENCES

Cawlfield, D. E., F. T. Lindstrom, D. F. Emer, G. J. Shott, and M. E. Donahue, 1992a, *CASCADER: An M-chain Gas Phase Radionuclide Transport and Fate Model*, Volume 2, "Users Guide to CASCADR8," USDOE/NV/10630-XX, Reynolds Electrical & Engineering Co., Inc., 1992 (work in progress).

Cawlfield, D. E., F. T. Lindstrom, D. F. Emer, G. J. Shott, and M. E. Donahue, 1992b, *CASCADER: An M-chain Gas Phase Radionuclide Transport and Fate Model*, Volume 4, "Users Guide to CASCADR9," USDOE/NV/10630-XX, Reynolds Electrical & Engineering Co., Inc., 1992 (work in progress).

Lindstrom, F. T., D. E. Cawlfield, D. F. Emer, G. J. Shott, and M. E. Donahue, 1992a, *CASCADER: An M-chain Gas Phase Radionuclide Transport and Fate Model*, Volume 1, "Basic Physics and Mathematics," USDOE/NV/10630-23, Reynolds Electrical & Engineering Co., Inc., 1992.

Lindstrom, F. T., D. E. Cawlfield, D. F. Emer, G. J. Shott, and M. E. Donahue, 1992b, *CASCADER: An M-chain Gas Phase Radionuclide Transport and Fate Model*, Volume 3, "Heterogenous Layered Porous Media," USDOE/NV/10630-XX, Reynolds Electrical & Engineering Co., Inc., 1992 (work in progress).

Marshall, T. J., 1958, "The Diffusion of Gases Through Porous Media," *Jour. Soil Sci. 10*: 1958, pp. 79-82.

Nazaroff, W. W., 1992, "Radon Transport from Soil to Air," *Reviews of Geophysics 30(2)*: 1992, pp. 137-160.

Press, W. H., B. P. Flannery, S. A. Teukolsky, and W. I. Vettering, 1986, *Numerical Recipes: the Art of Scientific Computing*, Cambridge, UK: Cambridge Press, 1986.

Terzaghi, K., and R. B. Peck, 1967, *Soil Mechanics in Engineering Practice,* 2nd Ed., New York: Wiley and Sons, 1967.

Tuma, J. J., and M. Abdel-Hady, 1973, *Engineering Soil Mechanics*, Englewood Cliffs, NJ: Prentice-Hall, 1973, p. 102.

U.S. Department of Energy, 1988, DOE Order 5820.2A, "Radioactive Waste Management," September 26, 1988.

NOMENCLATURE

Symbol	Definition	Units
A	total cross-sectional area at source region-soil interface	(cm^2)
ϵ_{in}	porosity of water table region	(cm^3/cm^3)
V_{in}	average flow velocity in the water table region	(cm/sec)
$_j$	average dispersion coefficient of jth	(cm^2/sec)
D_{in}	radionuclide in the water table region	
ϵ	porosity of soil region (homogeneous)	(cm^3/cm^3)
V_{air}	average gas flow velocity (seepage velocity) at (x,t) in the soil region	(cm/sec)
V_{out}	average gas flow velocity in the boundary	(cm/sec)
	layer region exterior to the soil-atmosphere	
	boundary $X = X_{Nx}$	
D_j	jth effective diffusion coefficient in soil region	(cm^2/sec)
Δx_{in}	thickness of water table coupling region	(cm)
Δx_{out}	thickness of boundary layer	(cm)
Δx	spacing between nodal points	(cm)
D_{out}	effective diffusivity coefficient of jth radionuclide in the boundary layer region	(cm^2/sec)
C^j	concentration of jth radionuclide in the soil subregion	(gm/cm^3)
R^j	linear equilibrium retardation coefficient of jth radionuclide in the soil subregion	(dimensionless)
λ_o	decay constant for stationary source	(1/sec)
SA_j	specific activity of the radionuclide j	(pCi/gm)
M_s	initial mass of radionuclide 1 source material in the source region	(gm)
λ_j	decay coefficient for jth radionuclide	(1/sec)
$_j\lambda_{irr}$	rate coefficient for irreversible binding of jth radionuclide	(1/sec)
ρ_p	porous medium particle density	(gm/cm^3)
f_{revj}	fraction of porous medium solids available for reversible binding of jth radionuclide	(dimensionless)
f_{irrj}	fraction of porous medium solids available for irreversible binding of jth radionuclide	(dimensionless)

Symbol	Definition	Units
K_{Aj}	adsorption rate coefficient of radionuclide j onto solid particles	$\frac{cm^3 \text{ air}}{cm^3 \text{ particles-sec}}$
K_{Dj}	desorption rate coefficient of radionuclide j onto solid particles	(1/sec)
K_{eqj}	linear equilibrium reversible sorption coefficient for radionuclide j onto the solid particles	$\frac{cm^3 \text{ air}}{\text{gm particles}}$
q_{air}	specific discharge of air in the porous medium	(cm^3/cm^2-sec)
$S_o(x)$	first constant in time, distributed in space source function, for first radionuclide in the transport and fate region	$\frac{\text{gm radionuclide}}{\text{gm soil-sec}}$
$S_{SP}(x)$	second constant in time, distributed in space, source function, for first radionuclide in the transport and fate region	$\frac{\text{gm radionuclide}}{cm^2\text{-sec}}$
κ_{air}	air permeability	(cm^2)
K_{air}	pneumatic conductivity	(cm/sec)
η_{air}	air viscosity	(dyne-sec/cm^2)
ρ_{air}	air density	(gm/cm^3)
g	gravitational acceleration	(cm/sec^2)
P_{air}	barometric air pressure	(dyne/cm^2)
M_{air}	molecular mass of air	(gm/mole)
M_j	atomic mass of radionuclide j	(gm/mole)
R_g	gas constant	$\frac{\text{erg}}{\text{mole-°K}}$
T	kelvin temperature	(°k)
D_{air}	pneumatic diffusivity	(cm^2/sec)
N_x	number of equal length subintervals into which [0, X_{wt}] is subdivided	(dimensionless)
Δt	time increment between adjacent time levels	(sec)
$q_{cj,n+1}$	flux of radionuclide j at time t_{n+1} at the atmosphere-soil interface	(gm/cm^2-sec)

Environmental Monitoring of Subsurface Low-Level Waste Disposal Facilities at Oak Ridge National Laboratory[a]

Tom L. Ashwood
Diana S. Hicks
Environmental Sciences Division
Oak Ridge National Laboratory
P.O. Box 2008
Oak Ridge, TN 37831-6036

INTRODUCTION

Oak Ridge National Laboratory (ORNL) generates low-level radioactive waste as part of its research and isotope production activities. This waste is managed according to DOE Order 5820.2A. Solid LLW[b] management includes disposal in aboveground, tumulus-type facilities as well as in various types of subsurface facilities. Since 1986, subsurface disposal has been conducted using various designs employing greater-confinement-disposal (GCD) techniques. The purpose of this paper is to present monitoring results that document the short-term performance of these GCD facilities.

REQUIREMENTS FOR MONITORING PROGRAM

Chapter III of DOE Order 5820.2A sets forth requirements for environmental monitoring of operational LLW disposal facilities. The order sets forth three general criteria for a monitoring program:

> The environmental monitoring program shall be designed to measure: (a) operational effluent releases; (b) migration of radionuclides; (c) disposal unit subsidence; and (d) changes in disposal facility and disposal site parameters which may affect long-term site performance. [Section 3.k.2]
>
> The monitoring program shall be capable of detecting changing trends in performance sufficiently in advance to allow application of any necessary corrective action prior to exceeding performance objectives. The monitoring program shall be able to ascertain whether or not effluents from each . . . disposal facility or disposal site meet the requirements of applicable EH Orders. [Section 3.k.4]
>
> Where practical, monitoring measurements to evaluate actual and prospective performance should be made at locations as required, within and outside each facility and disposal site. Monitoring should also be used to validate or modify the models used in performance assessments. [Section 3.b(3)]

In 1989, ORNL's Solid Waste Operations Department and Environmental Sciences Division implemented a monitoring program to meet these requirements for all LLW disposal sites that were active on or after the date of the order (September 1988). This Active Sites Environmental Monitoring Program (ASEMP) is based on the conceptual hydrologic model described later in this paper (Ashwood et al. 1990, 1992a).

---

a. Research supported by Office of Enviornmental Restoration and Waste Management, U.S. Department of Energy, under ontract DE-AC05-84OR21400 with Martin Marietta Energy Systems, Inc.

b. This discussion applies only to LLW that has been certified to be free of hazardous waste constituents and free liquids. Mixed (co-contaminated) waste at ORNL is currently being stored pending decisions on appropriate disposal methods.

DESCRIPTION OF LOW-LEVEL WASTE DISPOSAL FACILITIES

All solid LLW at ORNL is currently disposed of in Solid Waste Storage Area (SWSA) 6 (Figure 1). Low-level waste must meet certain waste acceptance criteria before being disposed of in SWSA 6. The waste cannot contain free liquids or hazardous waste constituents. Each waste package is inspected by real-time radiography to certify that free liquids are not included, and waste generators must certify that hazardous constituents are not included. Materials meeting the DOE definition of transuranic wastes (i.e., atomic number >92, half-life >20 years, concentration >100 nCi/g) may not be disposed of in SWSA 6. Transuranic wastes are stored in SWSA 5.

Aboveground disposal on the tumulus pads and at the Interim Waste Management Facility (Figure 1) is described in another presentation at this conference. Subsurface GCD facilities include concrete silos, high-range wells, and fissile wells.

Silos, used for low-activity (<200 mr/h at the surface of the package) and high-activity (200 1000 mr/h) LLW and for asbestos wastes that may contain LLW contamination, have undergone an evolution in design. The original design took advantage of large concrete pipes that become available after cancellation of the Clinch River Breeder Reactor program. Twenty-foot lengths of these pipes were installed vertically in trenches, and clean dirt was backfilled around the silos. The bottom of each silo was plugged with concrete, and wastes were loaded to within approximately 1 ft of the top. A concrete cap was poured over the silo. Initial evaluation of these silos demonstrated that water leakage into and out of the silos was occurring probably around the joint between the bottom and sides (Davis et al. 1989). Later designs have used sections of corrugated steel culvert to build a pipe-within-a-pipe with the annular space filled with concrete. Again, a concrete cap and concrete bottom were poured to isolate the waste (Davis et al. 1989).

High-range wells, used for high-activity wastes (>1 r/h at the surface of the package), are approximately 20-ft-deep auger holes with a steel-pipe liner and a concrete bottom plug. A concrete cap is placed over the top of the well. Some installations consist of a cluster of high-range wells encased in concrete within a silo. Fissile wells are similar to individual high-range wells.

CONCEPTUAL HYDROLOGIC MODEL

Understanding the movement of water through the disposal and storage areas is important because water is the primary vector for transport of contaminants. Within a trench or the backfill surrounding other subsurface facilities, contamination may be present in the perched water from one of three sources: (a) leaching of material from the silos if there has been a containment failure in the silo, (b) leaching of contaminants from the backfill in the trench if that backfill was contaminated, or (c) transport of contaminants from upgradient sources.

Moore (1988, 1989) suggests that most of the subsurface flow in the ORNL area occurs laterally in a shallow stormflow zone (≤2 m deep). This zone typically has a hydraulic conductivity much greater than deeper zones and is active when infiltrating precipitation exceeds the soil moisture deficit. Water in the stormflow zone moves rapidly to surface water drainages.

In SWSA 6, waste trenches are typically installed at least 0.6 m (2 ft) above the highest recorded water table (Boegly 1984). While these trenches are not in contact with the shallow aquifer, they may intercept shallow stormflow (Figure 2). Because the permeability of the trenches is substantially higher than that of the surrounding soil, water flows into the trenches faster than it can flow out, thereby creating a perched water table. This bathtubbing effect accounts for saturated conditions in trenches that are above the local water table. To a lesser extent, the disturbed area immediately next to high-range wells, fissile wells, and asbestos silos may also be subject to bathtubbing caused by shallow stormflow.

Solomon et al. (1989) summarized water level data collected from 1975 to 1988 from unlined waste trenches in SWSA 6. They estimated that 85% of the trenches had standing water during some part of that period. Ashwood and Spalding (1991) measured water levels in unlined SWSA 6 trenches covered by plastic

caps. They demonstrated that some trenches that were above the water table continued to receive water (probably via shallow subsurface stormflow) even after direct infiltration had been eliminated by the caps.

SAMPLING AND ANALYSIS APPROACH

Davis et al. (1989) installed eight wells in the silo trench backfill material (Figures 3 and 4). Two of these wells (1 and 2) were subsequently lost during trench maintenance activities. Solid Waste Operations personnel began a practice of installing wells made of slotted PVC pipe in the silo trenches as they were backfilled. In the summer of 1991, ASEMP staff installed 2-in.-diameter steel drivepoint wells into silo trenches that had no wells and into some trenches where we felt additional wells were desirable. Collectively these wells in silo trenches are referred to as intratrench wells (see Figures 3–5 for locations of all intratrench wells). Drivepoint wells were also installed in the backfill material next to nine high-range wells (Figure 6), two asbestos silos, and two fissile wells. These wells are referred to as backfill monitoring wells. A weighted plastic bottle (250 mL) is attached to a line and left in the bottom of each well to collect a sample of perched water. Bottles are checked quarterly; a sample is collected if the bottle contains ≥50 mL of water. Currently, samples are filtered through 0.45-μm filter paper to remove sediment, and the filtrate is acidified to pH<2 with nitric acid. Before fiscal year 1992, samples were acidified before filtration. Filters from each sample are air dried.

The primary constituents of LLW generated at ORNL are ^{3}H, ^{60}Co, ^{90}Sr, ^{137}Cs, and ^{154}Eu. Acidified liquid samples are scanned for gamma-ray emitters (EPA Procedure 901.1) and analyzed for gross alpha and a gross beta activity (EPA Procedure 900.0) by the Analytical Chemistry Division at ORNL. Dried filters generated since the beginning of FY 1992 are gamma scanned in the Environmental Sciences Division (internal procedure derived from EPA Procedure 901.1). Before FY 1992, filters were discarded without being analyzed. No analysis is performed for ^{3}H because there is usually insufficient sample available (typically ≤250 mL) to perform a ^{3}H analysis in addition to the gamma and gross alpha/beta analyses.

ACTION LEVELS

Gamma-emitting radionuclides, ^{60}Co and ^{137}Cs, exist in soil and groundwater from radioactive fallout not associated with the monitored disposal facilities. Alpha activity is present in all environmental samples due to naturally occurring uranium and thorium and their daughter products. Naturally occurring beta activity is derived from ^{40}K, which is found in all K-bearing materials. The presence of these and other naturally occurring sources of radioactivity leads to variable background concentrations of gross alpha, gross beta, ^{60}Co, and ^{137}Cs in all samples. To determine whether the activity measured in a sample is caused by leakage from a monitored facility, it is essential to determine the upper range of the local background concentrations. This upper range is then set as an action level. Samples that exceed the action level are likely to contain contamination from some source other than the natural background.

We used two methods to set action levels. Initially, action levels for gross alpha activity (1 Ba/L) and gross beta activity (5 Bq/L) were determined from rainwater (Ashwood et al. 1990). However, rainwater is not typical of shallow stormflow or groundwater because the latter media may contain trace levels of radionuclides leached from soil. Therefore, in 1991, historical monitoring data from the intratrench wells were evaluated to identify the upper limit of the background concentrations of gross alpha, gross beta, ^{60}Co, and ^{137}Cs (Ashwood and Ashwood 1991). No samples from intratrench wells or backfill monitoring wells have ever contained measurable ^{154}Eu, so no evaluation could be made of the background levels for this radionuclide.

Two problems frequently occur in radionuclide data sets: negative values and left-censored (i.e., "less than") data. Left-censored data arise when the sample concentrations are below the detection limit of the analysis procedure. Negative data arise when the measured value for a sample is less than the instrument background value. Both problems are common when evaluating the very lot concentrations associated with background samples. Because of the large proportion of left-censored data and the presence of negative values in our data sets, available statistical treatments were limited to a nonparametric approach (essentially a rank ordering of the data). Using this approach we were able to determine (with 95% confidence) the upper 95%

quantile of the background population for gross alpha, gross beta, ^{60}Co and ^{137}Cs (Table 1: based on Tables 2 and 3 in Ashwood and Ashwood 1991).

There is an important tradeoff that must be recognized when setting action levels. If the action level is set too high (e.g., the level below which 99% of the background population lies), then there is a greater chance that real leakage from the monitored facility will be missed. On the other hand, setting the action level too low causes too many false positives that also confound the identification of real leakage. For the ORNL program action levels were established at the level in Table 1. In most cases, these levels also reflect realistic analytical detection limits for the typical sample size and the counting times that our analytical labs are able to support.

RESULTS AND DISCUSSION

Seventeen intratrench wells and six backfill monitoring wells contained radionuclide concentrations greater than action levels during at least one sampling period (Tables 2 and 3). Nine of these seventeen intratrench wells were in trenches where the silos had been grouted as wastes were emplaced (Figures 3-5).

Intratrench Wells

Samples from intratrench wells 27, 31, 35, and 36 exceeded the gross alpha action level during one sampling period each (Table 3). In all cases, associated counting errors were low enough that the reported values are statistically significant ($p < 0.05$). Wells 31 and 35 are located in trenches where the silos were filled with grout as the wastes were emplaced (Figure 4). The presence of measurable gross alpha contamination is difficult to understand because waste records indicate that only trivial amounts of alpha-emitting isotopes were disposed of in SWSA 6 silo trenches. The occurrence of elevated gross alpha activity in only one sample per well suggests that there are no continuing leaks of alpha emitters.

Well 19 is the only well where samples have consistently exceeded an action label (Table 3). Gross beta concentrations in well 19 were closely correlated with ^{90}Sr concentrations during all four quarters of FY 1991 (Ashwood et al. 1991, 1992b). These four sampling periods were the only times when sufficient sample was collected to provide for ^{90}Sr analyses. Well 19 is located in a trench where none of the silos were grouted when wastes were emplaced (Figure 3).

Samples from intratrench wells 5, 13, and 40 have exceeded the gross beta action level once per well (Table 3). Small sample sizes from these wells have precluded concurrent analysis for ^{90}Sr. Succeeding samples from these wells have been below action levels, thereby indicating that there is not a continuing source of contamination within the trench.

The elevated concentration of ^{137}Cs in the 04 June 1992 sample from well 5 (Table 3) might suggest that ^{137}Cs contributed to the reported gross beta anomaly; however, the relatively high counting error indicates that the reported ^{137}Cs is not statistically significant ($p < 0.05$). Moreover, the 04 June 1992 sample from well 4, which is in the same trench as well 5 (Figure 3), contained only 0.24 ± 0.10 Bq/L of gross beta activity and only 0.10 ± 0.70 Bq/L of ^{137}Cs. Similarly, the gross beta anomaly in the 20 September 1990 sample from well 13 (Table 3) is not reflected in the sample from well 12 (gross beta = 0.51 ± 0.09 Bq/L), which is in the same trench as well 13 (Figure 3). Thus, any gross beta contamination in the perched water of these trenches was localized near wells 5 and 13.

Counting errors associated with the ^{60}Co anomalies reported for wells 7, 17, and 24 (Table 3) are so high that the reported values are not statistically significant ($p < 0.05$). The same is true for one each of the two ^{60}Co anomalies reported for both well 32 and well 35 (Table 3). Statistically significant levels of ^{60}Co did occur during one sampling period each in intratrench wells 12, 31, 32, 33, 35, 36, and 44 (Table 3). Cesium-137 exceeded the action level only in intratrench wells 5 and 45 (Table 3), but the reported value in well 5 was not statistically significant ($p < 0.05$).

Backfill Monitoring Wells

The pair of gross alpha anomalies in well C595 (Table 3) are statistically significant ($p < 0.05$). The source of alpha contamination is unknown, and subsequent measurements of gross alpha activity suggest that the source has disappeared.

The gross beta concentration in the 14 May 1991 sample from backfill monitoring well AUG 48 is closely correlated with the ^{137}Cs concentration, both of which greatly exceed action levels (Table 3). Gross beta and ^{137}Cs concentrations declined in succeeding samples, although the ^{137}Cs concentration was still above the action level in the 30 December 1991 sample. This pattern indicates that a slug of ^{137}Cs, possibly originating in the adjacent high-range well cluster, passed through the backfill surrounding well AUG 48. The gamma anomalies in wells AUG 51 and FIS 102 are associated with high counting errors (Table 3).

Although early indications of ^{60}Co in wells AUG 50 and FIS 102 (Table 3) were statistically significant, subsequent samples suggest that the source no longer exists. Other ^{60}Co anomalies in wells AUG 51, AUG 559, and FIS "?" (Table 3) are not statistically significant ($p < 0.05$).

CONCLUSIONS

Our results strongly suggest that ^{90}Sr was leaking from one or more of the ungrouted silos in the trench containing well 19. The source of other elevated radionuclide concentrations in the intratrench wells is not so clear. Recently, all other previously ungrouted silos in SWSA 6 were grouted in place using a grout injection technique (C. W. Francis, ORNL, personal communication to D. S. Hicks, ORNL, October 1992). Unfortunately, there was no water in well 19 during the most recent sampling period, which followed completion of the in situ grouting program. Hence, we are unable to evaluate the effectiveness of the grouting effort at reducing the ^{90}Sr leakage.

The elevated gross beta and ^{137}Cs concentrations reported in well AUG 48 are certainly symptomatic of a slug-type plume. This well and all other backfill monitoring wells are topographically down slope from a set of unlined disposal trenches (Figure 1) that were covered with a temporary plastic cap as part of an interim remedial action. These trenches contain leachate with elevated levels of various contaminants (Solomon et al. 1988, Ashwood and Spalding 1991). Thus, the contamination in AUG 48 and other backfill monitoring wells may originate from the unlined trenches or from the monitored GCD facilities. At this time, we have insufficient information to confidently identify the source.

Present plans for closure of SWSA 6 call for interim closure of the subsurface disposal facilities by covering them with a plastic cap that is extensive enough to cut off all sources of stormflow and direct infiltration. If water can be prevented from contacting the waste, then leakage will obviously stop. Eight temporary plastic caps were installed as part of an interim corrective measure under the Resource Conservation and Recovery Act. Water levels in trenches covered by the caps are monitored periodically, and a one-time sampling of trench leachates was conducted (Ashwood and Spalding 1991). Results of this monitoring program indicate that at least some of the trenches continue to collect water, probably from shallow storm flow that was not eliminated because the caps do not cover the recharge area (Ashwood and Spalding 1991).

Monitoring results reported here suggest that even some grouted silos may leak. Thus, one important implication of our results is that a representative number of existing intratrench wells and backfill monitoring wells be left in place after closure of SWSA 6 to determine whether the trenches are dry and, if not, to monitor for contaminant leakage.

We have collected samples from most backfill monitoring wells during most sampling periods. The presence of water in the sample bottles provides some evidence that our conceptual hydrologic model of the area is plausible. However, we are unable to conclusively demonstrate that contamination in these wells originates within the monitored facilities. Design of monitoring systems for such facilities should include some means of separating other potential contamination sources if any are present.

Another important lesson learned from our experience is that the sample sizes are inadequate to provide quantitative evidence of small leaks of gamma emitters. Recently, we have begun to check bottles in selected wells on a biweekly basis. Any water collected is stored for submission as part of a composite quarterly sample. This approach should provide sufficient sample size (~1 L) to reduce counting errors. A further benefit will be that an aliquot of the sample will be available as needed to be analyzed for ^{90}Sr.

ACKNOWLEDGMENTS

Della Marshall provided valuable assistance during field sampling activities. Jeff Wade and Norm Teasley, Analytical Chemistry Division, and Lauren Larsen, Environmental Sciences Division, analyzed the samples. Dave Hall and Dennis Borders reviewed an early draft of this paper. This is publication 4003 of the Environmental Sciences Division, ORNL.[a]

a. The submitted manuscript has been authored by a contractor of the U.S. Government under contract No. DE-AC05-84OR21400. Accordingly, the U.S. Government retains a nonexclusive, royalty-free license to publish or reproduce the published form of this contribution, or allow others to do so, for U.S. Government purposes.

Table 1. Action levels for SWSA 6 backfill monitoring wells

Analyte	95% quantile concentration of background population[a] (Bq/L)	Action level (Bq/L)
Gross alpha	1.4	1.0[b]
Gross beta[c]	4.5	5.0
^{60}Co	1.6	1.5[b]
^{137}Cs	2.4	2.5

[a] Based on 95% confidence level (1-α).

[b] Action level set below 95% quantile to minimize probability that significant contamination might be missed.

[c] Gross beta analysis does not include ^{3}H.

Table 2. Summary of results from backfill monitoring wells

Well(s)	Sampled?	Exceed action level?
	Low Activity Silos Area North	
3, 14	No[a]	
4, 6, 8, 9, 10, 11, 15, 16,	Yes	No
18, 20, 21, 22, 23, 25	Yes	No
5, 7, 12, 13, 17, 19, 24	Yes	Yes
	Low Activity Silos Area South	
38, 39, 41, 42, 43, 46, 47	Yes	No
40, 44, 45	Yes	Yes
	High Activity Silos Area	
37	No[a]	
26, 28, 30, 34	Yes	No
27, 29, 31, 32, 33, 35, 36	Yes	Yes
	High-Range Wells	
AUG 49, AUG 536	Yes	No
AUG 540, AUG 559, AUG 572	Yes	No
AUG 48, AUG 50, AUG 51	Yes	Yes
	Asbestos Silos and Fissile Wells	
C520	Yes	No
C595, FIS 102, FIS "?"	Yes	Yes

[a] Never sampled because sample bottles never contained water. Well 3 was buried during trench maintenance activities. Installation design of well 14 is uncertain. Well 37 has not been sampled because silo loading has only recently been completed.

Table 3. Monitoring data from backfill monitoring wells that exceeded action levels at least once[a]

Well	Sample date	Gross alpha	Gross beta	^{60}Co	^{137}Cs
5	12 Feb 90	0.26 ± 0.125	2.80 ± 0.35		
5	20 Sep 90	0.16 ± 0.055	0.73 ± 0.12		0.90 ± 1.30
5	07 Feb 91	-0.11 ± 0.02	0.32 ± 0.335		
5	07 May 91	0.14 ± 0.05	0.44 ± 0.095	-0.10 ± 0.55	0.37 ± 0.49
5	13 Sep 91	0.023± 0.048	0.30 ± 0.14	1.40 ± 1.30	1.90 ± 1.95
5	20 Dec 91	0.05 ± 0.06	1.20 ± 0.20	0.40 ± 0.90	0.10 ± 0.90
5	04 Mar 92	0.13 ± 0.07	0.23 ± 0.15	-0.20 ± 1.40	-0.70 ± 1.40
5	04 Jun 92	0.12 ± 0.11	**5.20** ± 0.50	-0.30 ± 3.20	**3.30** ± 2.90
7	19 Sep 90	0.015± 0.022	0.54 ± 0.085		0.60 ± 0.90
7	07 May 91	0.021± 0.027	2.70 ± 0.15	-0.10 ± 1.00	-0.60 ± 0.90
7	13 Sep 91	0.14 ± 0.10	0.21 ± 0.22	-0.30 ± 1.75	-3.00 ± 5.00
7	20 Dec 91	0.015± 0.043	1.10 ± 0.20	0.50 ± 0.50	-0.10 ± 0.60
7	17 Mar 92	0.08 ± 0.05	0.57 ± 0.18	**1.70** ± 1.10	0.50 ± 1.40
12	20 Sep 90	0.057± 0.034	0.51 ± 0.09		-0.30 ± 1.90
12	07 Feb 91	0.28 ± 0.12	0.64 ± 0.215		1.10 ± 0.20
12	04 Mar 91	0.046± 0.043	0.10 ± 0.12	0.40 ± 1.20	-0.40 ± 1.10
12	07 May 91	0.24 ± 0.06	0.48 ± 0.09		
12	13 Sep 91	0.09 ± 0.06	0.13 ± 0.125	**3.00** ± 0.75	-0.40 ± 2.10
12	20 Dec 92	0.056± 0.033	0.22 ± 0.07	-0.40 ± 1.00	-0.10 ± 0.80
13	25 Jan 90	0.32 ± 0.145	3.70 ± 0.40		
13	12 Feb 90	0.17 ± 0.11	3.40 ± 0.35		
13	20 Sep 90	0.70 ± 0.60	**9.30** ± 1.75		-2.30 ± 3.45
13	20 Dec 91	0.004± 0.029	2.40 ± 0.20	1.40 ± 0.50	**3.60** ± 0.63
13	04 Mar 92	0.19 ± 0.10	2.00 ± 0.30	-3.90 ±3.60	1.10 ± 0.81
17	07 May 91	0.053± 0.042	0.70 ± 0.10	1.10 ± 0.90	0.20 ± 0.95
17	13 Sep 91	0.06 ± 0.075	0.33 ± 0.205	**1.50** ± 1.60	-1.60 ± 2.20
17	20 Dec 91	-0.024± 0.005	0.41 ± 0.12	-0.30 ± 0.70	0.20 ± 0.50
17	04 Mar 92	0.065± 0.034	0.68 ± 0.10	-0.20 ± 0.60	0.30 ± 0.44
17	04 Jun 92	-0.005± 0.026	0.80 ± 0.14	1.40 ± 1.10	0.30 ± 1.10
19	25 Jul 90	0.34 ± 0.15	**60.00** ± 1.50		
19	20 Sep 90	0.72 ± 0.47	**50.00** ± 3.00		1.40 ± 1.75
19	07 Dec 90	0.09 ± 0.06	**85.00** ± 1.00		
19	22 Feb 91	0.07 ± 0.075	**44.00** ± 1.00		
19	22 Feb 91	-0.06 ± 0.01	**32.00** ± 1.00		
19	07 May 91	0.18 ± 0.075	**65.00** ± 1.00	0.20 ± 0.60	-0.10 ± 0.50
19	20 Dec 91	0.081± 0.042	**29.00** ± 0.50	-0.30 ± 1.00	1.20 ± 0.62
19	04 Mar 92	0.03 ± 0.029	**73.00** ± 1.00	0.80 ± 0.80	0.60 ± 0.70
24	07 Feb 91	-0.08 ± 0.105	0.20 ± 0.395		
24	07 May 91	0.06 ± 0.035	0.29 ± 0.09	0.98 ± 0.48	0.50 ± 0.45
24	13 Sep 91	-0.029± 0.043	0.17 ± 0.145	**1.90** ± 1.50	-1.70 ± 2.20
24	20 Dec 91	-0.005± 0.028	0.24 ± 0.10	1.10 ± 0.80	-0.60 ± 0.80
24	04 Mar 92	0.053± 0.032	0.17 ± 0.09	0.70 ± 0.50	0.10 ± 0.60

Table 3 (continued)

Well	Sample date	Gross alpha	Gross beta	^{60}Co	^{137}Cs
27	20 Sep 90	0.073± 0.043	0.69 ± 0.10		2.00 ± 2.95
27	12 Dec 90	0.25 ± 0.135	0.51 ± 0.20		
27	22 Feb 91	0.04 ± 0.07	-0.05 ± 0.155		
27	07 May 91	0.098± 0.038	2.00 ± 0.15	-0.10 ± 1.10	0.10 ± 0.80
27	08 Jun 91	0.016± 0.024	0.25 ± 0.07	1.20 ± 0.60	0.20 ± 0.60
27	13 Sep 91	**2.50** ± 0.90	1.90 ± 1.45	-0.30 ± 2.40	-0.10 ± 2.45
27	20 Dec 91	0.043± 0.03	0.14 ± 0.08	0.70 ± 0.80	-0.90 ± 0.80
27	20 Dec 91	0.041± 0.033	0.11 ± 0.08	1.00 ± 0.70	1.80 ± 0.70
27	17 Mar 92	0.084± 0.05	0.38 ± 0.12	0.30 ± 0.70	-0.20 ± 0.70
27	31 Aug 92	0.067± 0.034	2.10 ± 0.20	-0.70 ± 1.60	-0.20 ± 1.30
29	07 May 91	0.036± 0.033	4.10 ± 0.40		
29	08 Jun 92	0.14 ± 0.09	1.70 ± 0.25	**3.00** ± 1.70	0.80 ± 1.50
31	07 May 91	0.033± 0.057	0.44 ± 0.08	-0.60 ± 1.20	-0.10 ± 0.90
31	13 Sep 91	**1.80** ± 0.75	2.80 ± 3.10	**3.60** ± 0.75	0.20 ± 2.10
31	20 Dec 91	0.033± 0.024	0.29 ± 0.08	0.30 ± 0.80	0.50 ± 0.45
31	17 Mar 92	0.09 ± 0.06	0.29 ± 0.11	0.60 ± 0.60	1.30 ± 0.50
31	08 Jun 92	0.016± 0.023	0.28 ± 0.07	-0.10 ± 0.80	-0.30 ± 0.70
31	23 Sep 92	0.08 ± 0.037	0.24 ± 0.08	-0.01 ± 0.08	0.18 ± 0.05
32	20 Sep 90	-0.33 ± 0.065	0.80 ± 0.85		-0.40 ± 2.85
32	12 Dec 90	-0.73 ± 0.33	1.90 ± 0.20	-0.20 ± 2.05	0.70 ± 1.40
32	07 Feb 91	-0.05 ± 0.01	0.55 ± 0.205		
32	07 May 91			-0.10 ± 0.70	0.50 ± 0.60
32	13 Sep 91	0.016± 0.049	0.60 ± 0.165	**1.60** ± 1.45	0.40 ± 1.70
32	20 Dec 91	0.003± 0.018	0.80 ± 0.11	1.20 ± 0.60	0.00 ± 0.45
32	17 Mar 92	0.056± 0.029	0.24 ± 0.07	0.10 ± 0.90	0.49 ± 0.94
32	08 Jun 92	0.081± 0.037	0.51 ± 0.09	**1.60** ± 0.40	1.08 ± 0.28
33	20 Dec 91	0.13 ± 0.07	0.62 ± 0.15	**2.50** ± 0.90	2.20 ± 0.80
35	20 Sep 90	0.49 ± 0.41	2.20 ± 0.95		0.20 ± 1.30
35	12 Dec 90	0.10 ± 0.08	0.80 ± 0.15		
35	07 May 91	**1.50** ± 0.45	1.60 ± 0.70		
35	13 Sep 91	0.14 ± 0.07	0.68 ± 0.155	**3.90** ± 0.75	0.60 ± 2.10
35	20 Dec 91	-0.033± 0.006	1.90 ± 0.20	-0.70 ± 1.00	0.14 ± 0.76
35	17 Mar 92	-0.008± 0.016	0.29 ± 0.08	**1.60** ± 1.00	1.00 ± 1.20
35	08 Jun 92	0.035± 0.025	0.37 ± 0.08	0.40 ± 0.60	-0.04 ± 0.45
35	23 Sep 92	0.036± 0.03	0.64 ± 0.09	0.17 ± 0.10	0.31 ± 0.10
36	20 Sep 90	**1.40** ± 0.65	-0.20 ± 1.00		**2.40** ± 2.95
36	07 Feb 91	0.00 ± 0.10	0.67 ± 0.475		0.30 ± 0.40
36	07 May 91	0.03 ± 0.03	0.31 ± 0.085	-0.70 ± 1.80	-0.50 ± 1.55
36	13 Sep 91	0.10 ± 0.06	0.25 ± 0.14	0.30 ± 1.35	-0.40 ± 1.40
36	20 Dec 91	-0.005± 0.018	0.33 ± 0.08	1.50 ± 0.40	0.30 ± 0.57
36	17 Mar 92	0.00 ± 0.023	0.32 ± 0.09	**2.40** ± 0.90	-1.00 ± 1.60
36	08 Jun 92	0.48 ± 0.08	0.56 ± 0.08	1.40 ± 0.60	0.13 ± 0.44
36	23 Sep 92	0.026± 0.029	0.46 ± 0.09	-0.01 ± 0.10	0.06 ± 0.08

Table 3 (continued)

Well	Sample date	Gross alpha	Gross beta	^{60}Co	^{137}Cs
40	03 Aug 90	-0.01 ± 0.055	0.63 ± 0.24		
40	12 Dec 90	0.01 ± 0.03	0.28 ± 0.105		
40	07 Feb 91	-0.10 ± 0.095	0.24 ± 0.35		
40	07 May 91	0.12 ± 0.045	0.27 ± 0.075	0.23 ± 0.37	0.15 ± 0.42
40	16 Sep 91	0.11 ± 0.065	-0.08 ± 0.135	1.20 ± 0.40	1.20 ± 0.70
40	30 Dec 91	0.011± 0.031	0.48 ± 0.09	0.70 ± 0.70	0.10 ± 0.60
40	17 Mar 92	0.03 ± 0.027	0.13 ± 0.07	-0.10 ± 1.10	0.80 ± 0.70
40	12 Jun 92	0.038± 0.044	**38.00** ± 1.00	0.70 ± 0.60	-0.20 ± 0.90
40	02 Sep 92	-0.016± 0.021	0.42 ± 0.10	-0.90 ± 1.60	-0.70 ± 1.30
44	07 Feb 91	0.17 ± 0.165	0.14 ± 0.315		
44	07 May 91	0.054± 0.032	0.31 ± 0.075	0.50 ± 1.60	0.30 ± 1.20
44	16 Sep 91	0.12 ± 0.10	1.30 ± 0.25	0.90 ± 1.50	-0.50 ± 1.30
44	30 Dec 91	0.039± 0.029	0.46 ± 0.09	0.30 ± 0.80	0.50 ± 0.70
44	17 Mar 92	0.059± 0.035	0.43 ± 0.11	0.60 ± 0.90	0.02 ± 0.63
44	12 Jun 92	0.11 ± 0.05	1.40 ± 0.10	**1.60** ± 0.70	0.60 ± 0.90
44	02 Sep 92	-0.026± 0.005	0.40 ± 0.10	0.15 ± 0.27	0.16 ± 0.25
45	07 Feb 91	-0.02 ± 0.055	2.50 ± 0.30		**2.50** ± 0.55
45	17 Mar 92	0.34 ± 0.13	4.00 ± 0.30	-1.40 ± 1.90	1.70 ± 1.20
45	02 Sep 92	0.29 ± 0.19	2.00 ± 0.45	1.10 ± 2.70	-0.20 ± 2.70
AUG 48	12 Dec 90	0.06 ± 0.05	0.17 ± 0.09		
AUG 48	14 May 91	0.08 ± 0.037	**24.00** ± 0.50	0.40 ± 1.10	**29.00** ± 1.50
AUG 48	18 Sep 91	0.42 ± 0.155	2.10 ± 0.30	1.40 ± 0.65	2.00 ± 0.85
AUG 48	30 Dec 91	-0.013± 0.02	1.40 ± 0.10	0.30 ± 1.00	**3.20** ± 0.51
AUG 48	30 Dec 91	0.014± 0.028	0.65 ± 0.11	-0.90 ± 0.90	1.30 ± 0.50
AUG 48	24 Mar 92	0.02 ± 0.026	0.22 ± 0.07	0.10 ± 1.30	0.70 ± 0.71
AUG 48	24 Mar 92	0.032± 0.028	0.13 ± 0.07	0.70 ± 0.50	1.80 ± 0.24
AUG 48	12 Jun 92	0.10 ± 0.06	0.58 ± 0.13	-0.10 ± 0.60	2.17 ± 0.40
AUG 50	14 May 91	0.033± 0.031	0.31 ± 0.09		
AUG 50	18 Sep 91	0.36 ± 0.15	1.10 ± 0.25	**2.00** ± 0.75	1.20 ± 1.30
AUG 50	30 Dec 91	0.064± 0.038	0.27 ± 0.08	-0.80 ± 1.00	0.30 ± 1.00
AUG 50	24 Mar 92	0.016± 0.023	0.07 ± 0.06	-0.70 ± 1.30	-0.10 ± 0.98
AUG 50	12 Jun 92	0.017± 0.025	-0.07 ± 0.07	0.10 ± 0.70	-0.50 ± 0.60
AUG 51	22 Feb 91	0.00 ± 0.055	2.60 ± 0.30		
AUG 51	14 May 91	0.00 ± 0.025	0.31 ± 0.125	0.60 ± 0.60	0.52 ± 0.44
AUG 51	30 Dec 91	0.014± 0.041	0.20 ± 0.15	**1.70** ± 1.30	-0.50 ± 1.40
AUG 559	22 Feb 91	-0.06 ± 0.01	0.07 ± 0.155		
AUG 559	14 May 91	0.037± 0.038	0.27 ± 0.105	1.40 ± 0.35	0.98 ± 0.41
AUG 559	18 Sep 91	0.14 ± 0.105	0.55 ± 0.22	**3.30** ± 1.70	-0.10 ± 1.60
AUG 559	24 Mar 92	0.055± 0.033	0.18 ± 0.08	0.90 ± 0.50	-0.20 ± 0.70

Table 3 (continued)

Well	Sample date	Gross alpha	Gross beta	^{60}Co	^{137}Cs
C595	12 Dec 90	0.29 ± 0.10	0.80 ± 0.145	0.40 ± 0.70	-0.10 ± 0.65
C595	07 Feb 91	**1.40** ± 0.35	0.47 ± 0.40		
C595	14 May 91	**1.30** ± 0.20	1.80 ± 0.20	0.90 ± 0.80	0.50 ± 0.70
C595	18 Sep 91	0.47 ± 0.195	1.20 ± 0.30	-0.90 ± 3.15	-0.30 ± 2.30
C595	30 Dec 91	0.068± 0.035	0.18 ± 0.08	-0.30 ± 1.00	0.80 ± 0.70
C595	24 Mar 92	0.02 ± 0.026	0.51 ± 0.10	0.90 ± 1.00	0.80 ± 0.61
C595	12 Jun 92	0.069± 0.04	0.48 ± 0.09	-0.80 ± 1.70	0.54 ± 1.00
C595	03 Sep 92	0.04 ± 0.06	0.15 ± 0.15	-0.30 ± 1.50	0.40 ± 1.30
FIS 102	12 Dec 90	0.18 ± 0.07	1.20 ± 0.15	**1.60** ± 0.50	0.30 ± 0.65
FIS 102	07 Feb 91	0.04 ± 0.10	1.60 ± 0.45		
FIS 102	14 May 91	0.036± 0.031	1.10 ± 0.10		
FIS 102	18 Sep 91	0.52 ± 0.17	2.00 ± 0.30	0.80 ± 0.65	-0.10 ± 1.60
FIS 102	30 Dec 91	-0.018± 0.014	0.52 ± 0.09	0.10 ± 0.60	0.20 ± 0.48
FIS 102	24 Mar 92	-0.015± 0.012	0.20 ± 0.07	0.80 ± 0.90	-1.60 ± 1.50
FIS 102	12 Jun 92	0.003± 0.20	0.34 ± 0.07	1.00 ± 0.60	0.20 ± 0.70
FIS 102	23 Sep 92	0.008± 0.024	0.036± 0.008	0.12 ± 0.08	0.03 ± 0.08
FIS "?"	12 Dec 90	0.09 ± 0.055	0.69 ± 0.145	-0.30 ± 0.65	-0.01 ± 0.49
FIS "?"	07 Feb 91	-0.01 ± 0.065	1.00 ± 0.25		
FIS "?"	14 May 91	0.35 ± 0.09	1.10 ± 0.10		
FIS "?"	18 Sep 91	0.20 ± 0.11	0.90 ± 0.23	**1.60** ± 1.05	0.20 ± 1.20
FIS "?"	30 Dec 91	0.09 ± 0.038	0.15 ± 0.07	0.67 ± 0.47	0.74 ± 0.43
FIS "?"	24 Mar 92	0.00 ± 0.021	0.13 ± 0.07	-1.10 ± 1.70	0.40 ± 0.78
FIS "?"	12 Jun 92	0.028± 0.026	0.16 ± 0.07	1.00 ± 1.10	0.24 ± 0.78
FIS "?"	03 Sep 92	0.22 ± 0.09	0.57 ± 0.19	0.20 ± 0.09	0.13 ± 0.07

[a] All values are in Bq/L (mean ± 1 SE). Boldface indicates value exceeds action level.

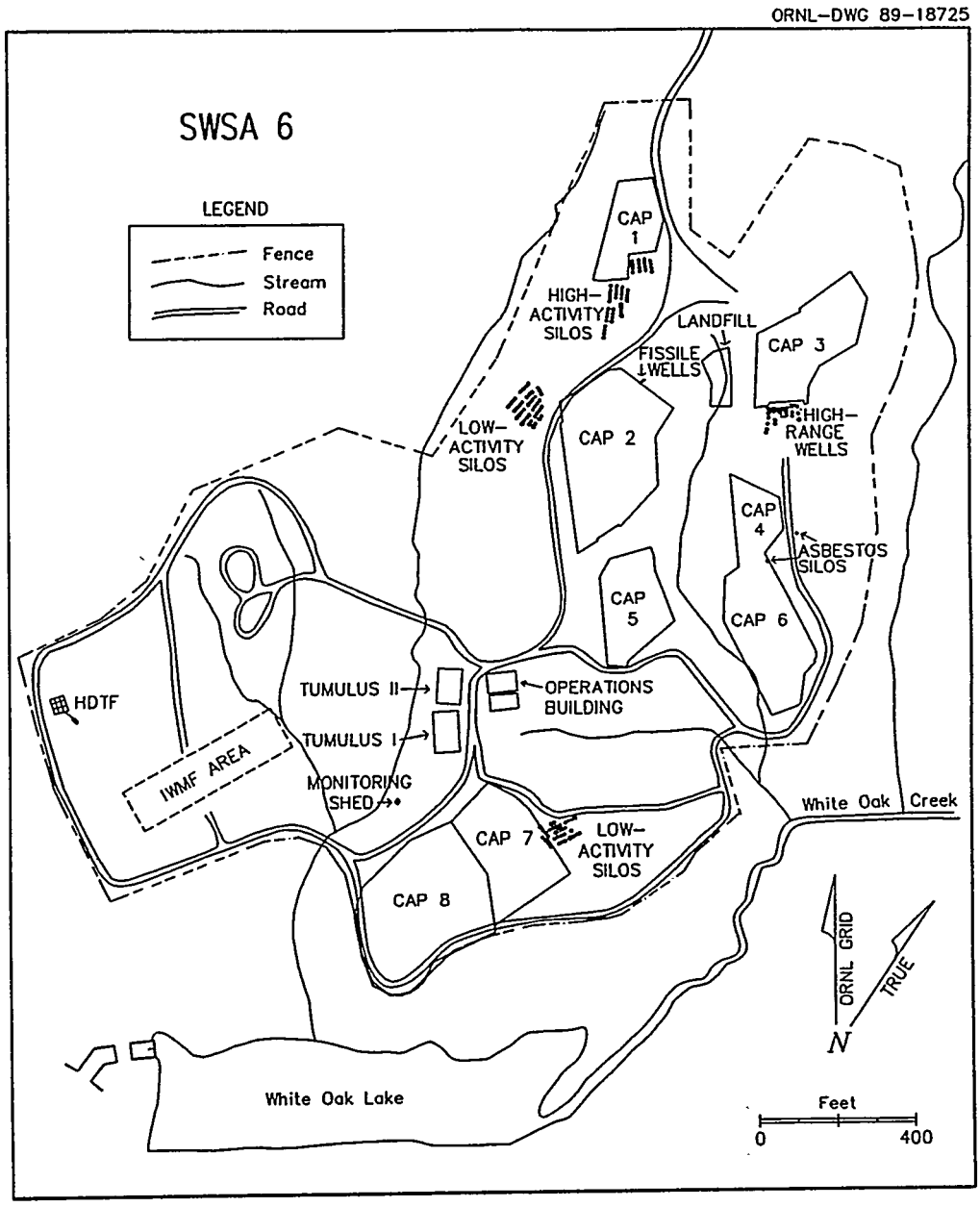


Figure 1. Solid Waste Storage Area 6 showing tumulus pads, interim waste management facility, silos, high-range wells, fissile wells, temporary plastic caps, drainage streams, and White Oak Lake.

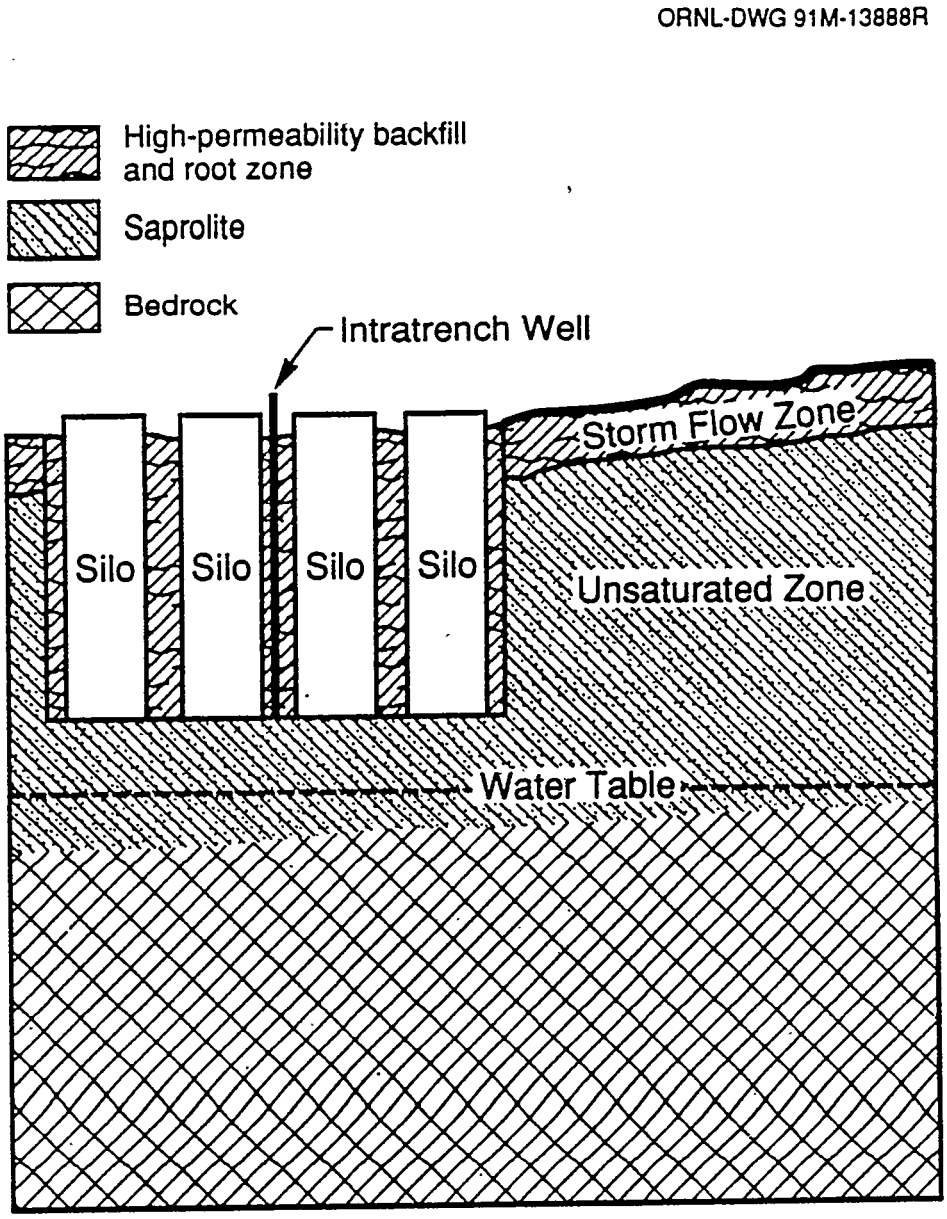


Figure 2. Cross-section drawing of a typical low-level radioactive waste silo trench.

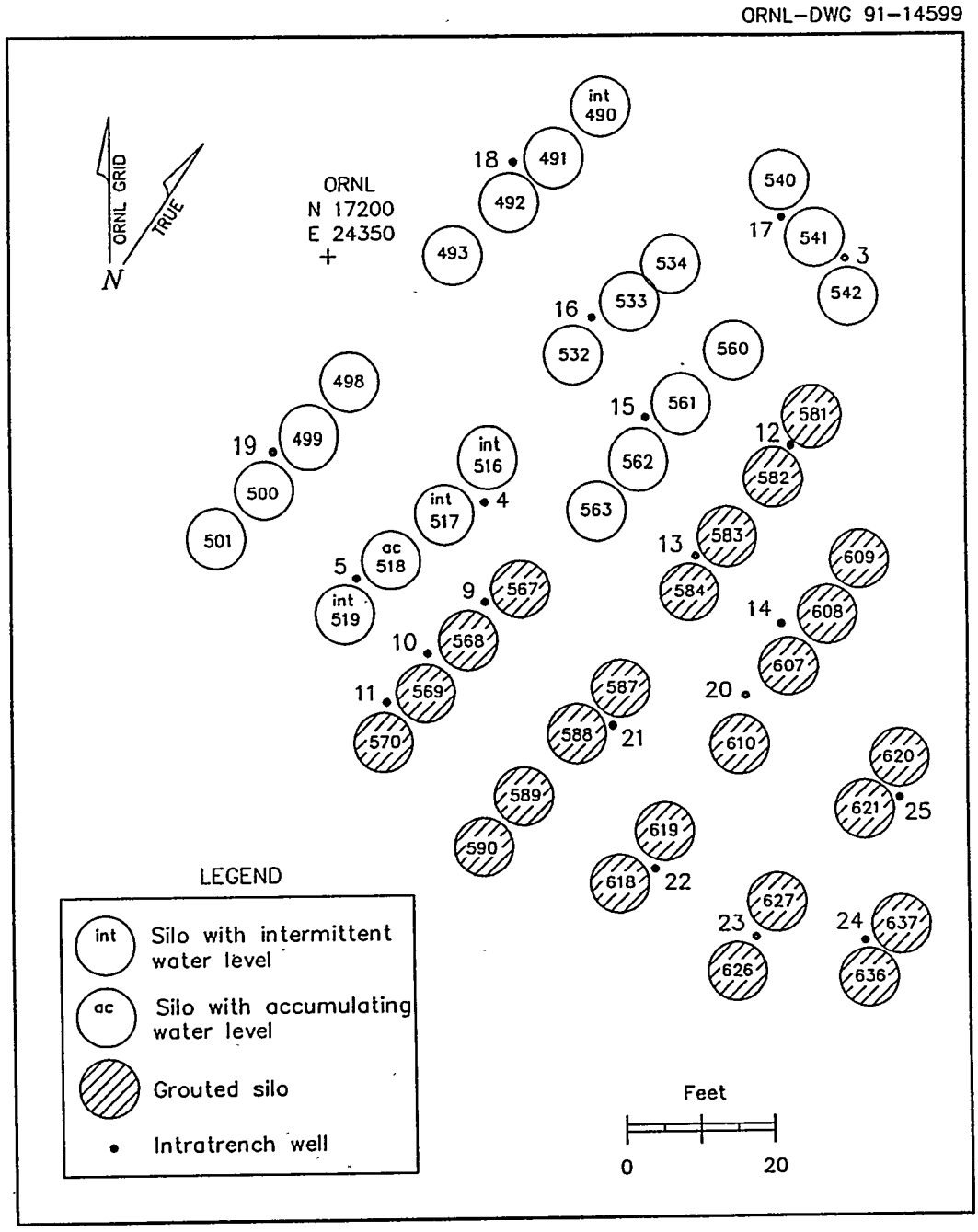


Figure 3. Silos and intratrench wells in low-activity silo area north.

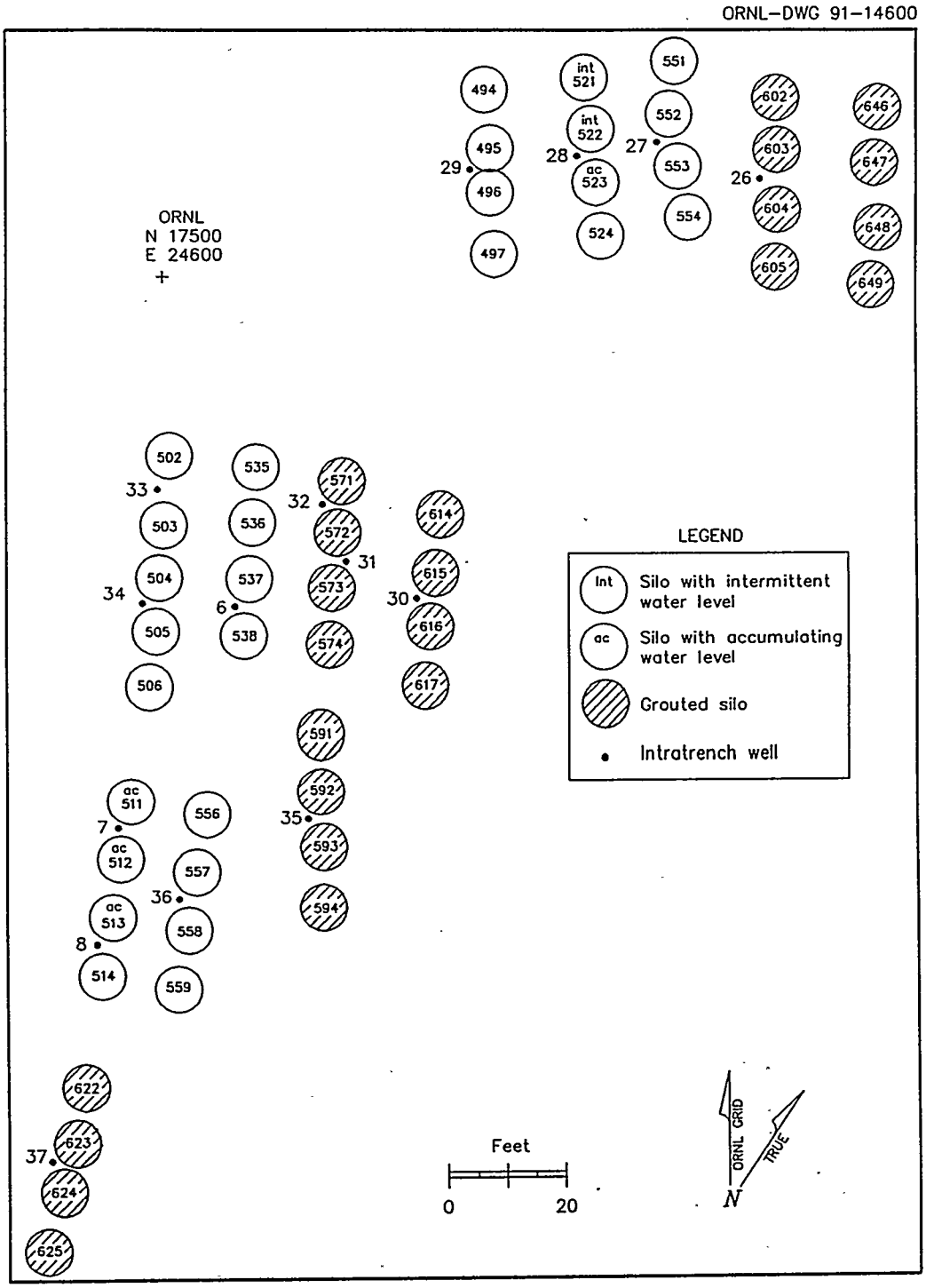


Figure 4. Silos and intratrench wells in high-activity silo area.

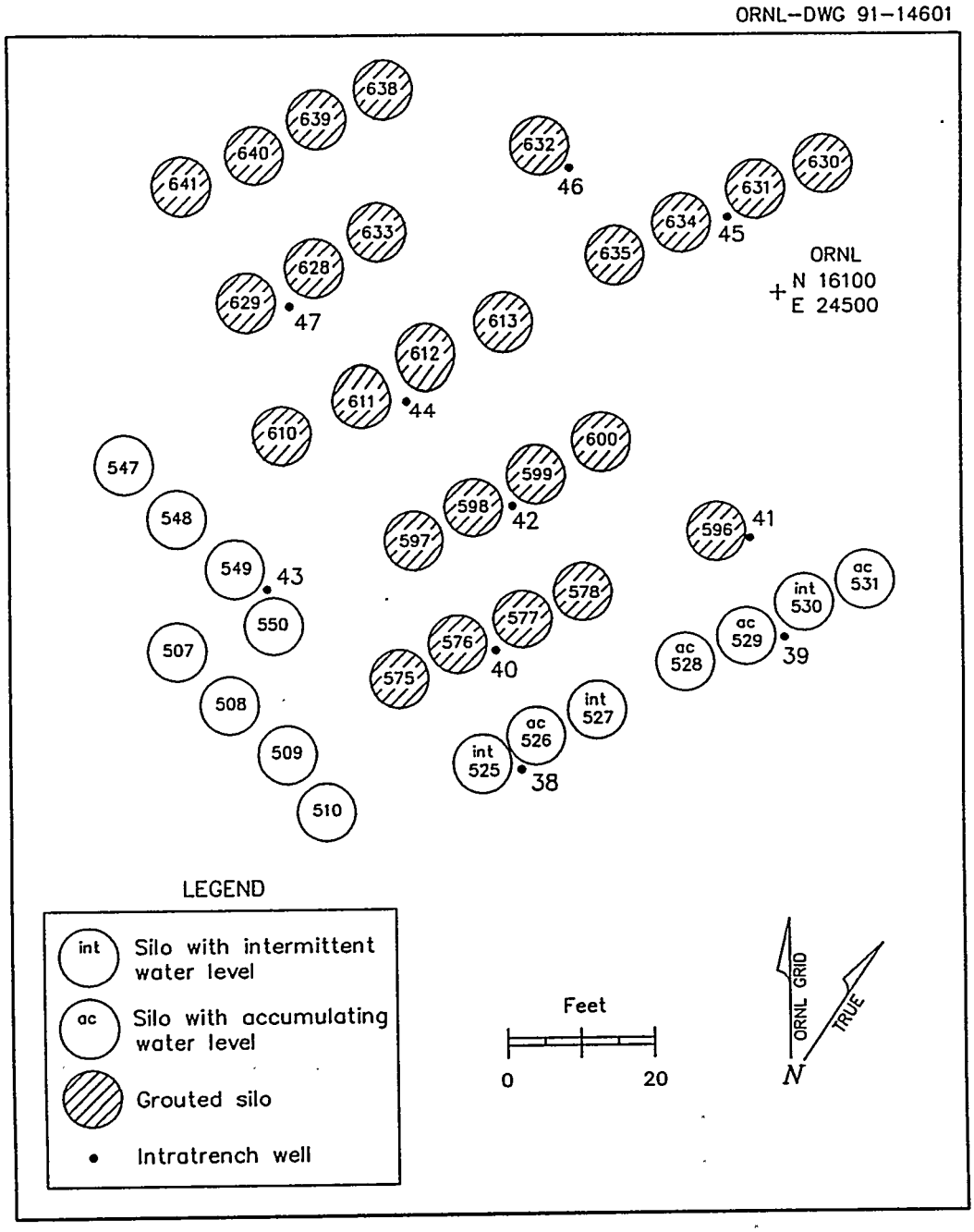


Figure 5. Silos and intratrench wells.

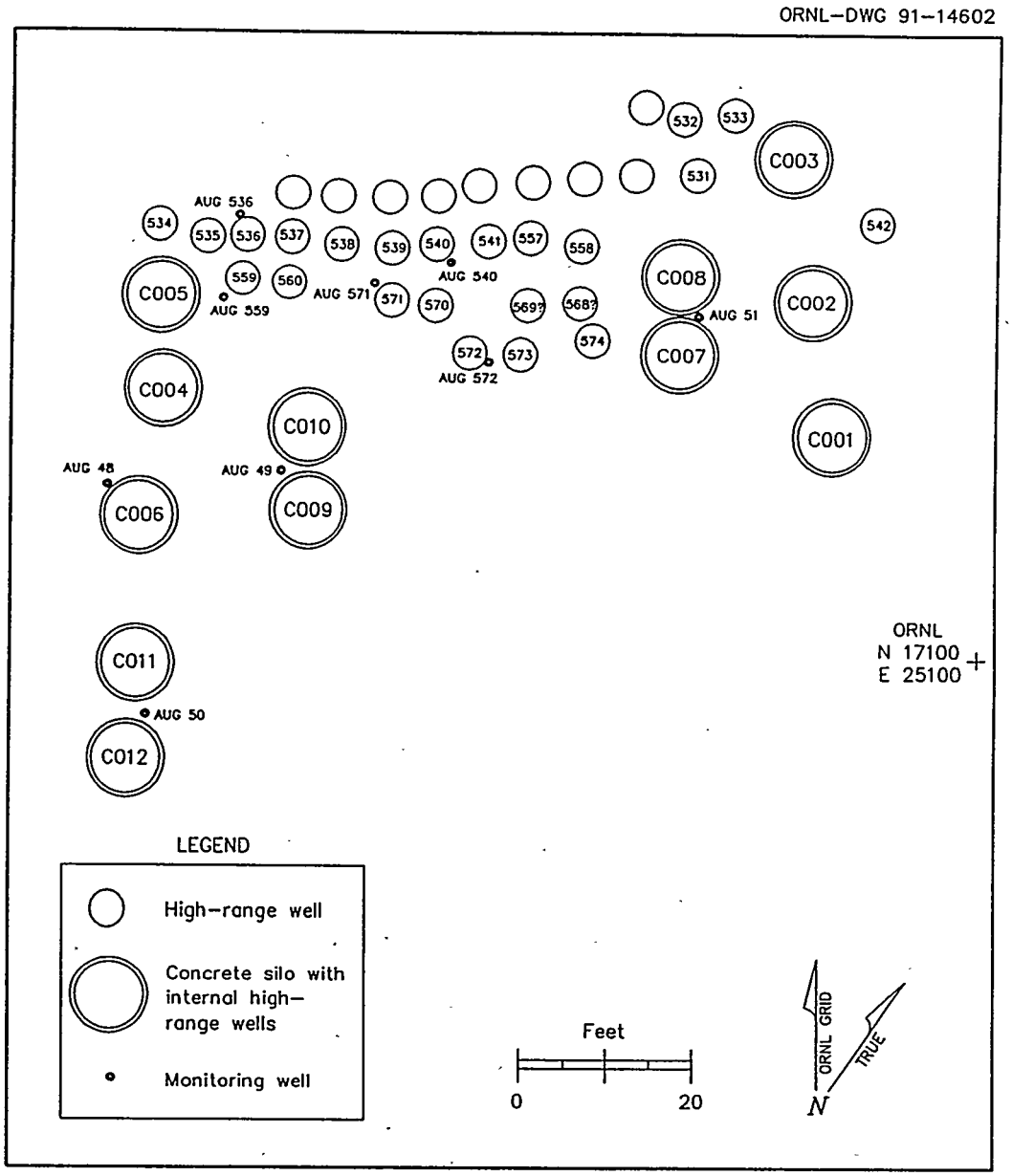


Figure 6. Backfill monitoring wells around high-range wells.

REFERENCES

Ashwood, J. S., and T. L. Ashwood, 1991, *Active Sites Environmental Monitoring Program: Action Levels*, ORNL/M-1569, Oak Ridge National Laboratory, 1991.

Ashwood, T. L., and B. P. Spalding, 1991, *SWSA 6 Interim Corrective Measures Environmental Monitoring: FY 1990 Results*, ORNL/ER-36, Oak Ridge National Laboratory, 1991.

Ashwood, T. L., D. S. Wickliff, and C. M. Morrissey, 1990, *Active Sites Environmental Monitoring Program: Program Plan*, ORNL/M-1197, Oak Ridge National Laboratory, 1990.

Ashwood, T. L., D. S. Wickliff, and C. M. Morrissey, 1991, *Active Sites Environmental Monitoring Program: Mid-FY 1991 Report*, ORNL/M-1442, Oak Ridge National Laboratory, 1991.

Ashwood, T. L., D. S. Hicks, and C. M. Morrissey, 1992a, *Active Sites Environmental Monitoring Program: Program Plan*, Rev. 1, ORNL/M-1793, Oak Ridge National Laboratory, 1992.

Ashwood, T. L., D. S. Wickliff, and C. M. Morrissey, 1992b, *Active Sites Environmental Monitoring Program: FY 1991 Report*, ORNL/M-1792, Oak Ridge National Laboratory, 1992.

Boegly, W. J. Jr, 1984, *Site Characterization Data for Solid Waste Storage Area 6*, ORNL/TM-9442, Oak Ridge National Laboratory, 1984.

Davis, E. C., C. W. Francis, and R. J. Luxmoore, 1989, *An Evaluation of Water Leakage Into Concrete Low-level Radioactive Waste Disposal Silos at ORNL's Solid Waste Storage Area Six*, ORNL/TM-11164, Oak Ridge National Laboratory, 1989.

Moore, G. K, 1988, *Concepts of Groundwater Occurrence and Flow Near Oak Ridge National Laboratory, Tennessee*, ORNL/TM-10969, Oak Ridge National Laboratory, 1988.

Moore, G. K. 1989, *Groundwater Parameters and Flow Systems Near Oak Ridge National Laboratory*, ORNL/TM-11368, Oak Ridge National Laboratory, 1989.

Solomon, D. K., R. C. Haese, T. V. Dinsmore, and A. D. Kelmers, 1988, *Sampling and Analysis of SWSA 6 Trench Leachates and Groundwaters*, ORNL/TM-10813, Oak Ridge National Laboratory, 1988.

Environmental Monitoring of the Tumulus Low-Level Waste Disposal Facilities at Oak Ridge National Laboratory[a]

C. M. Morrissey
T. L. Ashwood
Oak Ridge National Laboratory
Environmental Sciences Division
P.O. Box 2008
Oak Ridge, TN 37831-6035

INTRODUCTION

The tumulus facilities at Oak Ridge National Laboratory (ORNL) were constructed beginning in 1987 for abovegrade disposal of low-level radioactive waste. The facilities consist of Tumulus I, Tumulus II, and the Interim Waste Management Facility (IWMF). They are designed to meet performance criteria that require no release of radioactive contaminants to the environment for one hundred years.

The environmental monitoring program for the tumulus facilities is a part of the Active Sites Environmental Monitoring Program (ASEMP), which was established by the Solid Waste Operations Group and the Environmental Sciences Division at ORNL in 1989 (Ashwood et al. 1990, 1992). The purpose of the program is to monitor active LLW disposal areas according to DOE Order 5820.2A (DOE 1988). This order requires that an environmental monitoring program be established to provide early detection of contaminant release. Also, the program seeks to provide data for performance assessment of the tumulus facilities and for future environmental assessments.

This paper describes the tumulus facilities, the environmental monitoring program, and what we have learned from the program over approximately three years of operation. Our data suggest that the tumulus facilities are an effective means of disposal of low-level radioactive waste. However, problems with high pH and the leaching of ^{40}K, and potentially other elements from the concrete disposal pads and vaults, need to be addressed with regard to the long-term performance of the facilities.

FACILITIES DESIGN

The tumulus disposal facilities occupy several acres in the southwestern portion of Solid Waste Storage Area (SWSA) 6 (Figure 1). Many other waste disposal units exist in SWSA 6. These units include trenches, high- and low-activity silos, auger holes, asbestos silos, and fissile wells. SWSA 6 has been an active waste burial ground since 1973 and is slated for closure. The IWMF occupies the last relatively flat area in SWSA 6 that has not been used for waste disposal.

The containment structures for all three tumulus facilities are basically of the same design. Solid, dry, Class II (i.e., surface dose rate < 200 mrem/hr) radioactive waste is placed within steel boxes. The waste-containing steel boxes are then filled with grout, sealed, and placed inside concrete vaults that serve as the primary containment structures. The concrete disposal vault dimensions are typically 2.4 meters long, 1.7 meters wide, and 1.5 meters high. Each weighs 8.5 tons empty and approximately 13 tons when filled with grouted waste. The annular space between the steel box and the concrete vault is also grouted and a concrete lid is fastened to the vault. Sealed vaults are stacked on high-strength (6000 psi) concrete pads and are

a. The submitted manuscript has been authored by a contractor of the U.S. Government under contract No. DE-AC05-84OR21400. Accordingly, the U.S. Government retains a nonexclusive, royalty-free license to publish or reproduce the published form of this contribution, or allow others to do so, for U.S. Government purposes.

exposed to the weather during loading operations. The pads are designed to collect stormwater and route it to a monitoring facility.

Tumulus I and II are single concrete pads that are each fully loaded with approximately 200 waste-containing vaults stacked two high. Both are covered with temporary tent-like structures that prevent rainfall from contacting the waste vaults. They will be covered with an engineered clay cap during closure operations at SWSA 6.

The IWMF is actively being used for waste disposal. Two pads have been constructed; one of the two pads is being loaded with waste-containing vaults. There will eventually be at least six IWMF disposal pads.

Tumulus I. The Tumulus I pad is a high-strength concrete pad 32.0 meters by 19.8 meters with a 15 cm curb on all four sides. The pad serves as secondary containment for any leachate generated from the waste-containing vaults. The pad is sloped 1% to the west to a runoff collection system that routes pad runoff to a monitoring shed. The pad is underlain by a sand and gravel underpad system (Figure 2) designed as tertiary containment for any leachate from the vaults that might infiltrate through the pad. The underpad is designed to be hydrologically isolated from the surrounding environment by a 30 mil PVC liner. A separate drainage line is provided for water that collects below the underpad in the gravel construction base. Loading of waste onto Tumulus I began in mid-1987, was suspended until early 1988 due to a labor strike, and was completed in mid-1990.

Tumulus II. The Tumulus II pad measures 27.4 meters by 18.3 meters, is constructed of high-strength concrete, and is surrounded on three sides by a 30.5 cm high curb. The north end of the pad does not have a curb in order to facilitate loading. The pad is sloped at 1% to the south, where stormwater drains into two 10.2 cm PVC drain lines that route pad water to the monitoring shed. The sand and gravel underpad (Figure 3) is not hydrologically isolated and is designed to lower groundwater levels to below the base of the pad to ensure waste isolation from the groundwater. The underpad is sloped 1.73% to the west where drainage is collected and routed to the monitoring shed. The underpad system is also designed to collect potential leachate seepage through fissures in the concrete and may also collect groundwater, perched water, or direct infiltration. Loading of waste-containing vaults onto the Tumulus II pad began in October of 1990 and was completed in mid-1991.

Interim Waste Management Facility (IWMF). Each IWMF disposal pad is the same size as the Tumulus II pad and is designed to hold 300 waste disposal vaults. Each pad has a one foot wide by one foot high curb located along its perimeter except at the end opposite the surface drain where access is allowed for the loading crane. At least six pads will eventually be constructed. Once a pad is fully loaded, a temporary, low-permeability, plastic membrane cover will be placed over it. When all pads are loaded, the final engineered cover will be installed.

Surface drains are located on each pad to collect stormwater that falls upon disposal vaults during the loading period. When a pad is fully loaded, the same drain lines will be used to collect water that infiltrates through the temporary cover. The drain lines from the active pad (i.e., the pad that is not fully loaded) are termed "stormwater" lines and are routed to a stormwater sump in the monitoring area. The drain lines from each fully loaded pad are called "infiltration" water lines and are tied together and routed to an infiltration sump also in the monitoring area. The piping from both of these drainage systems is located inside a drainage gallery to allow easy inspection. Each empty pad is provided with a bypass drain that routes water to a small creek east of the facility.

The underpad drainage system is similar to that at Tumulus II. A gravel bed under each pad is sloped to a porous collection pipe that drains to an underpad sump in the monitoring area. Very little water is expected to accumulate in the underpad system due to an upgradient French drain located under the entire length of the drainage gallery. This french drain system is designed to collect and drain near-surface water upslope of the facility as well as any upwelling groundwater. It discharges through a sampling vault to the east of the IWMF.

MONITORING PROGRAM

Sections 3.b and 3.k of DOE Order 5820.2A (DOE 1988) provide the following guidelines for environmental monitoring of LLW facilities:

- "The environmental monitoring program shall be designed to measure operational effluent releases, migration of radionuclides, disposal unit subsidence, and changes in disposal facility and disposal site parameters which may affect long-term site performance." (Sect. 3.k.2)

- "Based on the characteristics of the facility being monitored, the environmental monitoring program may include, but not necessarily be limited to, monitoring surface soil, air, surface water, and subsurface soil and water both in the saturated and unsaturated zones." (Sect. 3.k.3)

- "The environmental monitoring program shall be capable of detecting changing trends in performance sufficiently in advance to allow application of any necessary corrective action prior to exceeding performance objectives." (Sect. 3.k.4)

- "Where practical, monitoring measurements to evaluate actual and prospective performance should be made at locations as required, within and outside each facility and disposal site. Monitoring should be used to validate or modify the models used in performance assessments." (Sect. 3.b.3)

To meet the guidelines of 5820.2A, monitoring activities at the tumulus facilities include the following.

- Sampling and analysis of water from the waste disposal pads is conducted after every significant rainfall. Disposal pads that are actively being loaded with waste are exposed to the weather until they are completely full. Therefore, precipitation (>125 cm/year; pH ≤5) contacts the vaults containing waste. Pad water is routinely monitored for pH, specific conductance, gross alpha activity, gross beta activity, gamma emitting radionuclides, tritium activity, and total organic carbon.

- Water from the underpad drains is sampled at least quarterly. More frequent sampling is initiated if data from the pad water indicate problems. Analyses are performed for the same parameters as for the pad water with the exception of total organic carbon.

- Surface soils around the pads are sampled and analyzed for gross alpha, beta, and gamma activity. The purpose is to monitor any operational releases during loading activities as well as to provide data on a possible source of contamination that could migrate onto the surface of the pads.

- Groundwater is monitored by a series of shallow monitoring wells that encircle the tumulus pads. Water levels in these wells were continuously measured electronically over a three-year period to observe the groundwater response to storm events. The wells are sampled quarterly and analyzed for field parameters (pH, temperature, *etc.*), gross alpha, beta, and gamma activity, and tritium. Selected wells are sampled annually for volatile and semivolatile organics, total organic carbon, metals, and anions. Groundwater upgradient of the IWMF area is diverted around the facility by a French drain with an outlet that provides for periodic grab sampling. Groundwater downgradient of the IWMF is presently monitored by wells that were installed as part of the RCRA directed groundwater monitoring program.

- Meteorological parameters in the tumulus area were measured for several years. Parameters measured included rainfall, wind speed and direction, solar irradiance, relative humidity, and air temperature. Only rainfall is currently being measured. The other instrumentation is being recalibrated, and meteorological measurements will be resumed soon.

- Pad subsidence has been monitored by the ORNL Engineering Division through periodic surveys of the pad elevations.

MONITORING FACILITIES

Tumulus I and II. Pad water and underpad drainage from both Tumulus I and Tumulus II flow to a flume and sump area in a monitoring shed about 45 meters southwest of the pads and then discharge to a small creek that drains the western portion of SWSA 6 (Figure 4). Surface drainage from the two pads can be controlled independently by a series of valves. Underpad drainage flows to separate sumps in the monitoring shed. The construction base drain from Tumulus I discharges toward the creek west of the pads.

The monitoring shed contains a one-inch Parshall flume through which pad surface drainage flows (Figure 5). The stilling well of the flume is equipped with a sonic water level indicator that sends a signal to a flow totalizer to measure flow rate and total flow. The flow totalizer in turn signals a sampling device to collect a one-liter sample upstream of the flume for every 1000 liters of flow from the surface of the pad. An online pH meter was also installed in the flume area for a few months. Both the flow rate through the flume and the pH data were recorded electronically and downloaded to a computer for permanent storage. Flow from the underpad drain sumps can be sampled and pumped to the downstream side of the flume for discharge.

Interim Waste Management Facility. Drainage to the three sumps (stormwater, infiltration water, and underpad water) can be controlled independently and allowed to flow through the monitoring flume. The flume is equipped with electronic equipment for flow totalization and automatic sampling. Unfortunately, since the flume was designed for the 100 year, 24-hour storm, it is probably too large to measure the normal flows expected from the pads. Therefore, a pressure transducer has been installed in the active pad sump to trigger the sampler based on depth of water in the sump. Probes for online pH measurement have been installed in the active pad sump and at the effluent discharge point. Also, for pH control, a CO_2 bubbling system activated by water level and pH has been installed in the active pad sump. Flow from the underpad drains is expected to be minimal due to the influence of the French drain.

Groundwater Monitoring Wells. Eleven monitoring wells that were installed to RCRA standards (except that the casing material is PVC instead of stainless steel) surround the Tumulus I and II pads (Figure 4). Each well was drilled to auger refusal (approximately 9 meters) and is cased with 7.6-centimeter PVC pipe with slotted screens of either 1.5 or 3.0 meters depending upon well depth. The intent is to intercept as much of the shallow groundwater in the area as practicable. Dedicated bladder-type sampling pumps are installed in each well.

Several years of water level measurements were obtained from all eleven tumulus wells and an additional well in the area that is not part of the ASEMP. A pressure transducer was installed in each well and the data was recorded at 15-minute intervals. This provided information about the short-term response of groundwater to storm events as well as long-term water level trends. Groundwater levels are currently monitored by periodic manual measurements.

RESULTS

Action levels for pad and underpad water and groundwater of 1 Bq/L gross alpha activity, 5 Bq/L gross beta activity, 2.5 Bq/L ^{137}Cs activity, and 1.5 Bq/L ^{60}Co activity have been established as a basis for flagging possible radioactive contamination in tumulus samples. These action levels are based on a statistical analysis of background data for water in the area (Ashwood and Ashwood 1991). Analytical data from tumulus facility effluents are interpreted with regard to these action levels. Any effluent sample that meets or exceeds an action level is reported to the facility operators.

Several effluent release points from the tumulus facilities are regulated by a National Pollutant Discharge Elimination System (NPDES) permit. One of the discharge limits established in the NPDES permit is a pH of 9.0. The pad surface water from all three tumulus facilities has exceeded this pH limit (Figures 6-8). This high pH probably results from the post-curing leaching of lime from the concrete. In response to the high pH, the surface drain lines on Tumulus I and Tumulus II were closed in June of 1991. Water was subsequently sampled directly from the pads and transported to the ORNL Process Waste Treatment Plant (PWTP) for

disposal. When Tumulus II was being prepared for loading in July of 1990, water on Tumulus I was allowed to stand on the pad and was drained and sampled after flow from Tumulus II ceased. Therefore, data for Tumulus I pad water after July 1990 represent water that had a much longer contact time with the concrete pad than did samples before this date. Only one sample of Tumulus I pad water collected after July 1990 had a pH less than 9.0. Tumulus II pad water pH values have been more variable than those for pad I. About half the pad II samples were above pH 9.0 after the drain lines were closed. Six of the 37 samples from pad II collected before the drain lines were closed reached or exceeded a pH of 9.0. However, instantaneous pH readings made with the pH probe in the effluent flume indicated that the pH of the water running off the pad frequently exceeded 9.0. Since the tent-like covers were placed over Tumulus I and II in January of 1992, no water has accumulated on either pad. The IWMF pad water pH has exceeded 9.0 on three occasions and has been transported to the PWTP since loading operations began.

Concern over the release of high pH water led to investigations into the effects of such release on the biological activity in the creek that receives the tumulus effluent waters. Biological toxicity tests showed that full-strength water from the Tumulus I pad was toxic to *Ceriodaphnia*; however, a 50% dilution was not toxic. Sampling of the benthic invertebrates showed no adverse effects that could be distinguished from other SWSA 6 discharges.

Until early 1990, gross beta activity in Tumulus I pad water only occasionally exceeded the 5 Bq/L action level. When water was allowed an extended contact time with the concrete pad, samples routinely exceeded the action level and on one occasion exceeded 80 Bq/L (Figure 9). This activity is apparently due to ^{40}K that leached from the concrete and was detected in almost all samples that contained elevated gross beta activity (Figure 10). Nine samples collected during the summer of 1990 that exceeded the gross beta activity action level were analyzed for ^{90}Sr. Only one of these samples showed a ^{90}Sr activity statistically greater than zero. This sample had the lowest gross beta activity of those analyzed for strontium, and the reported ^{90}Sr activity was only 0.31 ± 0.13 Bq/L. Since the gross beta and ^{40}K activity varied seasonally, the leaching was apparently affected by temperature. Gross beta activity in Tumulus II pad water gradually rose during the first year of loading with two exceedances of the action level (Figure 11). Thereafter, Tumulus II pad water gross beta activity fluctuated slightly and exceeded the action level on three occasions. The IWMF pad water gross beta activity also appears to be gradually rising with perhaps a seasonal trend (Figure 12). The gross beta activity action level has been exceeded in the IWMF pad water only once.

Gross alpha activity, ^{137}Cs, and ^{60}Co activity have only rarely been detected at or above action levels in tumulus effluents. Most exceedances of an action level for gross alpha activity, ^{137}Cs, and ^{60}Co activity were attributable to analytical or sampling error. In all cases, the subsequent sample was below the action level.

Detection of elevated tritium activity (normal background for rainfall in the area is 75 to 150 Bq/L) in the Tumulus II underpad led to an investigation of tritium contamination on and under the pads. Elevated tritium levels were detected in Tumulus II pad water (Figure 13). Tritium waste had been disposed of in one of the vaults. The tritium apparently diffused out of the vault and was released to the pad. In early August of 1991, the leaking vault was moved to a location on the pad where it was not exposed to standing water. Tritium levels in the pad water then declined. Lower, but still elevated levels of tritium were detected in Tumulus I pad water (Figure 14).

A tritium plume exists in the groundwater in the tumulus area. The tumulus pads are not suspected as the source since tritium activity is observed in both upgradient and downgradient wells. A French drain that intercepts shallow groundwater upgradient of the tumulus pads discharged about 200 meters east of the pads until being extended a few years ago. This discharge is possibly a tritium source (tritium activity measured 260,000 Bq/L), although recent increases in tritium activity in several of the monitoring wells suggest that there are other sources (Figures 15 and 16).

Surface soil sampling in the tumulus area does not indicate that loading operations have released any radionuclides to the surrounding area. Natural ^{40}K and fallout ^{137}Cs are detected in the soil samples and could possibly be a source of activity if allowed to accumulate on the pads.

CONCLUSIONS AND FUTURE PLANS

An environmental monitoring program for the tumulus LLW facilities at ORNL has been established to meet the requirements of DOE Order 5820.2A. The program has demonstrated that the tumulus facilities have thus far proven very effective at containing Class II, low-level waste. No operational releases of radionuclides (other than tritium) have been observed.

The program has detected two problems that, while not directly related to the short-term performance of the facilities, warrant further investigation relative to long-term performance. Since the performance criteria for the tumulus facilities require no release of radionuclides to the environment for 100 years, the implications of the observed high pH and elevated gross beta (^{40}K) activity for long-term disposal unit integrity need to be explored. In particular, we are beginning to collaborate with concrete chemistry experts to develop chemical measures of concrete degradation that can be applied to present and future tumulus-type facilities.

The environmental monitoring program is being expanded to include tumulus facilities planned for the new SWSA 7.

ACKNOWLEDGMENTS

The authors wish to thank Libby West and Diana Hicks for reviewing the manuscript. Tony Thomas provided valuable field assistance. Jeff Riggs and Roy Freeman have provided excellent electronic instrumentation service over the life of the project. Dave Hall suggested the use of the CO_2 system. The advice generously given by many other members of the Environmental Sciences Division at ORNL is greatly appreciated.

REFERENCES

Ashwood, J.S., and T.L. Ashwood, 1991, *Active Sites Environmental Monitoring Program: Action Levels*, ORNL/M-1569, Oak Ridge National Laboratory, 1991.

Ashwood, T.L., D.S. Wickliff, C.M. Morrissey, 1990, *Active Sites Environmental Monitoring Program: Program Plan*, ORNL/M-1197, Oak Ridge National Laboratory, 1990.

Ashwood, T.L., D.S. Wickliff, C.M. Morrissey, 1992, *Active Sites Environmental Program: Program Plan*, Rev. 1, ORNL/M-1793, Oak Ridge National Laboratory, 1992.

U.S. Department of Energy, 1988, DOE Order 5820.2A, "Radioactive Waste Management, "September 26, 1988.

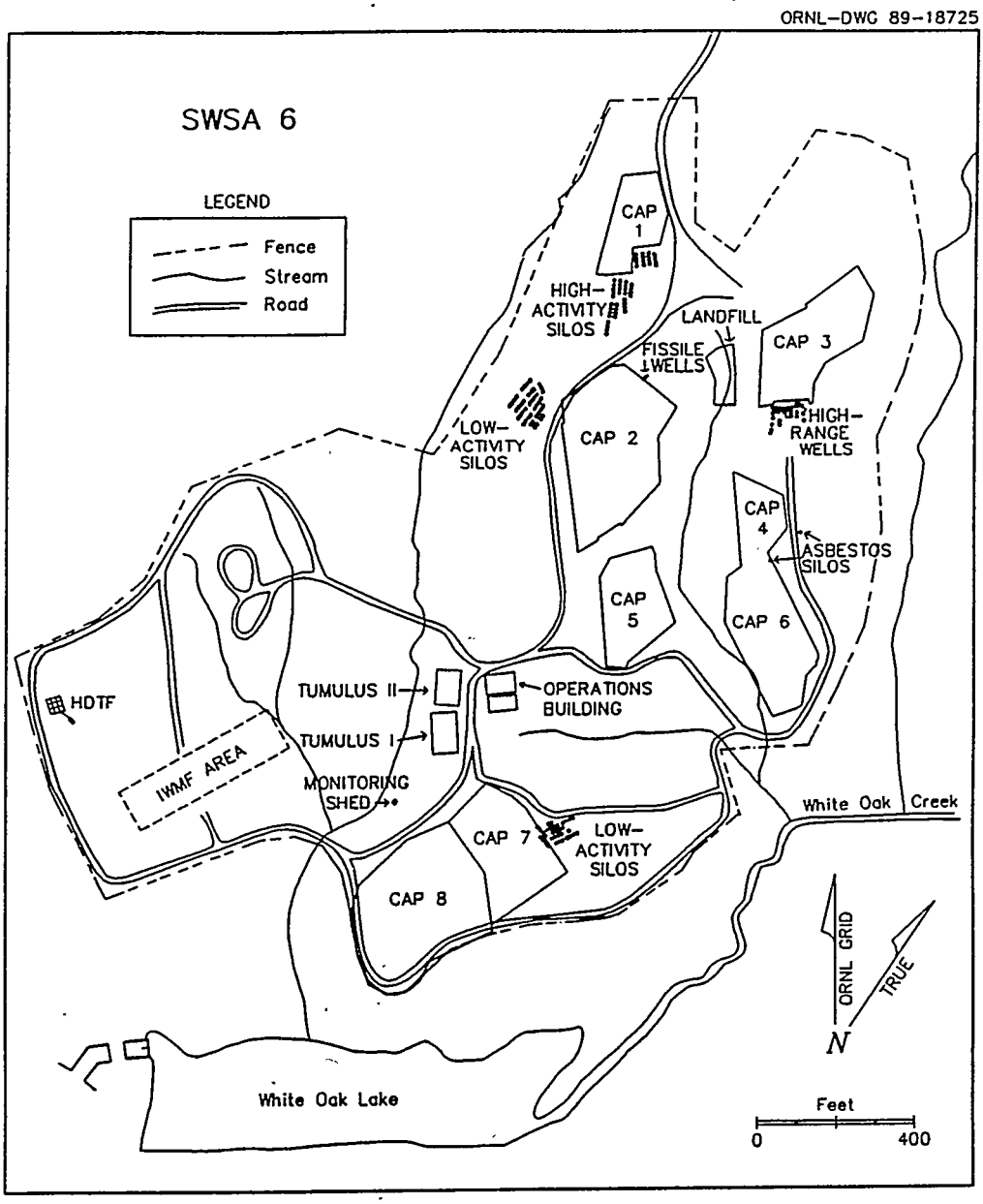


Fig. 1. Solid Waste Storage Area 6 at ORNL

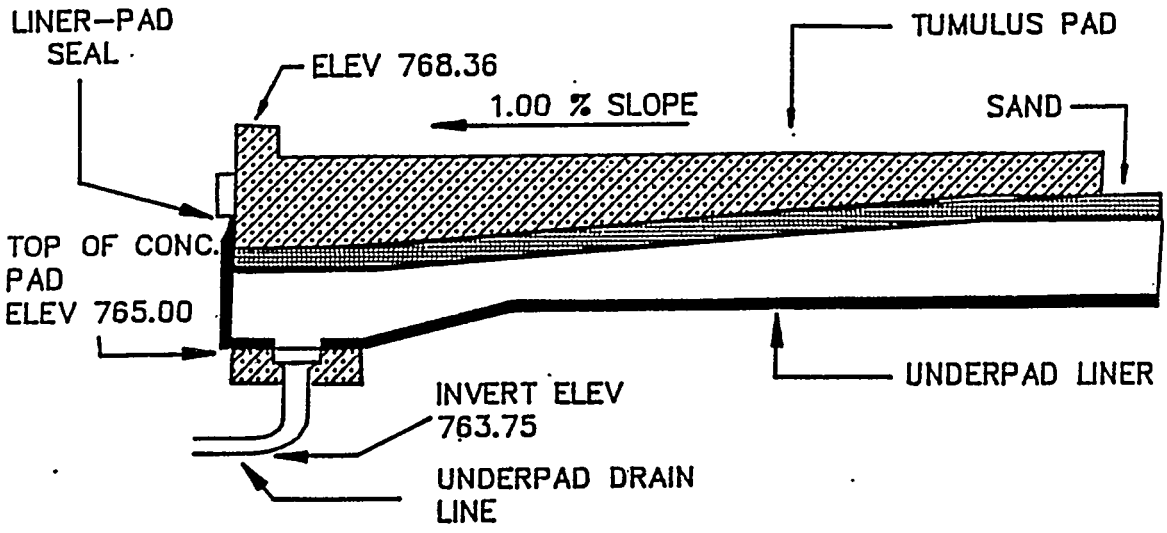


Fig. 2. Cross section of Tumulus I underpad drain

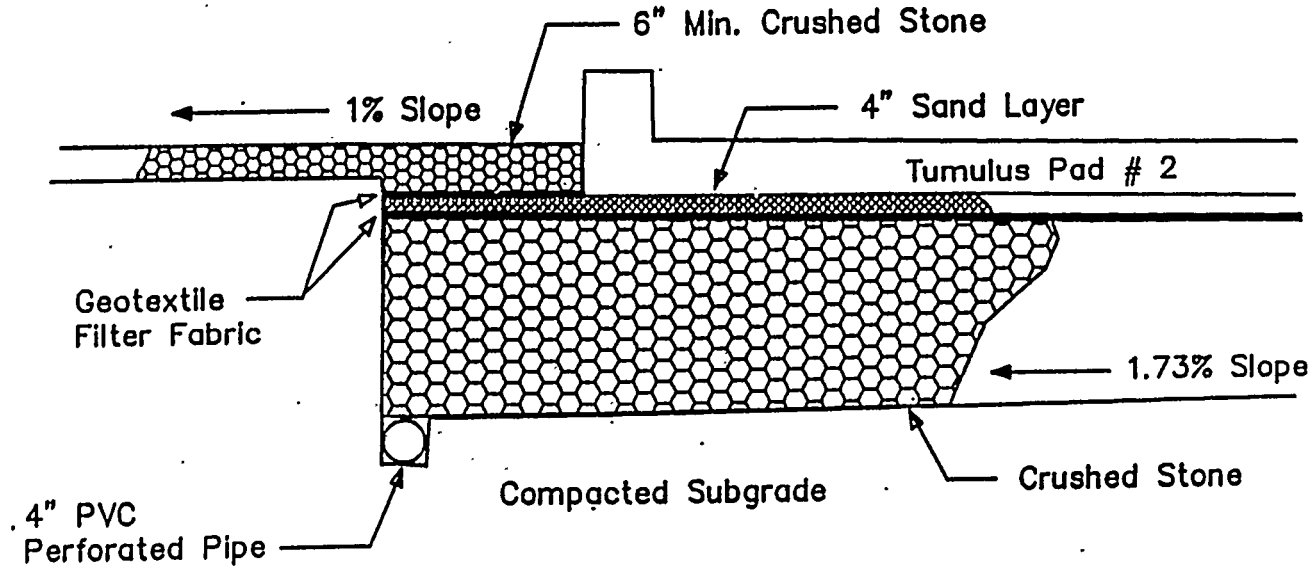


Fig. 3. Cross section of Tumulus II underpad drain

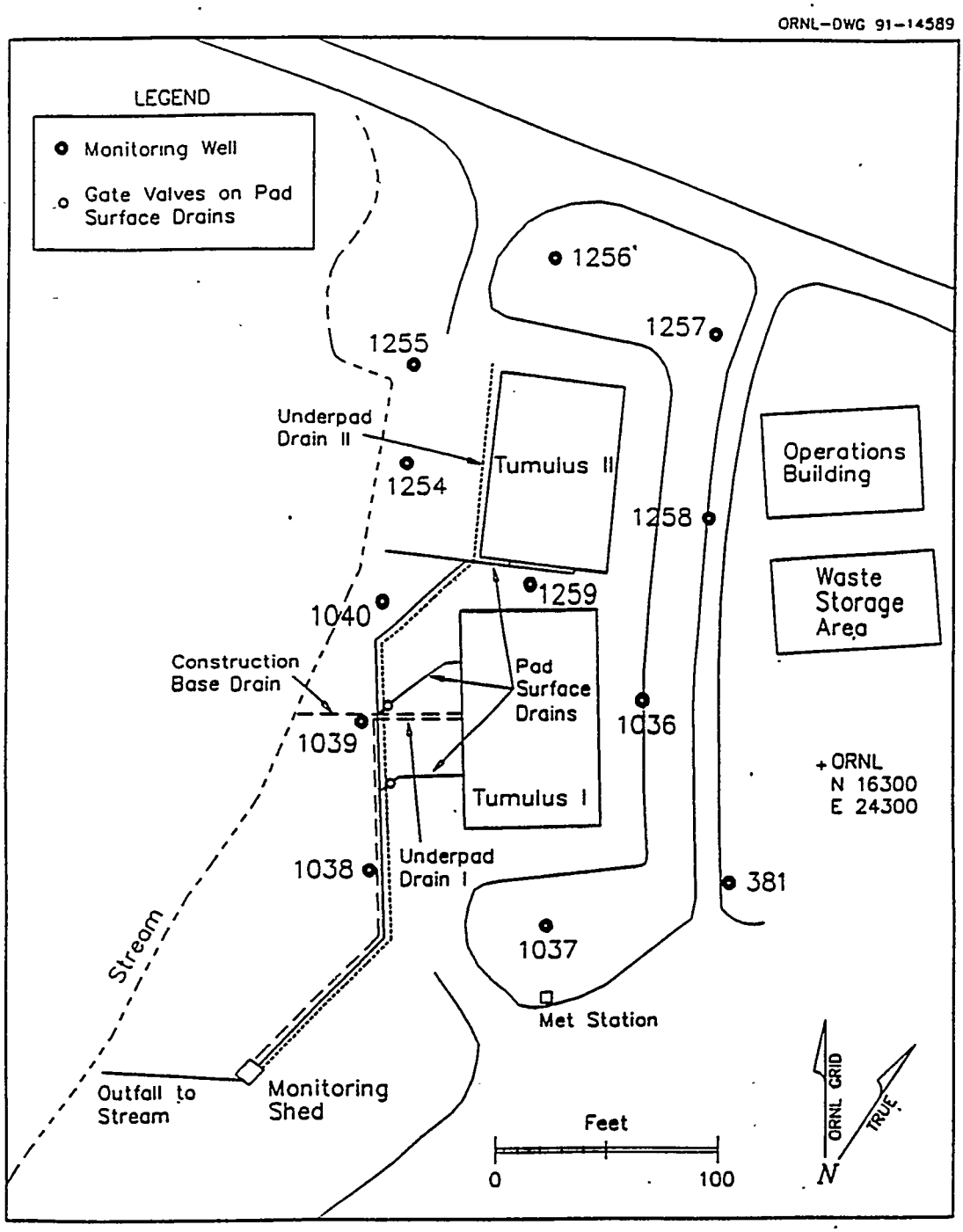


Fig. 4. Tumulus area in Solid Waste Storage Area 6

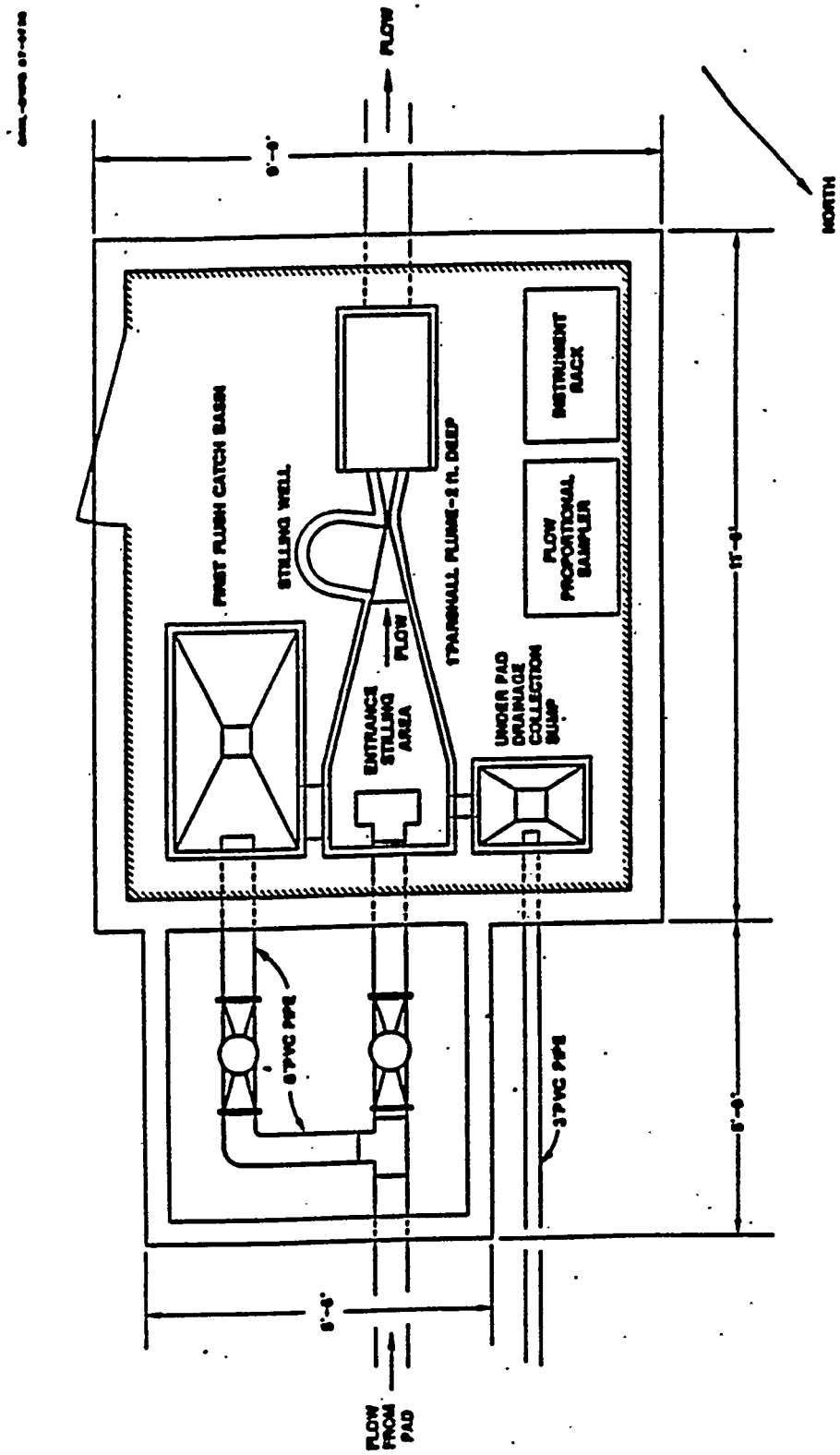


Fig. 5. Tumulus monitoring shed layout

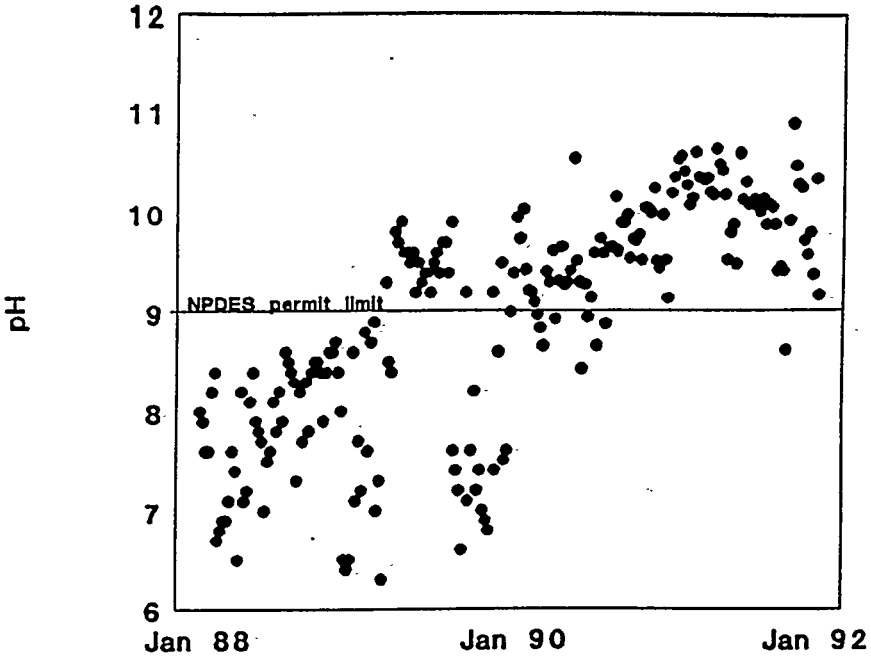


Fig. 6. Tumulus I pad water pH

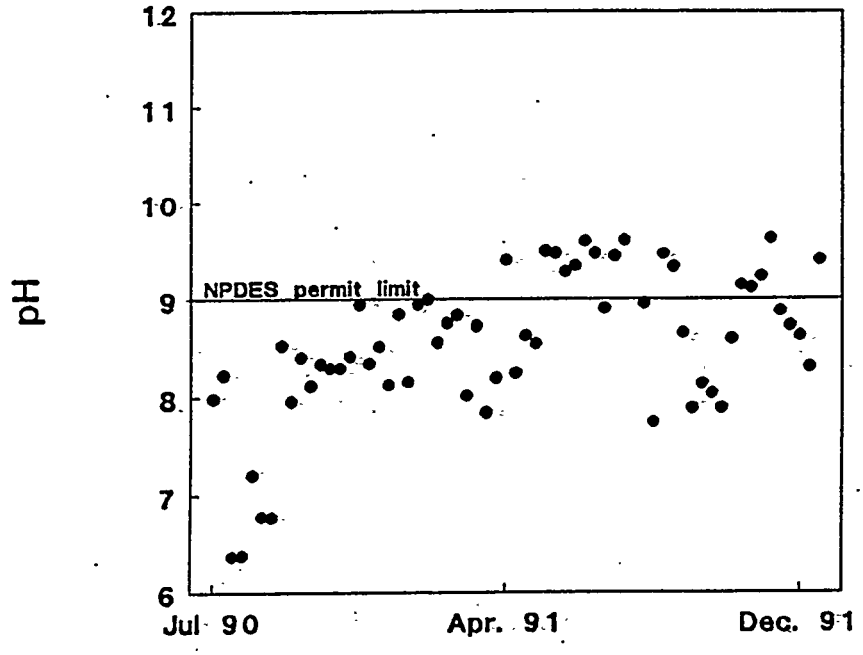


Fig. 7. Tumulus II pad water pH

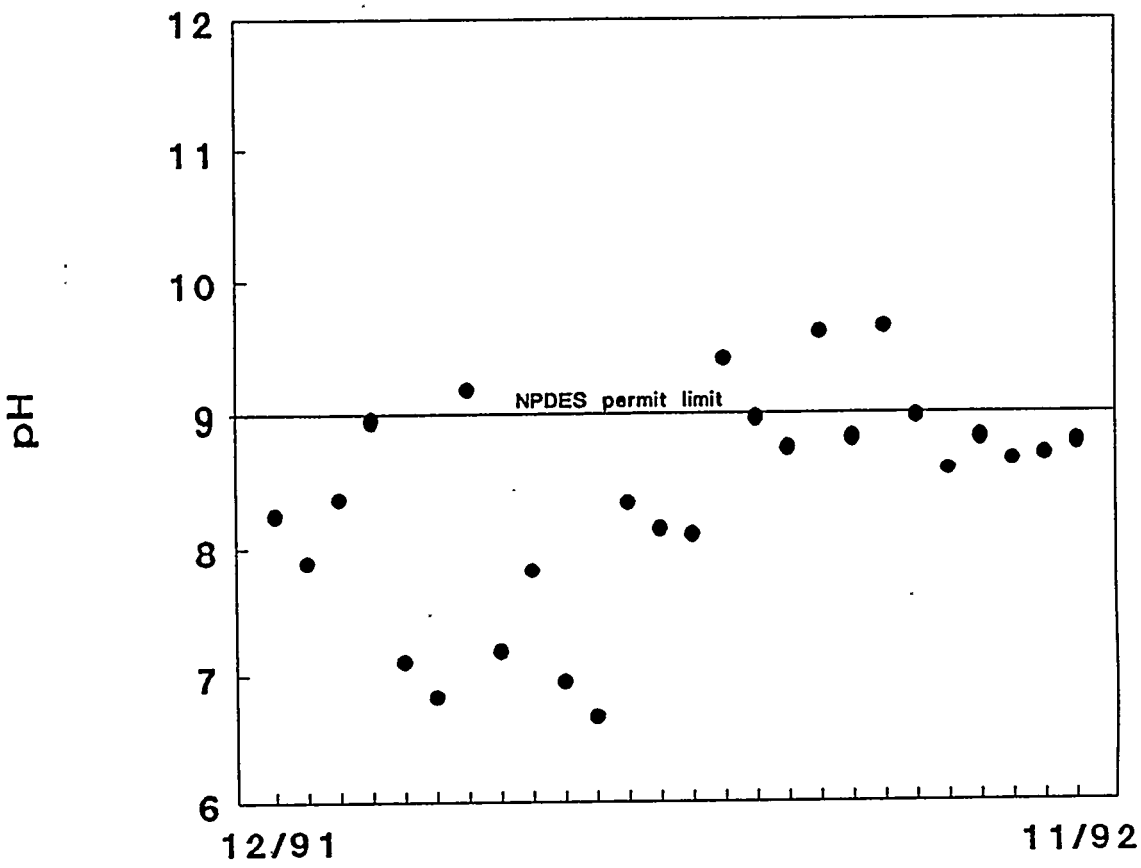


Fig. 8. IWMF pad water pH

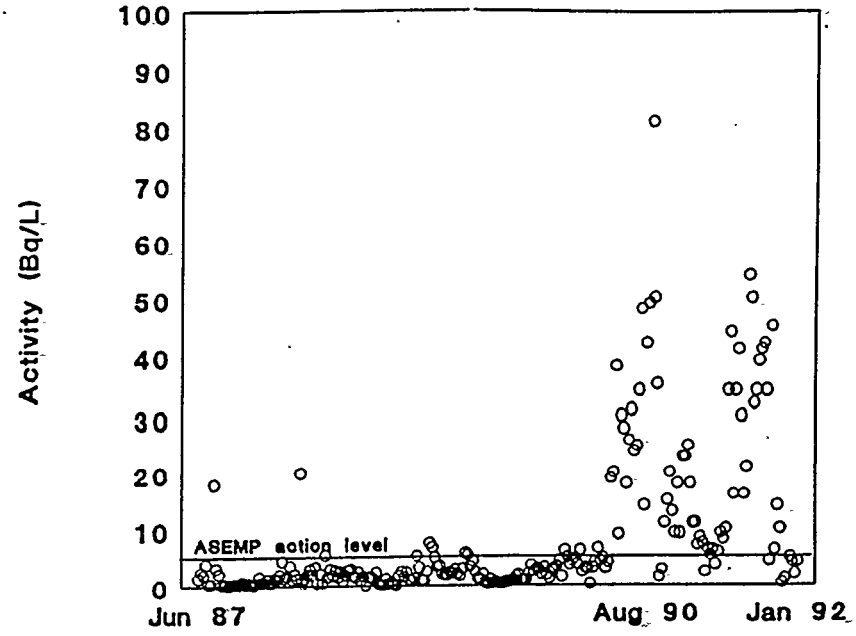


Fig. 9. Tumulus I pad water gross beta activity

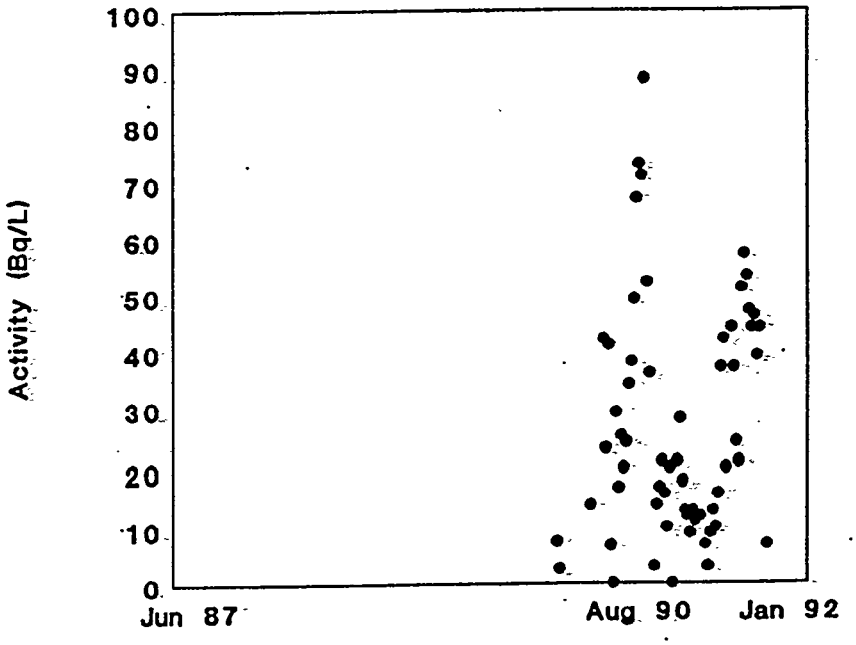


Fig. 10. Tumulus I pad water ^{40}K activity

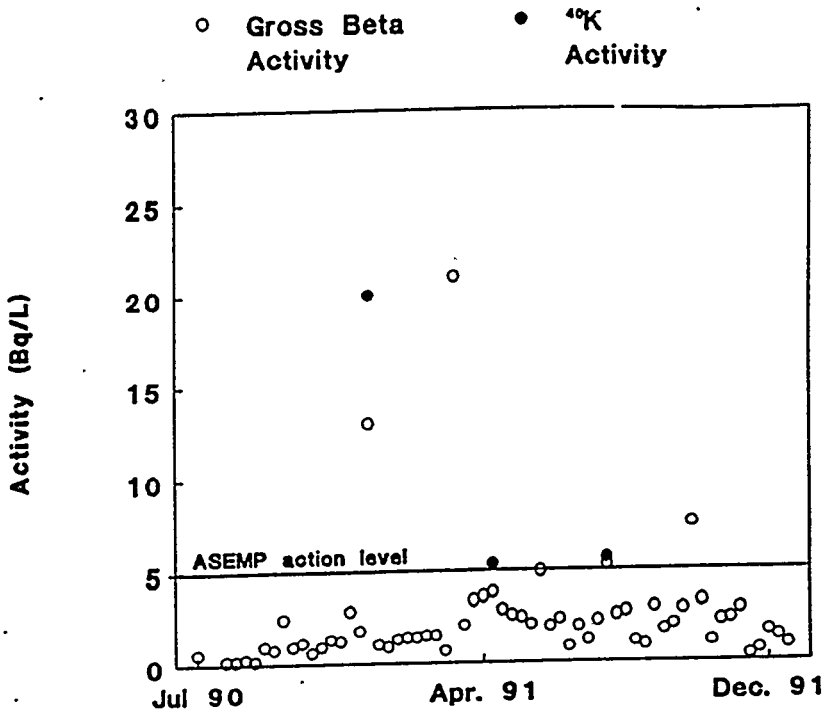


Fig. 11. Tumulus II pad water gross beta and ^{40}K activity

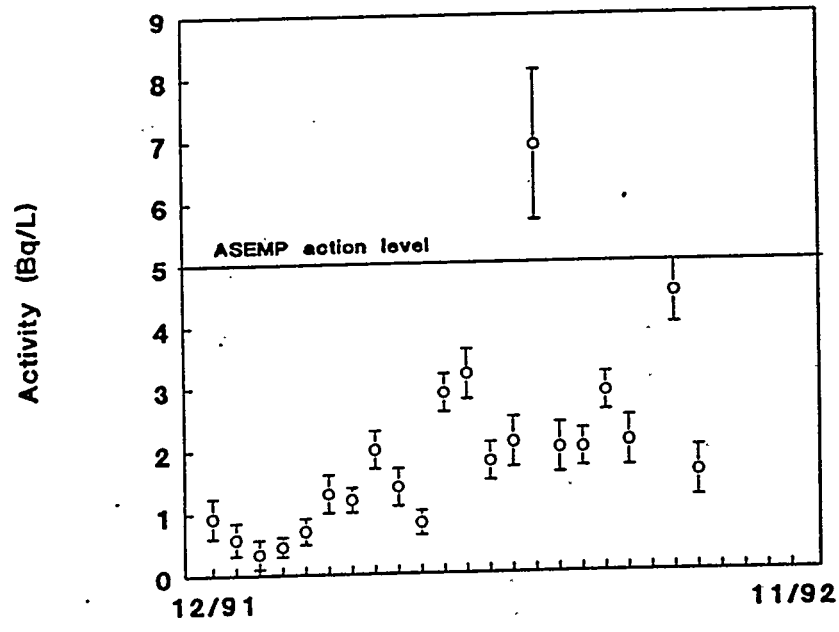


Fig. 12. IWMF pad water gross beta activity

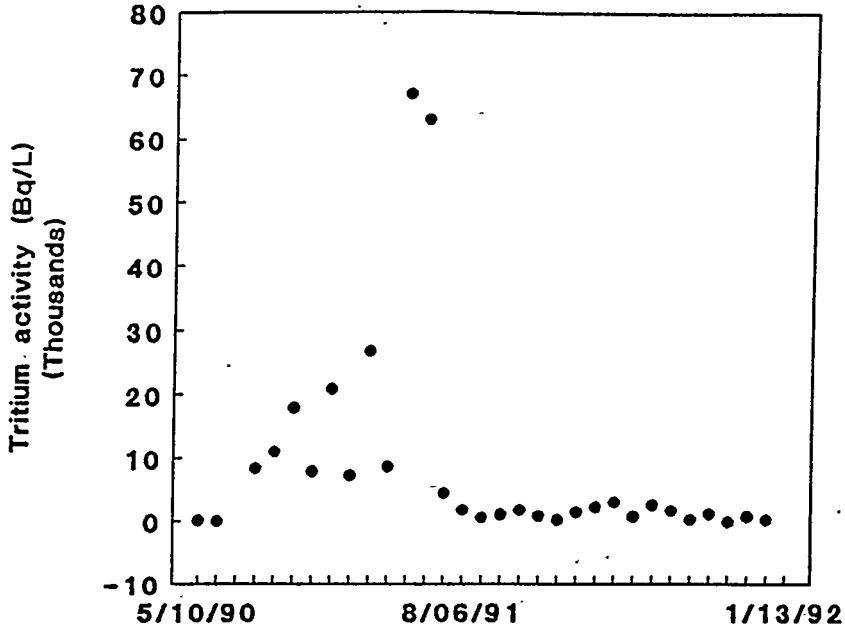


Fig. 13. Tumulus II pad water tritium activity

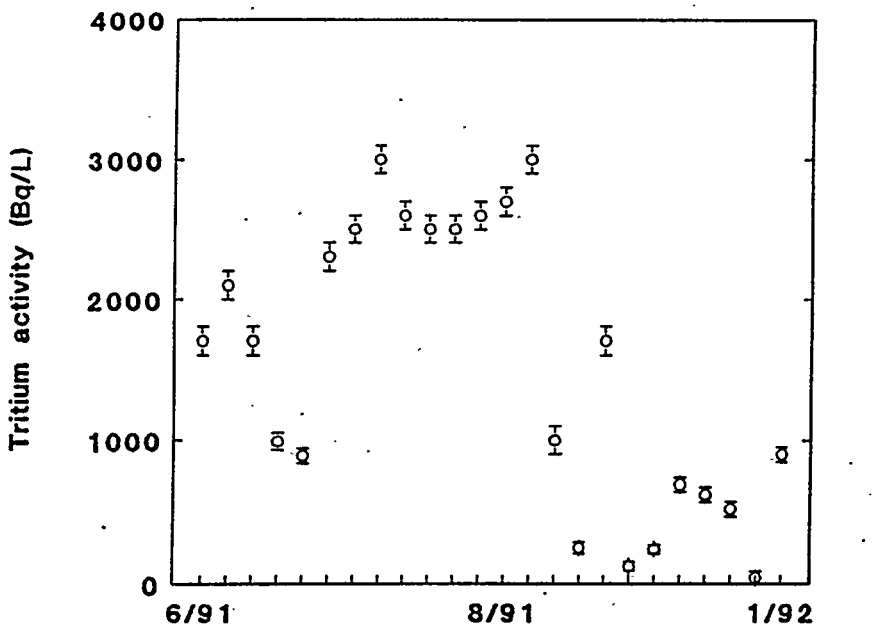


Fig. 14. Tumulus I pad water tritium activity

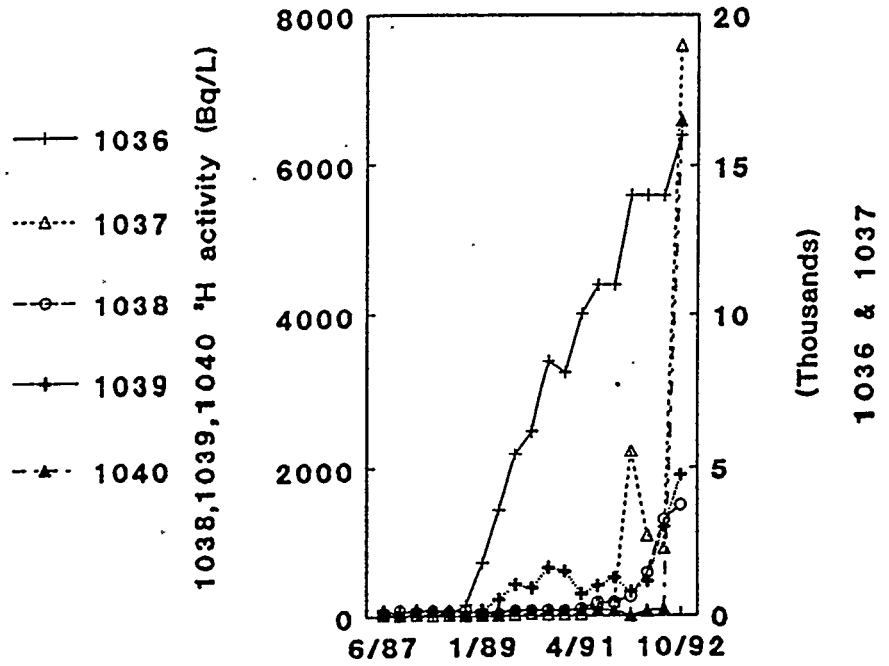


Fig. 15. Tumulus I monitoring well tritium activity

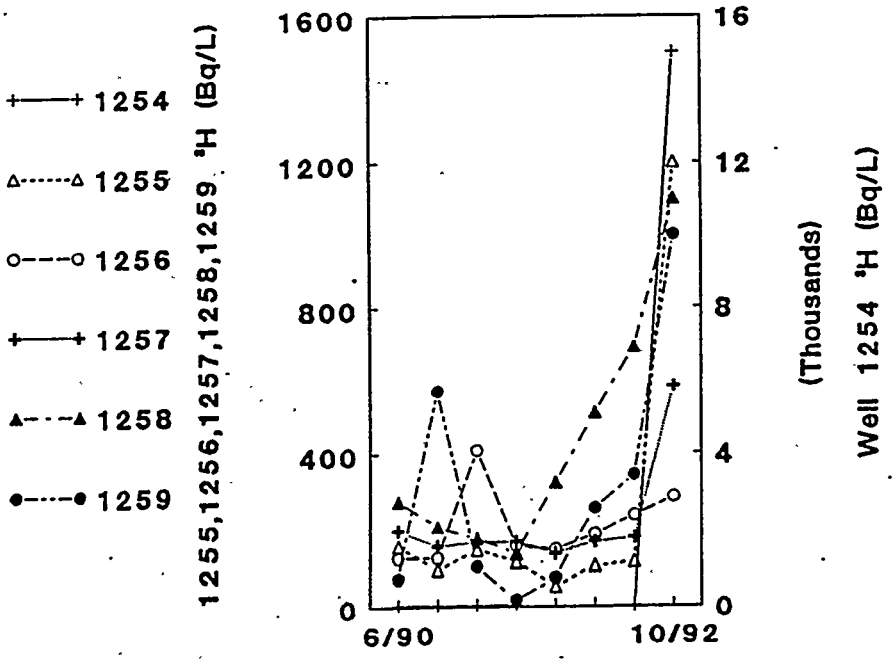


Fig. 16. Tumulus II monitoring well tritium activity

Potential Impact of DOE's Performance Objective for Protection of Inadvertent Intruders on Low-level Radioactive Waste Disposal at Oak Ridge National Laboratory[a]

D. C. Kocher
Health and Safety Research Division
Oak Ridge National Laboratory
Oak Ridge, TN 37831-6383

ABSTRACT

The Department of Energy's Order 5820.2A, Chapter III, specifies performance objectives for disposal of low-level radioactive waste that include limits on effective dose equivalent for inadvertent intruders. This paper investigates the potential impact of the performance objective for protection of inadvertent intruders on the acceptability of waste disposals in Solid Waste Storage Area (SWSA) 6 at Oak Ridge National Laboratory (ORNL). The analysis is based on radionuclide inventories and waste volumes for recent disposals in SWSA 6 and calculated doses to an inadvertent intruder per unit concentration of radionuclides in disposed waste for assumed exposure scenarios. The analysis indicates that more than 99% of the total volume of waste in recent disposals would meet the performance objective for inadvertent intruders, and the volume of waste found to be unacceptable for disposal is only about 16 m^3. Therefore, we conclude that the performance objective for protection of inadvertent intruders probably will not have unreasonably adverse impacts on acceptable waste disposals at ORNL.

INTRODUCTION

DOE Order 5820.2A, Chapter III (DOE 1988a), specifies performance objectives for disposal of low-level radioactive waste at all DOE sites. In addition to performance objectives for protection of offsite members of the public and groundwater resources, which are used to determine limits on releases of radionuclides to the environment, the order includes a performance objective for protection of inadvertent intruders onto disposal sites following loss of active institutional control at 100 years after facility closure. Specifically, effective dose equivalents to inadvertent intruders should not exceed 0.1 rem (1 mSv) per year for chronic exposures or 0.5 rem (5 mSv) for a single acute exposure. This performance objective is used to determine limits on concentrations of radionuclides that would be acceptable for disposal, based on a site-specific analysis of assumed exposure scenarios and exposure pathways for inadvertent intruders.

The purpose of this paper is to investigate the potential impact of DOE's performance objective for protection of inadvertent intruders on the acceptability of low-level waste disposal in Solid Waste Storage Area (SWSA) 6 at Oak Ridge National Laboratory (ORNL). The amount of waste that would be unacceptable for disposal is estimated using radionuclide inventories and waste volumes for recent disposals in SWSA 6 and calculated doses to an inadvertent intruder per unit concentration of radionuclides in disposed waste for assumed exposure scenarios.

This analysis is of interest because, as discussed below, DOE's performance objective for protection of inadvertent intruders is expected to result in limits on concentrations of radionuclides at most DOE sites that are considerably lower than the concentration limits for disposal of civilian low-level waste—the so-called

a. The submitted manuscript has been authored by a contractor of the U.S. Government under contract No. DE-AC05-84OR21400. Accordingly, the U.S. Government retains a nonexclusive, royalty-free license to publish or reproduce the published form of this contribution, or allow others to do so, for U.S. Government purposes.

Class-C limits—established by the Nuclear Regulatory Commission in 10 CFR 61 (NRC 1982a); e.g., see Kennedy and Peloquin (1988) and Aaberg and Kennedy (1990). Thus, there is concern that DOE's performance objective may result in significant volumes of DOE's low-level waste being unacceptable for disposal, even though the radionuclide concentrations are considerably less than the NRC's Class C limits and assumed scenarios for inadvertent intrusion are largely hypothetical and possibly quite pessimistic.

The approach to protection of inadvertent intruders prescribed in the DOE order is fundamentally different from the approach embodied in the NRC's 10 CFR 61. That is, the DOE order includes explicit dose limits, and compliance with the limits must be demonstrated by means of a site-specific analysis. However, the NRC regulations essentially define protection of inadvertent intruders by means of concentration limits of radionuclides that apply at any disposal site, and a site-specific analysis of potential exposures is not required.

The NRC's Class C limits are based on dose analyses for inadvertent intruders (NRC 1982b) that are similar to the analyses required at each DOE site. However, for the following two reasons, the concentration limits of radionuclides derived from DOE's performance objective are expected to be considerably less than the NRC's Class C limits, even when similar exposure scenarios are assumed. First, the NRC's concentration limits were derived using implicit dose limits for chronic exposures of inadvertent intruders (NRC 1981)—i.e., 0.5 rem per year to whole body and bone or 1.5 rem per year to any other organ—that are higher for most radionuclides than the limit on effective dose equivalent of 0.1 rem per year specified in the DOE order. Second, the NRC increased the concentration limits for Class C waste by a factor of 10 to take into account the presumed lower probability of inadvertent intrusion into such waste, due to its relatively small volume and the stringent requirements for its disposal that are expected to provide protection against intrusion for a considerable period of time. In addition, the dose conversion factors for ingestion and inhalation of radionuclides used by DOE (1988b) are significantly different for many radionuclides than the values used by the NRC (Oztunali et al. 1981).

Because of the different approaches used by DOE and NRC in defining protection of inadvertent intruders, there is no a priori reason to expect that the concentration limits of radionuclides at DOE disposal sites should be consistent with the NRC's Class C limits for civilian disposal facilities. Nonetheless, if the more restrictive concentration limits likely to apply at most DOE sites result in large volumes of waste that are unacceptable for disposal, and for which acceptable disposal systems have not been identified, then there is incentive to seek an alternative approach to defining protection of inadvertent intruders at DOE sites that would allow most of the waste to be acceptable for disposal while still protecting public health and the environment.

This analysis thus represents an effort to investigate a posteriori whether DOE's performance objective for inadvertent intruders could have serious adverse impacts on the acceptability of waste disposals at one DOE site, particularly when the concentrations of radionuclides in the waste are well below the NRC's Class C limits. The SWSA 6 site at ORNL provides a suitable test of this possibility, because a variety of wastes with widely varying radionuclide compositions and concentrations are intended for disposal in several different types of disposal units. In addition, the shallow depth of the water table at SWSA 6 (ORNL 1990) precludes the use of deeper burial as a deterrent to inadvertent intrusion (NRC 1982b), and some of the exposure scenarios assumed in this analysis probably are credible at the site.

DISPOSAL UNITS AND WASTES IN SWSA 6

This section briefly describes the different types of disposal units in SWSA 6 and presents data on radionuclide inventories and waste volumes for recent disposals in these units.

Tumulus I and II. Tumulus I and II are abovegrade units intended for disposal of contact-handled waste packages with an exposure rate at the surface of less than 200 mR/h. Most of the waste is slightly contaminated debris (e.g., plastic, rags, metal, wood, solidified sludges) from a variety of sources and processes. Waste packages are placed in concrete box-like casks that are backfilled with concrete. The casks are stacked on a concrete pad and capped with natural materials.

Low-Level Radioactive Waste Silos. Low-level radioactive waste silos are belowgrade units also used for disposal of contact-handled waste packages. These units consist of clusters of two concentric steel pipes placed vertically in a trench. Waste packages are stacked inside the inner steel pipe, which is backfilled with concrete. The annular space between the two pipes is filled with concrete, and the top and bottom of the silos are capped with concrete.

High-Level Radioactive Waste Silos. High-level radioactive waste silos are constructed in the same manner as the low-level silos described above. These units are used for disposal of higher-activity, remote-handled waste packages with an exposure rate at the surface of between 200 mR/h and 1 R/h. The waste consists primarily of debris from reactors and operations of hot cells and solidified sludges from liquid low-level waste handling systems.

High-Level Radioactive Waste Wells. High-level radioactive waste wells are belowgrade units used for disposal of high-activity, remote-handled waste packages with an exposure rate at the surface of greater than 1 R/h. The waste is similar to the waste in the high-level silos. In these units, several iron pipes are placed vertically inside cylindrical concrete containment tiles, and the space between the pipes and the inner surface of the containment tile is filled with concrete. Waste packages are stacked inside the iron pipes, and the top and bottom of the wells are capped with concrete.

Fissile Wells. Fissile wells are used for disposal of any low-level wastes containing more than 1 g of U-235. The waste usually consists of debris from processing of enriched uranium. The disposal units consist of vertical auger holes lined with steel pipe, and waste packages are stacked inside the pipes. The space outside the pipes is backfilled with dirt, and the top and bottom of the wells are capped with concrete.

Asbestos Silos. Asbestos silos are constructed in the same manner as the low-level silos described above. These units are used for disposal of low-level waste contaminated with asbestos. The waste consists primarily of debris generated during maintenance or demolition of contaminated facilities. The exposure rate at the surface of waste packages usually is low (i.e., much less than 10 mR/h).

Biological Trenches. Biological trenches are unlined, belowgrade excavations used for disposal of wastes, primarily animal excrement and whole animals or body parts, generated when radionuclides are used in biological research. The exposure rate at the surface of waste packages usually is low (i.e., much less than 10 mR/h).

Data on Recent Disposals. As shown in Table 1, more than 30 radionuclides with half-lives sufficiently long that they could be of concern in a dose analysis for inadvertent intruders have been reported in recent waste disposals at SWSA 6. Other potentially important long-lived radionuclides have not been reported in recent disposals but are presumed to be present (e.g., I-129, Pu-241, Pu-242). However, based on the preliminary dose analysis described in this paper, only a few radionuclides appear to occur in concentrations sufficiently high that the estimated doses to an inadvertent intruder would be more than a small fraction of the dose limits in the performance objective.

Table 2 summarizes data on the inventories in waste in disposal for the potentially important radionuclides for the intruder dose analysis and the waste volumes for the different disposal units in SWSA 6. These data apply only to recent disposals—i.e., disposals between September 26, 1988, which is the beginning date for implementation of the DOE order (DOE 1988a), and April 7, 1992.

SCENARIOS FOR INADVERTENT INTRUSION

Three scenarios for inadvertent intrusion were assumed in the draft performance assessment for SWSA 6 (ORNL 1990)—the so-called agriculture, discovery, and post-drilling scenarios. This section briefly describes these scenarios and presents a summary of the preliminary results of the dose analysis for each intrusion scenario.

Agriculture Scenario. In the agriculture scenario, an intruder is assumed to excavate into waste while constructing a foundation for a home at the location of disposal units. Waste exhumed during excavation is assumed to be indistinguishable from native soil, and some of the exhumed waste is assumed to be mixed with native soil in the intruder's vegetable garden. The following exposure pathways then are assumed to occur: ingestion of contaminated vegetables from the garden, ingestion of contaminated soil from the garden in conjunction with vegetable intakes, external exposure to contaminated soil while working in the garden or residing in the home on top of the disposal units, and inhalation of radionuclides suspended into air while working in the garden or residing in the home. The agriculture scenario results in chronic exposures and, thus, is subject to a dose limit of 0.1 rem (1 mSv) per year.

For disposal units constructed using engineered barriers, direct intrusion into waste using normal excavation procedures is assumed to be precluded while the engineered barriers maintain their structural integrity. In the preliminary dose analysis, all engineered barriers are assumed to maintain their integrity for 300 years after disposal. The assumption that the agriculture scenario occurs at 300 years after disposal thus applies to all disposal units except the biological trenches. Since no engineered barriers are used in these trenches, the agriculture scenario is assumed to occur at 100 years after disposal in this case. The time at which the agriculture scenario is assumed to occur affects the dose estimates only for the shorter-lived radionuclides listed in Table 2, i.e., Sr-90, Cs-137, Eu-152, and Eu-154.

Discovery Scenario. In the discovery scenario, an intruder is assumed to excavate at the location of disposal units in constructing a foundation for a home, as in the agriculture scenario. However, for all disposal units except the biological trenches, the intruder is assumed to encounter an intact engineered barrier that cannot be penetrated by normal excavation procedures. Therefore, shortly after encountering the engineered barrier, the intruder decides to abandon excavation at that location and moves elsewhere. Since the engineered barrier is not breached during excavation, the only exposure pathway is external exposure to photon-emitting radionuclides during the time the intruder works at the site. The discovery scenario results in a single acute exposure and, thus, is subject to a dose limit of 0.5 rem (5 mSv).

The discovery scenario is assumed to occur at any time after loss of active institutional control at 100 years after disposal. Since the most important photon-emitting radionuclides listed in Table 2 (i.e., Cs-137, Eu-152, and Eu-154) have relatively short half-lives, the dose for the discovery scenario would be reduced significantly if inadvertent intrusion were precluded for a substantial time beyond the institutional control period. Again, this scenario is not relevant in the dose analysis for the biological trenches.

Post-Drilling Scenario. In the post-drilling scenario, an intruder is assumed to drill through disposal units, e.g., to construct a well. The drilling waste is assumed to be indistinguishable from native soil, and all the drilling waste is assumed to be mixed with native soil in the intruder's vegetable garden. The following exposure pathways then are assumed to occur: ingestion of contaminated vegetables from the garden, ingestion of contaminated soil from the garden in conjunction with vegetable intakes, external exposure to contaminated soil while working in the garden, and inhalation of radionuclides suspended into air while working in the garden. These pathways are the same as the corresponding pathways assumed for the agriculture scenario, except the volume of waste mixed with garden soil is assumed to be ten times greater for the agriculture scenario than for the post-drilling scenario. In addition, for activated metals, only 1% of the activity in the waste is assumed to be exhumed by drilling (NRC 1982a). The post-drilling scenario results in chronic exposures and, thus, is subject to a dose limit of 0.1 rem (1 mSv) per year.

Normal drilling procedures at ORNL are capable of penetrating through hard rock. Therefore, drilling through disposal units is assumed to occur even in the presence of intact engineered barriers, and the post-drilling scenario is assumed to occur at any time after loss of active institutional control at 100 years after disposal. Since the dose per unit concentration of a radionuclide will always be greater for the agriculture scenario than for the post-drilling scenario when the two scenarios occur at the same time (see Table 3), the post-drilling scenario is not relevant in the dose analysis for the biological trenches. The time at which the post-drilling scenario is assumed to occur affects the dose estimates only for the shorter-lived radionuclides listed in Table 2, i.e., Sr-90, Cs-137, Eu-152, and Eu-154.

Summary of Dose Analyses for Intruder Scenarios. The results of the preliminary dose analyses for the three intrusion scenarios assumed in the draft performance assessment for SWSA 6 (ORNL 1990) are summarized in Table 3. The results are presented in the form of so-called scenario dose conversion factors (SDCFs), which are doses per unit concentration of radionuclides. The SDCFs are applied, as described below, to the concentrations of radionuclides in disposal units at the time an intrusion scenario is assumed to occur.

RESULTS OF DOSE ANALYSIS FOR INADVERTENT INTRUDERS IN SWSA 6

For an assumed exposure scenario, the effective dose equivalent to an inadvertent intruder from any radionuclide is estimated by the equation

$$H = C_o \times SDCF \times G \times e^{-\lambda t}, \quad (1)$$

where H is the effective dose equivalent in rem per year for chronic exposure scenarios (i.e., the agriculture and post-drilling scenarios) or in rem for acute exposure scenarios (i.e., the discovery scenario), C_o is the radionuclide concentration in waste at the time of disposal in $\mu Ci/m^3$, SDCF is the scenario dose conversion factor for the radionuclide in rem/y per $\mu Ci/m^3$ for chronic exposure scenarios or in rem per $\mu Ci/m^3$ for acute exposure scenarios, G is a geometrical correction factor described below, λ is the decay constant for the radionuclide in y^{-1}, and t is the assumed time between disposal and the occurrence of the exposure scenario in years.

The values of C_o for the different disposal units in SWSA 6 are obtained from the data on radionuclide inventories and waste volumes in Table 2, and the SDCFs for the radionuclides are given in Table 3. As described previously, the agriculture scenario is assumed to occur at 100 years after disposal for the biological trenches or at 300 years after disposal for all other disposal units. The discovery and post-drilling scenarios are assumed to occur at 100 years after disposal for all disposal units, except these scenarios are not relevant in the dose analysis for the biological trenches. The dose analyses based on Eq. (1) may be conservative, because the model assumes that no activity is released from any disposal units before the time intrusion occurs.

The geometrical correction factor, G, in Eq. (1) takes into account that, for some exposure scenarios, the average concentration of a radionuclide to which an intruder would be exposed is less than the average concentration in waste at the time of disposal, because a substantial fraction of the volume encompassed by disposal units contains uncontaminated material. This correction factor particularly applies to the agriculture and discovery scenarios, because an intruder is assumed to excavate into a volume of soil that is considerably larger than the volume occupied by individual disposal units. Therefore, the average concentrations of radionuclides to which an intruder would be exposed are given by the average concentrations in disposed waste multiplied by the fraction of the volume encompassed by disposal units that is occupied by waste. This fraction is the geometrical correction factor.

For the agriculture and discovery scenarios, the assumed geometrical correction factor is 0.4 for Tumulus I and II, 0.25 for the low-level silos, high-level silos, fissile wells, asbestos silos, and biological trenches, and 0.075 for the high-level wells. These values are based on current designs or operating practices for the different types of disposal units (ORNL 1990). The geometrical correction factor for the high-level wells is less than the value for the other silos and wells because the waste is confined to the iron pipes within individual wells, rather than distributed throughout the interior volume of the wells.

For the post-drilling scenario, the geometrical correction factor is assumed to be unity for all disposal units; i.e., an intruder is assumed to drill only through contaminated regions in disposal units. Any uncontaminated material exhumed by drilling is taken into account in estimating the dilution factor for mixing of drilling waste with native soil in the intruder's vegetable garden. The assumed location for drilling clearly is pessimistic for disposal in the silos and wells, particularly the high-level wells. Thus, the post-drilling scenario is less credible (i.e., would occur with a lower probability) than the agriculture or discovery scenarios for several types of disposal units.

In the dose analyses for the agriculture and discovery scenarios, the use of average concentrations of radionuclides in disposed waste and the geometrical correction factor described above essentially is based on the assumption that an intruder would access disposal units at random locations. This is a reasonable assumption when an intruder is unaware of the presence of a disposal facility. Average concentrations of radionuclides in disposed waste also are used in the dose analysis for the post-drilling scenario. By using average concentrations of radionuclides in the dose analyses and, thus, in determining limits on concentrations that would be acceptable for disposal, acceptable disposals could include a relatively small number of waste packages in which the concentrations of radionuclides far exceed the allowable average values. However, the concentrations of radionuclides in individual low-level waste packages at DOE disposal sites cannot exceed the NRC's Class C limits for civilian waste (DOE, 1988a), even if the average concentrations in particular disposal units would be less than the allowable limits.

The results of the dose analyses for inadvertent intruders for the different disposal units in SWSA 6 are summarized in Table 4. For each exposure scenario, the results are expressed in terms of the ratio of the effective dose equivalent, as estimated from Eq. (1), to the dose limit (i.e., 0.1 rem per year for the agriculture and post-drilling scenarios and 0.5 rem for the discovery scenario). Particular disposal units then would be in compliance with the performance objective for inadvertent intruders if the ratio of the dose from each radionuclide to the dose limit, summed over all radionuclides, is less than unity for all scenarios; this is the so-called sum-of-fractions rule, which applies when exposure to all radionuclides occurs at the same time.

Results for individual radionuclides are listed in Table 4 only if the ratio of the estimated dose to the dose limit for a particular scenario is 0.01 or greater. Based on the recent data on concentrations of radionuclides in all wastes, the total dose from all radionuclides that each contributes which is less than 1% of the dose limit is not of concern in regard to meeting the performance objective for protection of inadvertent intruders; i.e., the total dose from all radionuclides not listed in Table 4 would be insignificant.

DISCUSSION OF RESULTS

The results of the dose analyses for the different disposal units in SWSA 6 and the assumed scenarios for inadvertent intrusion, as summarized in Table 4, are discussed as follows.

For Tumulus I and II, the low-level silos, the asbestos silos, and the biological trenches, the estimated doses to an inadvertent intruder from all radionuclides and for all exposure scenarios are well below the dose limits. The total volume of waste in these units of 2,044 m^3 comprises 87% of the volume of all recent disposals in SWSA 6.

For the high-level silos, the estimated dose to an inadvertent intruder from all radionuclides exceeds the dose limit by a factor of two for the post-drilling scenario, but the doses are well below the limits for the agriculture and discovery scenarios. For the post-drilling scenario, the dose is due almost entirely to the inventory of Sr-90. Thus, if this scenario were precluded for an additional 30 years after loss of active institutional control (e.g., by use of such passive institutional controls as fences and warning signs), the dose would be below the limit. The total volume of waste in these units of 286 m^3 comprises 12% of the volume of all recent disposals in SWSA 6. However, only 23% of the waste packages in these disposals contain concentrations of Sr-90 greater than the limit on the average concentration for acceptable disposals. The volume of waste in these packages is 66 m^3.

For the high-level wells, the estimated doses to an inadvertent intruder from all radionuclides exceed the dose limits by a factor of nearly 100 for the agriculture scenario, a factor of nearly 10 for the discovery scenario, and a factor of 2300 for the post-drilling scenario. For each scenario, the dose is due primarily to the inventory of Sr-90 and/or Cs-137. The doses for the discovery and post-drilling scenarios would be reduced below the limits if these scenarios were precluded for about 200 and 420 years after disposal, respectively, by such measures as passive institutional controls or engineered barriers. However, the dose at times long after disposal would still exceed the limit by a factor of two for the agriculture scenario, due only to the inventory of long-lived Tc-99 and Th-229, and it is not reasonable to assume that engineered barriers or passive controls

would be effective in reducing the dose in this case. The total volume of waste in these units of 15.6 m^3 comprises less than 1% of the volume of all recent disposals in SWSA 6.

For the fissile wells, the estimated doses to an inadvertent intruder from all radionuclides exceed the dose limits by a factor of 200 for the agriculture scenario, a factor of nearly 20 for the discovery scenario, and a factor of nearly 100 for the post-drilling scenario. For each scenario, the dose is due primarily to the inventory of Cs-137. The doses for the discovery and post-drilling scenarios would be reduced below the limits if these scenarios were precluded for about 230 and 300 years after disposal, respectively, by such measures as passive institutional controls or engineered barriers. However, similar to the case of disposal in the high-level wells, the dose at times long after disposal would still exceed the limit by a factor of two for the agriculture scenario, due only to the inventory of long-lived U-235 and U-238. The total volume of waste in these units of 0.54 m^3 comprises about 0.02% of the volume of all recent disposals in SWSA 6.

Thus, if inadvertent intrusion into the high-level silos according to the post-drilling scenario could be precluded for an additional 30 years after loss of active institutional control, which seems reasonable, the analysis indicates that only disposals in the high-level wells and fissile wells would result in doses to inadvertent intruders that exceed the performance objective. The unacceptability of waste disposals in these units does not depend on assumptions regarding the time after disposal at which the different exposure scenarios would occur (i.e., on the lifetime of engineered barriers or passive institutional controls), because the dose for the agriculture scenario exceeds the limit at times long after disposal due only to the high concentrations of long-lived radionuclides. The total volume of waste in these disposal units is about 16 m^3, which is less than 1% of the total volume of all recent disposals in SWSA 6.

SUMMARY AND CONCLUSIONS

This paper has investigated the potential impact of the performance objective for protection of inadvertent intruders in DOE Order 5820.2A (DOE 1988a) on the acceptability of low-level waste disposal in SWSA 6 at ORNL. Estimates of dose to inadvertent intruders, based on assumed exposure scenarios, were obtained from data on radionuclide inventories and waste volumes for recent disposals in SWSA 6 and information on the design of the different disposal units at the site. A separate dose analysis was performed for each type of disposal unit in SWSA 6.

The analysis showed that only about 16 m^3, or less than 1%, of the waste in recent disposals in SWSA 6 would be unacceptable in regard to meeting DOE's performance objective for inadvertent intruders. Thus, although the performance objective was developed without first investigating its impact on the acceptability of low-level waste disposals at DOE sites, we conclude that the impact on acceptable disposals at ORNL does not appear to be severe. However, this conclusion is valid only if substantial volumes of waste generated in the future do not contain average concentrations of long-lived radionuclides that are considerably higher than the concentrations reported in recent disposals. In addition, future wastes could not contain high concentrations of other long-lived radionuclides that have not been reported in recent disposals.

REFERENCES

Aaberg, R. L., and W. E. Kennedy, Jr., 1990, *Definition of Intrusion Scenarios and Example Concentration Ranges for the Disposal of Near-Surface Waste at the Hanford Site*, PNL-6312, Pacific Northwest Laboratory, 1990.

Department of Energy, 1988a, Order 5820.2A, "Management of Low-Level Waste," Chapter III in "Radioactive Waste Management," September 26, 1988.

Department of Energy, 1988b, *Internal Dose Conversion Factors for Calculation of Dose to the Public*, DOE/EH-0071, 1988.

Kennedy, W. E., Jr, and R. A. Peloquin, 1988, *Intruder Scenarios for Site-Specific Low-Level Radioactive Waste Classification*, DOE/LLW-71T, U.S. Department of Energy, 1988.

Nuclear Regulatory Commission, 1981, *Draft Environmental Impact Statement on 10 CFR Part 61 "Licensing Requirements for Land Disposal of Radioactive Waste,"* NUREG-0782, 1981.

Nuclear Regulatory Commission, 1982a, "10 CFR Part 61—Licensing Requirements for Land Disposal of Radioactive Waste," Final Rule, *Federal Register 47*, 57446, 1982.

Nuclear Regulatory Commission, 1982b, *Final Environmental Impact Statement on 10 CFR Part 61 "Licensing Requirements for Land Disposal of Radioactive Waste,"* NUREG-0945, Vol. 3, 1982.

Oak Ridge National Laboratory, 1990, *Performance Assessment for Continuing and Future Operations at SWSA 6*, draft report. 1990.

Oztunali, O. I., et al., 1981, *Data Base for Radioactive Waste Management, Volume 3: Impacts Analysis Methodology Report*, NUREG/CR-1759, Dames and Moore, Inc., 1981.

Table 1. Potentially important radionuclides for intruder dose analysis reported in recent low-level waste disposals in SWSA 6 at ORNL[a]

H-3	Cs-137
Be-10	Eu-152,-154,-155
C-14	Pb-210
Ar-39	Ra-226
K-40	Th-229,-230,-232
Ca-41	U-232,-233,-234,-235,-236,-238
Co-60	Np-237
Ni-63	Pu-238,-239,-240
Kr-85	Am-241,-243
Sr-90	Cm-243,-244
Tc-99	Cf-249

[a]J. R. Forgy, ORNL, private communication. Radionuclide is listed only if half-life is about 5 years or greater.

Table 2. Data on recent disposals of low-level waste in different disposal units in SWSA 6 at ORNL[a]

Disposal units	Volume (m^3)	Nuclide[b]	Activity (Ci)
Tumulus I and II	1,134	Sr-90	11
		Tc-99	0.019
		Cs-137	27
		Ra-226	0.0017
		Th-232	0.00067
		Pu-239	0.022
		Am-241	0.035
Low-Level Silos	594	Sr-90	2.7
		Cs-137	3.2
		Th-232	0.0011
		Am-243	0.0062
High-Level Silos	286	Sr-90	23
		Cs-137	26
		Th-232	0.00014
High-Level Wells	15.6	Sr-90	1,400
		Tc-99	0.40
		Cs-137	1,400
		Eu-152	1,100
		Eu-154	580
		Th-229	0.0075
		Th-232	0.000037
Fissile Wells	0.54	Cs-137	43
		U-235	0.00088
		U-238	0.048
Asbestos Silos	108	Sr-90	0.042
		Tc-99	0.0012
		Cs-137	0.057
		Th-232	0.000043
Biological Trenches	208	Sr-90	0.010
		Cs-137	0.0022

[a]Data apply to reported disposals between September 26, 1988, and April 7, 1992 (J. R. Forgy, ORNL, private communication).

[b]Only those radionuclides in different disposal units that contribute most of the estimated dose to an inadvertent intruder are listed.

Table 3. Scenario dose conversion factors for assumed exposure scenarios for inadvertent intruders in performance assessment for SWSA 6 at ORNL[a]

Nuclide	Scenario dose conversion factor[b]		
	Agriculture	Discovery	Post-drilling[c]
Sr-90	2.7E-4		2.7E-5
Tc-99	8.4E-5		8.4E-6
Cs-137	1.0E-3	4.5E-6	1.1E-6
Eu-152	2.0E-3	1.1E-5	9.6E-7
Eu-154	2.2E-3	1.2E-5	1.1E-6
Ra-226	4.2E-3	1.8E-5	1.1E-4
Th-229	7.3E-4	1.5E-6	1.7E-5
Th-232	4.9E-3	2.7E-5	6.0E-5
U-235	1.9E-4	2.5E-7	4.2E-7
U-238	4.2E-5	1.4E-7	3.4E-7
Pu-239	6.8E-5		3.3E-6
Am-241	7.7E-5		3.1E-6
Am-243	2.9E-4	3.4E-7	3.2E-6

[a]Values obtained from Tables 4.17, 4.18, and 4.19 of draft performance assessment report (ORNL, 1990).

[b]Values are in units of rem/y per $\mu Ci/m^3$ for agriculture and post-drilling scenarios and rem per $\mu Ci/m^3$ for discovery scenario.

[c]Value is reduced by factor of 100 if radionuclide occurs in activated metal.

Table 4. Ratios of estimated doses to inadvertent intruders to dose limits for assumed exposure scenarios and different disposal units in SWSA 6 at ORNL

Disposal units	Nuclide	Dose/Dose limit[a]		
		Agriculture	Discovery	Post-drilling
Tumulus I and II	Sr-90	0.01		0.23
	Tc-99	0.01		
	Cs-137	0.10	0.01	0.03
	Ra-226	0.03		
	Th-232	0.01		
	Pu-239	0.01		
	Am-241	0.01		
	Sum	0.18	0.01	0.26
Low-Level Silos	Sr-90			0.11
	Cs-137	0.01		0.01
	Th-232	0.02		
	Am-243	0.01		
	Sum	0.04		0.12
High-Level Silos	Sr-90	0.04		1.9
	Cs-137	0.23	0.02	0.10
	Th-232	0.01		
	Sum	0.28	0.02	2.0
High-Level Wells	Sr-90	13		2200
	Tc-99	1.6		0.65
	Cs-137	69	6.1	100
	Eu-152	0.02	0.71	4.1
	Eu-154		0.03	0.16
	Th-229	0.26	0.03	
	Th-232	0.01		
	Sum	84	6.9	2300
Fissile Wells	Cs-137	200	18	88
	U-235	0.77		0.01
	U-238	0.93		0.03
	Sum	200	18	88
Asbestos Wells	Sr-90			0.01
	Sum	<0.01		0.01
Biological Trenches	Sum	<0.01		

[a]Dose limit is 0.1 rem per year for agriculture and post-drilling scenarios and 0.5 rem for discovery scenario.

Integration and Interpretation of Results from Performance Assessments of Low-Level Radioactive Waste Disposal Facilities[a]

D. W. Lee
D. C. Kocher
J. M. Bownds
Applied Physical Sciences
Oak Ridge National Laboratory
Oak Ridge, TN 37831-6185

INTRODUCTION

DOE Order 5820.2A specifies that a site-specific radiological performance assessment is required to demonstrate compliance of LLW disposal facilities with the long-term performance objectives for protection of offsite individuals, inadvertent intruders, and groundwater resources. Performance assessments for low-level radioactive waste disposal facilities at each DOE disposal site are being prepared that include a thorough description of the wastes intended for disposal, the facility and surrounding natural environment, the methodology used in analyzing the long-term performance of the facility, and the results of the analysis. The analysis necessarily includes the use of models to evaluate the performance of the facility and site, as well as scenarios for future human activities that need to be integrated into a meaningful analysis. Sufficient data typically are not available to provide a complete understanding of the site-specific behavior of the disposal system and the surrounding environment. Consequently, the results have to be interpreted with respect to the uncertainties and assumptions included in the analysis.

This paper reviews efforts toward integrating and interpreting the results of the preliminary performance assessments prepared for DOE sites to demonstrate compliance with the performance objectives contained in DOE Order 5820.2A. The review illustrates the nature of uncertainties associated with performance assessments and identifies several issues being addressed. A method for providing quantitative estimates of the uncertainty in performance assessments is presented, which is useful in identifying areas of the performance assessment that would most benefit from additional investigation.

REVIEW OF EXISTING PERFORMANCE ASSESSMENTS

Preliminary performance assessments have been prepared for low-level radioactive waste disposal facilities at the Hanford Reservation, the Nevada Test Site (NTS), Idaho National Engineering Laboratory (INEL), Los Alamos National Laboratory (LANL), Oak Ridge National Laboratory (ORNL), and Savannah River Site (SRS). Each of these performance assessments includes an integration and interpretation of results as part of the performance assessment, although to varying degrees. The final performance assessments are anticipated to have an expanded emphasis on the integration and interpretation of results. The approach used for each of the preliminary performance assessments is discussed in the following sections.

Hanford Reservation. The Hanford performance assessment has been prepared for the disposal of low-level radioactive liquid wastes as grout material in belowgrade vaults. The facility includes elaborate engineered enhancements that are intended to minimize the release of contaminants from the facility. In the performance assessment, the results are compared with performance goals, the sensitivity of the results to selected parameters is presented, and significant areas of uncertainty are identified along with suggestions for improving the performance assessment. The revision of the performance assessment will include additional

---

a. The submitted manuscript has been authored by a contractor of the U.S. Government under contract No. DE-AC05-84OR21400. Accordingly, the U.S. Government retains a nonexclusive, royalty-free license to publish or reproduce the published form of this contribution, or allow others to do so, for U.S. Government purposes.

material describing how each component contributes to overall performance and the effect of concrete degradation, uncertainties, and conservatisms on the overall analysis of facility performance.

Nevada Test Site. The NTS performance assessment has been prepared for the disposal of contact-handled, low specific-activity wastes in shallow trenches and pits and for the disposal of high specific-activity wastes in boreholes. Wastes are disposed of in metal drums, plywood boxes, bulk form, and nonstandard containers. The performance assessment makes use of an integrated computer code to calculate the transport of radionuclides and a second computer code to calculate the transport of airborne contaminants to offsite locations. The calculated results are compared with the performance objectives in DOE Order 5820.2A to support the conclusion that the facility is in compliance. The revision of the performance assessment is anticipated to include additional material describing the uncertainties and conservatisms in the analysis and the impact they have on the overall evaluation of the performance of the facility.

Idaho National Engineering Laboratory. The INEL performance assessment has been prepared for the disposal of containerized low-level waste in shallow trenches and soil pits. The performance assessment makes use of an integrated computer code to calculate the transfer of contamination from the wastes to the environment. Additional computer codes were used to estimate the transport of contamination through air and water. The exposures resulting from waste disposal were calculated using another computer code. The uncertainty and sensitivity of the models were examined, and the results were evaluated against the performance objectives of DOE Order 5820.2A. The revision of the performance assessment is anticipated to include additional material to interpret the results, including the effect of uncertainties on the results of the performance assessment.

Los Alamos National Laboratory. The LANL performance assessment has been prepared for the disposal of low-level wastes in pits and shafts. The preliminary performance assessment used several computer codes to investigate the various pathways for the transport of contamination through the environment. The uncertainty and sensitivity of the models had not been addressed at the time the preliminary analysis was prepared. Subsequent integration and interpretation of results are anticipated before preparation of the revised performance assessment.

Oak Ridge National Laboratory. The ORNL performance assessment has been prepared for the disposal of low-level wastes in shallow trenches, wells, silos, and tumuli. The preliminary performance assessment made use of a series of computer codes that were linked to analyze facility performance. The results of the codes were integrated to provide an evaluation of facility compliance with DOE Order 5820.2A. Uncertainty and sensitivity of the models were examined, and the results were interpreted to provide an overall evaluation of facility performance. Additional efforts to improve the analysis of uncertainty and sensitivity along with an expanded interpretation of results are expected in the revised performance assessment.

Savannah River Site. The SRS performance assessment has been prepared for the disposal of liquid low-level wastes as grouted materials in abovegrade engineered monoliths. The facility includes engineered features to minimize the release of contamination to the environment. The performance assessment makes use of several models that are linked to represent the generation and transport of contamination from the grouted waste to the point of exposure. The interpretation of the results and the evaluation of the uncertainties and conservatisms in the results were incomplete in the preliminary performance assessment. The revised performance assessment is expected to address these concerns.

INTEGRATING RESULTS

Each of the performance assessment efforts to date has recognized the need for integrating the results of the analysis. However, the approaches have varied and revisions are anticipated for each facility assessment. Conceptually, the integration of results simply requires that the various components of the analysis be combined to present a unified result. While this seems elementary, the site-specific nature of performance assessment has made the elementary concept challenging to execute. The variety of model components associated with the analysis of a facility, each component having a different level of rigor, makes the task of integration of results challenging. Difficulties arise from the transfer of output from one model to the input

of the next model. Larger difficulties arise when the output from one model needs to be analyzed to provide input for the next model. In some instances, results from one model have to be supplemented with assumptions before executing the next step in the analysis. As a consequence, performance assessments have included diverse results that are difficult to understand in the context of an overall evaluation of facility performance. A single, fully integrated model has not been utilized in the performance assessments prepared to date because of the site-specific issues that are important to consider in assessing the overall performance of the facilities. In addition, performance assessments naturally lend themselves to a modular approach with different submodels for the various components of the evaluation selected based on the available data.

A conventional analysis would have the assumptions incorporated into the analysis stated at the beginning along with the data identified that are to be used in the analysis. Using the data and the assumptions, a model is defined, the calculations are performed, and the results are reported. With the interdisciplinary teams necessary for preparing a performance assessment, and the variety of models used in an assessment, an a priori listing of assumptions and the data used in model formulation is not reasonable. Results from any one model may be needed as input for several other models or used in conjunction with other model outputs to formulate conclusions. With the use of several models (five were used in the ORNL performance assessment), the integration of results becomes cumbersome.

Issues to be considered in the integration of results that have arisen to date include the linkage of models and their results; consistency between models; appropriateness of the models; and the critical assumptions, data, and model components applied to the analysis. Each of these issues varied in importance in the performance assessments for the different sites. An understanding of the linkage between separate models is elementary to appreciating the relationship between the various components of the facility design and the surrounding environment. While the physical relationship is simple to explain, the passing of data and results from one model to another puts a burden on the preparers. In one case, the definition and units of retardation for determining the generation of leachate differed from the definition and units used for evaluating radionuclide retardation in environmental transport. Likewise, the conversion of radionuclide contamination from mass to activity can become complicated by the process of decay. Some models may account for the decay of radionuclides as part of the calculation procedure, but other models do not account for decay internally and the decay process must be accounted for external to the model calculation. Failure to address the linkage of models and the features they incorporate can produce results that are incorrect.

Consistency between models is another major difficulty. Since the time period over which an analysis is performed extends into the indefinite future, consideration of time-varying processes that have short time scales can become difficult. As an example, runoff processes typically are considered in terms of hours, evapotranspiration in days or seasons, and groundwater transport in months or years. Simple averages for the longest interval of time tend to artificially dampen responses. A simple example of this issue is the appearance of a flood. The flood occurs over a period of hours but can affect a facility's performance for years. Averaging the flood discharge over a period of years will remove the process that causes the impact.

Ensuring the appropriateness of models is central to preparing a site-specific analysis. A serious concern in preparing performance assessments is the selection of models that represent the processes that are present at the facility and that can be supported with the available site data. Failure to address this concern can result in an elegant model study that is not applicable to the facility being considered, which generates results that have nothing to do with the modeled facility. Available data from the site remain the best measure for selecting models. Models that require inputs that vastly exceed the available data pose the danger of introducing processes that cannot be defended as being present at the facility. In a performance assessment, some components of a facility may be capable of being modeled more rigorously than others. Only through the integration of results can a reasoned conclusion be formed as to the value of a rigorous analysis for one part of the disposal system when the next model component can only be addressed in an approximate manner. Overall, the models used for the performance assessment can provide meaningful estimates only to the extent that the weakest model can provide meaningful estimates.

Finally, an evaluation of critical assumptions, data, and model components is necessary for integrating results. As a simple illustration, a minor assumption in evaluating leachate generation from a waste form that

is saturated can turn into a major assumption in an evaluation of a facility where insufficient percolating water is available to maintain saturated conditions. The failure to recognize the apparently minor assumption as critical can result in extraordinarily high release rates. Similarly, assuming that concrete has a permeability that is consistent with laboratory data where cracks were not present can lead to extraordinarily low rates of contaminant release from a material that naturally cracks and degrades. Integration of results requires an identification of those assumptions and data related to individual model components that have a significant effect on the overall performance of the facility. Without care in integrating results, performance assessments could end up depending on the acceptability of a single assumption or data point.

Site-specific performance assessments will by nature pose a perpetual challenge in integrating results, so long as our understanding of the long-term performance of waste disposal systems remains incomplete. Since our understanding is likely to remain incomplete for hundreds of years, integrating results will remain difficult but essential for technically defensible performance assessments. Similarly, the means for integrating results at one facility will not necessarily be the same at other facilities because of differences in technologies and environments.

INTERPRETING RESULTS

The results from a well-integrated analysis of a facility provide an estimate of endpoints (i.e., doses to offsite individuals and inadvertent intruders, or contamination of groundwater) that are compared to the performance objectives contained in DOE Order 5820.2A. The difficulty that arises is the accuracy that should be attached to these calculated results. Several sites have considered the uncertainties and sensitivities of the model parameters associated with the analysis. All attempts thus far have underscored the lack of certainty to be attached to the results. This harsh reality, that we cannot accurately forecast hundreds of thousands of years into the future, is one of the compelling reasons for interpreting results. The other reason is derived from the purpose of the performance assessment. The performance assessment is intended to demonstrate compliance with the performance objectives, but the order is silent on the degree of assurance required to demonstrate compliance. The Performance Assessment Task Team has amended this charge to include the notion that compliance must be demonstrated with reasonable assurance. Since "reasonable assurance" is a legal term that refers to weight of evidence, simple reliance on the quantitative results of a model calculation may not be sufficient for demonstrating compliance. When coupled with the results of a sensitivity and uncertainty analysis, it may be difficult to conclude that a calculated model result is sufficient to demonstrate compliance. In addition, there are important aspects of uncertainty, such as the choice of an appropriate model, that may not be quantifiable but may rely on scientific judgment.

Interpretation of results suggests that the results need to be viewed against the original intent of understanding the site-specific performance of a waste disposal facility. A performance assessment necessarily makes assumptions regarding a broad range of physical processes and human behaviors that are considered to be reasonably conservative for long periods of time. A simple example is climate. All performance assessments that have been prepared to date have included a presumption that the climate will remain relatively consistent with historical records, even though our records are less than two hundred years old. While these trends might remain constant for the indefinite future, geologic evidence suggests that major shifts in climate have occurred and might occur again. To include all possibilities of future climates in the calculations of a performance assessment would tax the capabilities of any organization and provide no added insight. However, accepting that significant changes could occur means that the results of the calculations merit further consideration that include unforeseen changes over long periods of time. Naturally, this affects the accuracy of the results and introduces sources of subjective uncertainty.

Uncertainties in the data, conceptual models, and quantitative models tend to broaden the range of doses that are estimated from a performance assessment. Many of these uncertainties cannot be removed because of our lack of understanding. Examples include the degradation of concrete and the future waste inventory. In addition to the uncertainties related to the base of knowledge, there are uncertainties that arise from the use of conservative assumptions. The possibility of accumulating conservatisms to generate an unreasonable result is a concern that is carefully reviewed. In the preparation of a performance assessment, a frequent dilemma arises where a conservative assumption from one aspect of the analysis is not a conservative

assumption for another aspect of the analysis. Attempting to provide a reasoned balance between the many components of a performance assessment is an ongoing challenge in modeling that needs to be addressed as part of interpreting results. Two sources of uncertainty are implicit in all performance assessments. These are uncertainties that arise from the model parameters that are based on data or assumptions, and uncertainties that arise from the correctness of the model in describing the site-specific conditions. Both of these uncertainties are basic to the interpretation of results.

The challenge of interpreting results is to present the strengths and weaknesses of the calculations included in the performance assessment. A clear presentation of the strengths and weaknesses allows for the establishment of reasonable assurance that the results demonstrate compliance with the performance objectives. To assert that the results in a performance assessment are themselves accurate forecasts of the future is simply not reasonable. Naturally, quantifying precisely the uncertainty of results where definitive information is lacking is impossible. However, approximate methods can be used to estimate the uncertainty inherent in performance assessment using the limited knowledge that is available. This is discussed further in the next section.

UNCERTAINTY ANALYSIS IN PERFORMANCE ASSESSMENT

The body of literature on uncertainty analysis is rich, but its application to performance assessment is relatively new. An approach to evaluating uncertainty in performance assessment needs to account for the many sources of uncertainty that are difficult to quantify. Since, by definition, the uncertainty is not known, it must be approximated. The approximation should account for the modeling results, but, more importantly, it should also account for the major assumptions in the performance assessment.

The composite model of the facility used in the performance assessment converts a radionuclide inventory into an estimated dose. The determination of the computational variance of the result is conceptually straightforward and is a component of the overall uncertainty. The determination involves an analysis of how variances in model parameters are propagated to the computed results. This procedure is typically accomplished by Monte Carlo sampling, which is computationally intense. The results are statistical distributions for concentrations and dose, yielding a computed probability that a calculated result is less than a maximum allowable value. The probability that the calculated result is less than the maximum allowable value is not certain. Hence, no simple conclusion can be drawn that the calculated result is sufficiently low to be declared acceptable. Rather, the calculated result is sufficiently low with a computed probability, which is approximated from the Monte Carlo sampling. The approximation can, with confidence, only be known to satisfy a range of probabilities that are determined with statistical methods. Unless the range of probabilities is very small, the computed probability will not be determined very precisely. In addition, when other sources of uncertainty are considered, such as the assumptions in the analysis, the range of probabilities increases.

The likelihood that the calculated result is sufficiently low is given by the computed probability. For example, if the computed probability is nearly one, then the calculated result is likely to be less than the maximum allowable value. If the computed probability is nearly zero, then the calculated result is not likely to be less than the maximum allowable value. If the computed probability is nearly one-half, then a definitive statement can not be made concerning the calculated result and the maximum allowable value.

The calculated result from the application of the composite model will either be below the maximum allowable value or it will not. If the computed probability of the calculated result being sufficiently low is neither zero nor near one, then there is significant uncertainty in the calculated result. On the other hand, if the computed probability is near zero (the calculated result is not likely to be below the maximum allowable value) or near one (The calculated result is likely to be below the maximum allowable value), then there is little uncertainty associated with the calculated result. Hence, the uncertainty, while not being a probability itself, is tied directly to the computed probability. The uncertainty can be calculated from basic uncertainty results in probability theory and has a value between 0 and 1. A small value for the uncertainty means that the calculated result can be compared to the maximum allowable value with confidence. However, a large value for the uncertainty occurs when the computed probability is near one-half. This means that little credence can be given to the possibility that the calculated result is less than the maximum allowable value.

The probabilities and uncertainties determined from Monte Carlo sampling of the performance assessment model do not address the assumptions, both implicit and explicit, that are incorporated into performance assessment modeling. The composite model used for a performance assessment is predicated on the presumption that the model is an adequate representation of the facility and its performance. To complete the analysis of uncertainty, an estimate is needed of the uncertainty associated with the modeling. This is not a consequence of computations. Instead, it is based on the subjective judgment of the modeler regarding the acceptability of all the perceived points in the analysis where uncertainties could contribute.

One procedure used to make subjective estimates of uncertainty involves a review of recognized assumptions and methods used in the formulation of the conceptual model, the mathematical or physical model, the algorithms, the computer routines, and the presentation of results. Each component is reviewed and assigned a consensus weight from zero to one that is a measure of the acceptability of the model component. The weights are treated as probabilities and combined with the probabilities determined from the Monte Carlo results. The inclusion of these subjective estimates results in a smearing of the Monte Carlo results that leads to a wider range of probabilities for the computed probability that a projected result is less that the maximum allowable value. The uncertainty resulting from including subjective estimates is always higher than the original Monte Carlo results. This observation highlights that subjective scientific judgment will remain a crucial part of performance assessment, and the use of scientific judgment cannot be removed by using sophisticated quantitative methods. The evaluation of how high the uncertainty can be, yet still provide reasonable assurance that the performance objectives are complied with, is an important facet of the interpretation of results. By combining the uncertainties resulting from the Monte-Carlo results and the subjective estimates of the uncertainties incorporated into the composite model, a comprehensive estimate is provided of the uncertainty in the performance assessment.

DISCUSSION

Integration and interpretation of the results of performance assessments have proven to be a difficult challenge. Each site is endeavoring to improve the integration and interpretation of the results as the preliminary performance assessments are revised. While the concept of integration and interpretation of results is rather elementary, its application to several models that reach across a variety of disciplines is challenging. Simple solutions are not available and all solutions are likely to be as unique as the respective sites being considered. Incorporation of uncertainty analysis into the interpretation of results poses a special challenge, especially when the uncertainties associated with the choice of models and assumptions are considered.

Integration and interpretation of results are the means for establishing reasonable assurance that a disposal facility will be in compliance with the performance objectives of DOE Order 5820.2A. Integration of results ensures that the performance assessment is a unified presentation of the site-specific behavior of the facility over an extended time. Interpretation of results provides the vehicle for establishing justified conclusions that consider uncertainties. In the process of integrating and interpreting results, weaknesses are identified in the performance assessment to be addressed in future revisions. While integration and interpretation of results will remain a challenge for the preparers of performance assessments, the need remains essential if performance assessments are to serve as meaningful representations of the site-specific behavior of low-level radioactive waste disposal facilities. Performance assessments that are prepared with a comprehensive effort toward integrating and interpreting results are unquestionably the best means for providing confidence that radioactive waste disposal will protect public health and the environment.

TECHNICAL TRACK

Strategy for Upgrade of ORNL Treatment Facilities to Minimize Secondary Waste Generation

S. M. Robinson
S. M. DePaoli
T. E. Kent

Chemical Technology Division
Oak Ridge National Laboratory[a]
Oak Ridge, TN 37831

INTRODUCTION

Oak Ridge National Laboratory (ORNL) has implemented an aggressive waste minimization program that has resulted in significant reductions in many types of wastes in recent years. This program encompasses both near-term and long-term aspects of waste reduction for all types of wastes at the generation source as well as the waste handling and treatment facilities. This paper focuses primarily on the methodology used to incorporate waste minimization into the long-term waste management strategies for radioactive liquid waste generated at ORNL.

ORNL has taken a systems analysis approach to define and prioritize upgrade projects for their liquid waste treatment systems with the objective of minimizing the amount and specific types of secondary waste generated for disposal. Researchers are using the results of the systems analysis to guide development of improved waste treatment processes for use in the design of future wastewater treatment plants at ORNL. Projections indicate that this approach could reduce the secondary waste generation rates for ORNL liquid treatment systems by more than 50% over the next decade.

This paper describes the methodology that is being used to identify areas for upgrades and determine whether source treatment, pretreatment, or centralized treatment should be implemented. The research that is under way to support these new treatment approaches will also be discussed.

BACKGROUND

ORNL uses two systems for handling and processing liquids that contain radioactive constituents — the Liquid Low-Level Radioactive Waste (LLLW) System and the Process Waste System (PWS) — as shown in Figure 1. The LLLW System is an assemblage of 42 tanks, miles of associated transfer pipelines, and ancillary equipment (e.g., pumps and evaporators) designed for collecting, neutralizing, concentrating, and storing wastes before disposal. The bulk of the LLLW tanks and transfer lines are buried underground for purposes of radiation shielding. The LLLW System handles waste solutions with significant amounts of radioactivity including waste streams originating from hot sinks and drains in research and development (R&D) facilities and from other facilities such as the transuranium element production plants, nuclear reactors, and concentrated wastes from the Process Waste Treatment Plant (PWTP).

Figure 2 shows a schematic of the LLLW system. In most cases, LLLW generated by various activities at the Laboratory is discharged by way of "hot" drains located in laboratory sinks, hoods, floors, and hot cells. However, in a few instances liquid waste is collected and trucked to the LLLW System. Waste that is collected in "hot" drains flows by gravity through singly or doubly contained pipes to underground, stainless steel collection tanks where the waste is neutralized if necessary. The waste accumulated in the collection tanks is transferred via underground piping to evaporator units that reduce the volume of LLLW by a factor of ~20.

---

a. Managed by Martin Marietta Energy Systems, Inc., for the U.S. Department of Energy under contract DE-AC05-84OR21400.

From there the concentrated waste is transferred to one of several storage tanks awaiting treatment for disposal as solid waste.

The LLLW System was designed to handle waste solutions with an activity of 20 Ci/gal and has historically been used to collect, treat, and store all liquid waste containing significant quantities of radioactivity, including LLW radioactive waste and transuranic (TRU) waste. Present waste acceptance criteria limit radiological inputs to 2 Ci/gal of ^{90}Sr equivalent and <100 nCi/g of alpha-emitting transuranic elements. Generator surveys indicate that newly generated waste solutions do not contain significant quantities of hazardous chemicals. However, both past and current waste treatment and storage practices (e.g., waste neutralization and evaporation) have produced LLLW concentrates containing concentrations of hazardous chemicals high enough to be subject to Resource Conservation and Recovery Act (RCRA) regulations (i.e., for mixed radioactive and hazardous chemical wastes). The LLLW System, which uses an evaporation system for volume reduction, processed 540,000 gal of waste and produced 22,000 gal of concentrate in fiscal year 1991. The evaporator overheads are discharged to the PWS, and the concentrates have been placed in storage since 1984 when disposal by hydrofracture, a deep-well injection process, was discontinued. The concentrates segregate into 4M $NaNO_3$ liquids and transuranic sludges.

The PWS handles aqueous waste containing trace amounts of radioactivity, heavy metals, and organics or waste that has the potential to be contaminated with these constituents. The process waste solutions generated by various program activities throughout ORNL are collected into central holding tanks and are processed through the PWTP, which uses softening and ion exchange to remove radionuclides. The PWTP throughput is ~70,000,000 gal/year. The ion-exchange regenerant solution is discharged to the LLLW System, and softening sludges are disposed of as solid LLW. In April 1990, the Nonradiological Wastewater Treatment Plant (NRWTP) began polishing the PWTP effluent and nonradiological process waste streams before release to a surface stream through a National Pollutant Discharge Elimination System (NPDES) monitoring station. The NRWTP uses chemical precipitation, air stripping, and carbon adsorption to remove heavy metals and organics. The NRWTP throughput was ~140,000,000 gal/year in 1991.

The PWTP is being upgraded because of a number of operating and regulatory driving forces. The 20-year-old plant is reaching its life expectancy. It needs to be replaced to increase treatment capacity and provide improved treatment processes to (a) meet stricter discharge requirements, (b) accommodate new waste streams, and (c) minimize secondary waste generation.

Major upgrades are planned for the ORNL LLLW System to meet a number of requirements. The storage capacity for concentrated LLLW is very limited. Although additional storage tanks will be added in the new future, ORNL would like to reduce the waste generation rate and segregate waste entering the new tanks to make future waste treatment easier. EPA regulations and DOE orders are drivers for treatment and disposal of the stored LLLW concentrates containing TRU and RCRA components resulting from evaporation. The recent Federal Facilities Agreement for ORNL requires that essentially all the waste collection and transfer systems be replaced to meet new containment and leak-detection standards.

A comprehensive strategic plan was needed to define and implement upgrades to the ORNL liquid waste treatment system to meet multiple objectives. A systems analysis approach is being used to develop the strategy for system upgrades.

LLLW SYSTEMS ANALYSIS

Although data are routinely collected on the LLLW operations, the information was not organized in a central location and in formats needed for engineering analysis. Therefore, in 1989 an effort was undertaken to (a) collect and tabulate data concerning the LLLW System, (b) analyze the current LLLW System operation, and (c) develop the information necessary for the development of long-term treatment options for the LLLW generated at ORNL. The systems analysis approach is summarized in Figure 3.

The data for the systems analysis were collected through a survey of ORNL documents, such as strategic planning reports, plant operating records, analytical data, and a survey of all current LLLW generators. The

detailed data were compiled in several data bases using dBase III Plus software. Menu-driven programs were written to access and evaluate the data in such a way that it is not necessary for the user to own a copy or be familiar with dBase III. The data base allows the quick retrieval of all information collected on the ORNL LLLW System and greatly benefits LLLW analysis efforts.

Information contained in the data base includes: (a) LLLW generator information, (b) LLLW collection tank volume data, (c) evaporator operating data, (d) LLLW concentrate volume, and (e) characterization data. The data base presently includes all data available on the LLLW System for the 1986 to 1992 operating period. The data base is routinely updated using annual generator surveys and monthly operating data.

Data analyses have been used to (a) determine where systems operations could be improved, (b) project future waste generation rates, and (c) determine the major generators that affect the composition and volume of the LLLW concentrate being stored for disposal. This information feeds into strategic planning efforts for long-term upgrade of the LLLW system. The systems analysis results are summarized below.

Several facilities at ORNL contribute to the generation of LLLW. The radioactive liquid waste generated at ORNL can be categorized into several waste types: (a) liquid wastes that are a result of air and water treatment facility operations, (b) wastes that result from decontamination of hot cells, reactor operations, radioisotope production, R&D projects, and (c) rainwater/groundwater infiltration. Of these types of LLLW, air and water treatment facility operations have accounted for ~ 20% of the dilute LLLW generated in 1989 and 1990. Decontamination, radioisotope production, reactor operations, and R&D activities have generated ~40% of the waste, and rainwater/groundwater infiltration accounts for the remaining 40% of the dilute LLLW generation in the past 2 years. The LLLW generation rates for the last 3 years are summarized in Table 1.

The leakage of rainfall into the LLLW System has been qualitatively recognized for some time as a major contributor to the quantity of waste requiring processing by the LLLW evaporator. However, a quantitative estimate of the effects of rainfall on the volume of LLLW collected at ORNL was not determined until 1989. A time series analysis identified LLLW collected in 9 of 98 (active and inactive) tanks to be significantly influenced by rainfall. Approximately 1500 gal of LLLW are collected for each inch of rainfall.

Generator data were modeled to predict LLLW concentrate generation rates. Table 2 indicates that the model is accurate. The impact of individual generators on LLLW concentrate is shown in Table 3 and summarized below.

The systems analysis data indicate that only 5 of 42 sources significantly affect the volume and composition of LLLW concentrate. Those sources are the PWTP, the Radiochemical Engineering Development Center (REDC), the High Flux Isotope Reactor (HFIR), the Oak Ridge Research and Bulk Shielding Reactors (ORR/BSR), and the High-Radiation-Level Examination Laboratory (HRLEL, Building 3525). The REDC is the major source of radionuclides entering the LLLW system. The only other sources that currently produce waste containing more than 5 Ci/year are the HFIR, Building 3525, and Building 4501 in the 4500 area R&D complex. The majority of the TRU isotopes and mixed fission products (Cs, Ru, Ce, Eu) enter the system in the REDC waste stream. Buildings 3525 and 4501 produce Cs-137, and the HFIR stream is the primary source of the Co-60. PWTP and REDC are the primary contributors of dissolved solids to the LLLW. These results are of particular importance because the dissolved solids in each waste stream primarily determine the amount of resulting concentrate.

The results of these waste characterization and systems analysis studies are being used to (a) identify areas for waste minimization and source treatment, (b) aid in the developmental studies required to implement these activities, and (c) define the system requirements for a new facility to treat LLLW concentrates for disposal. Evaluations of future waste generation estimates have been undertaken to assess the long-term LLLW treatment needs and to determine where waste minimization emphasis should be placed.

WASTE MINIMIZATION PLAN

Table 2 indicates that waste minimization efforts have significantly reduced LLLW concentrate generation from 1987 to 1990. A significant increase in waste generation occurred in 1991 due to (1) decontamination of inactive facilities, and (2) technical problems at two of the larger generating facilities resulted in increased waste generation rates. Waste minimization projects and/or treatment at the source are being considered for the major generators of LLLW to reduce LLLW concentrate production. Generators producing wastes high in dissolved solids in proportion to their relatively small amounts of radioactivity (PWTP, HFIR, and ORR/BSR) are good candidates for source treatment (i.e., conversion to solid waste). Waste streams with components that are difficult to treat in the centralized facilities (potassium, cobalt, and TRU waste) are also considered candidates for treatment at the source (HFIR and REDC). R&D efforts have been initiated to identify operational changes and develop recycle, pretreatment, and/or treatment systems that can be implemented at the source of generation for all major generators listed in Table 3. Projects have also been identified to implement each of these upgrades.

Process modifications to the REDC off-gas scrubber were made recently as a result of studies identified by the systems analysis. They are expected to reduce the annual ORNL LLLW concentrate generation rate by 20-25%. Other upgrades will require capital projects whthatake 4 to 10 years to implement (see Table 4). If successful, these projects have the potential to reduce the LLLW concentrate generation at ORNL by 60% and to segregate TRU and highly contaminated waste streams from the bulk of the waste produced. Design of systems to treat the remaining LLLW for discharge to a new PWTP and to produce solid waste for on-site storage/disposal are also being developed. This will result in minimizing the volume of solid waste generated as a result of LLLW processing.

Development studies for replacement of the PWTP indicate that replacing existing organic ion-exchange resins with inorganic zeolite will significantly reduce LLLW and solid waste generation at ORNL. Estimated secondary waste generation rates for this process would be approximately 50% of that produced by the existing PWTP flow sheet. The flow sheet completely eliminates LLLW generation by the PWTP (4000 gal/year) and reduces the solid waste generation rate from 4700 to 3000 ft^3/year by 2001.

HFIR is an operating research reactor. At the HFIR facility, mixed bed ion-exchange columns will be installed to pretreat LLLW generated by R&D activities for discharge to the PWTP. The organic resins from the wastewater treatment operation will be combined with loaded resins from the reactor pool demineralizer system w,hich will be disposed of as solid waste. This will segregate Co-60 from the LLLW system and reduce the solid waste compared to solidifying LLLW in the centralized treatment system.

The ORR and BSR are shut down reactors but the pool demineralization must continue to reduce corrosion. A project is in place to divert the demineralizer ion-exchange feed to the PWTP for treatment. Fresh demineralized water will be added to the reactor pool, and the ion-exchange columns will be removed from service. Since demineralized water does not generate secondary waste at the PWTP, this project will eliminate an LLLW stream without increasing solid waste generation rates.

SUMMARY

A systems approach has been taken to solve complex liquid waste management problems at ORNL that will incur major cost and span multiple years for implementation. The systems analysis is being used to aid in strategy development, resource allocation, operational improvements, and in guiding what R&D is required. The systems analysis of the ORNL LLLW System indicated that only 5 of 42 sources significantly affect the volume and composition of the waste that will be processed for disposal. Implementation of waste minimization projects at these 5 sites is expected to reduce LLLW concentrate generation rates by over 50% over the next 10 years. The systems analysis has also been useful in defining where pretreatment or source treatment, as opposed to centralized treatment, would be most effective for use in design of new wastewater treatment facilities.

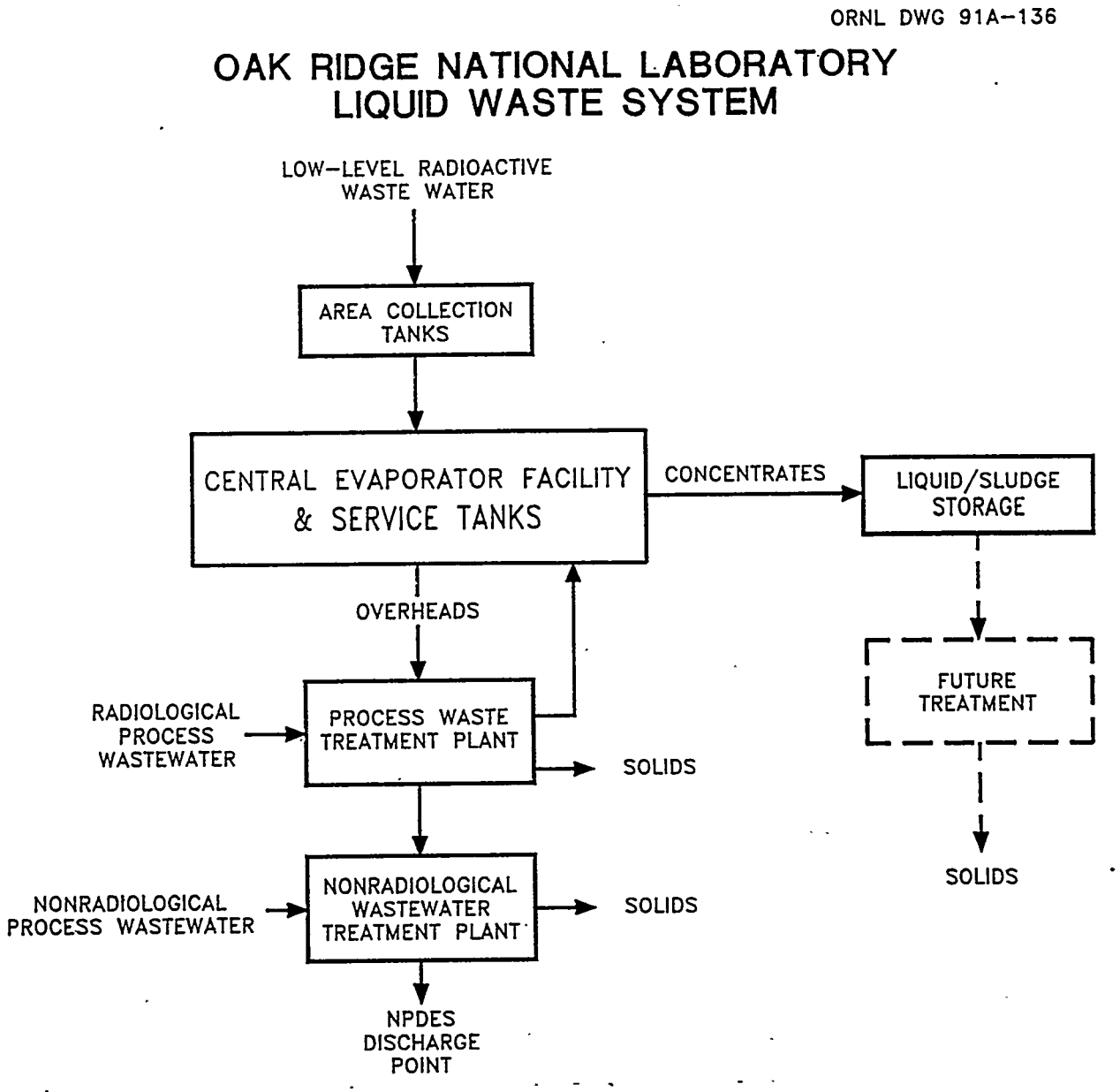


Figure 1. Schematic of the Oak Ridge National Laboratory Liquid Radioactive Waste System.

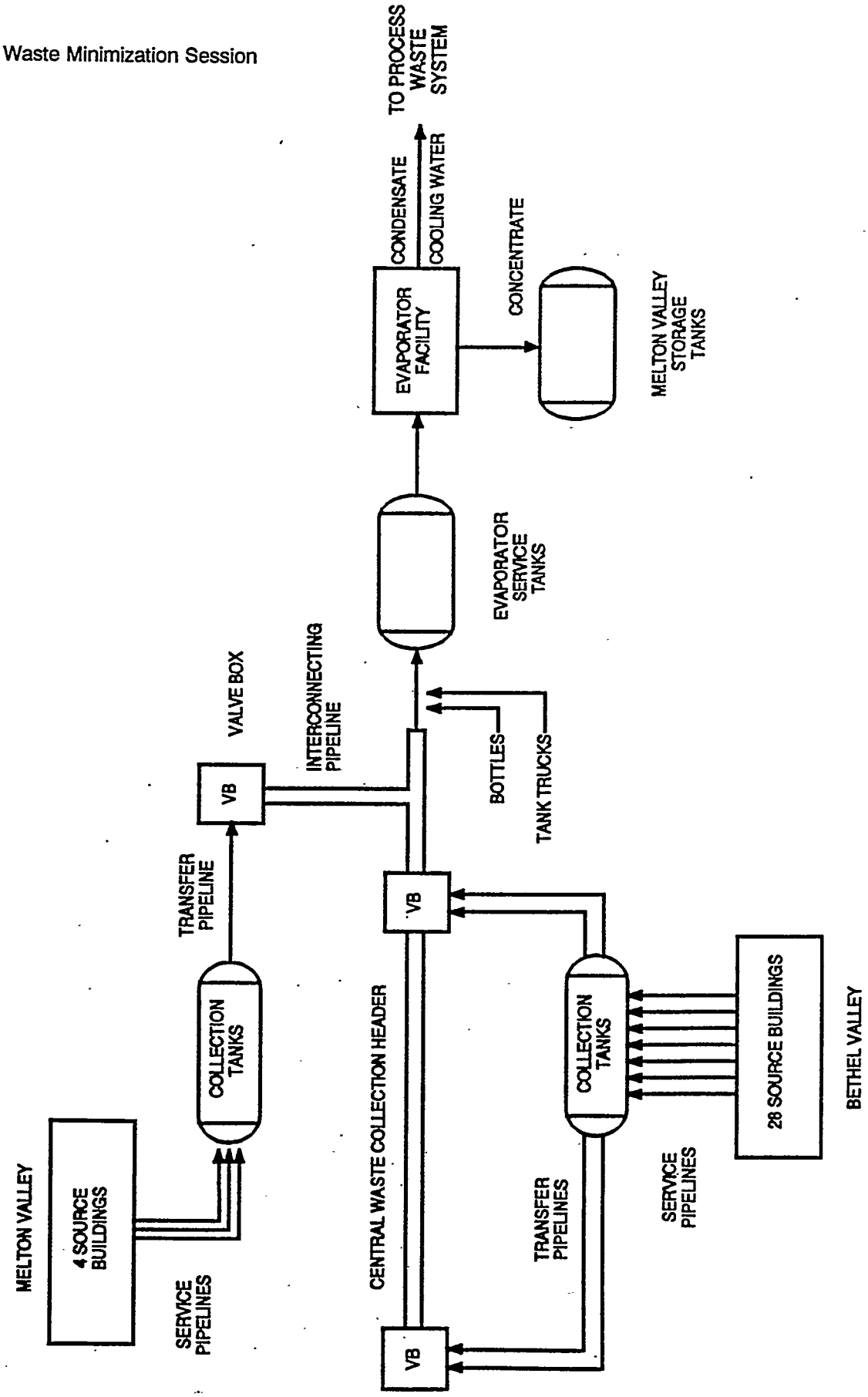


Figure 2. Schematic of the Existing LLLW Collection, Transfer, and Treatment System.

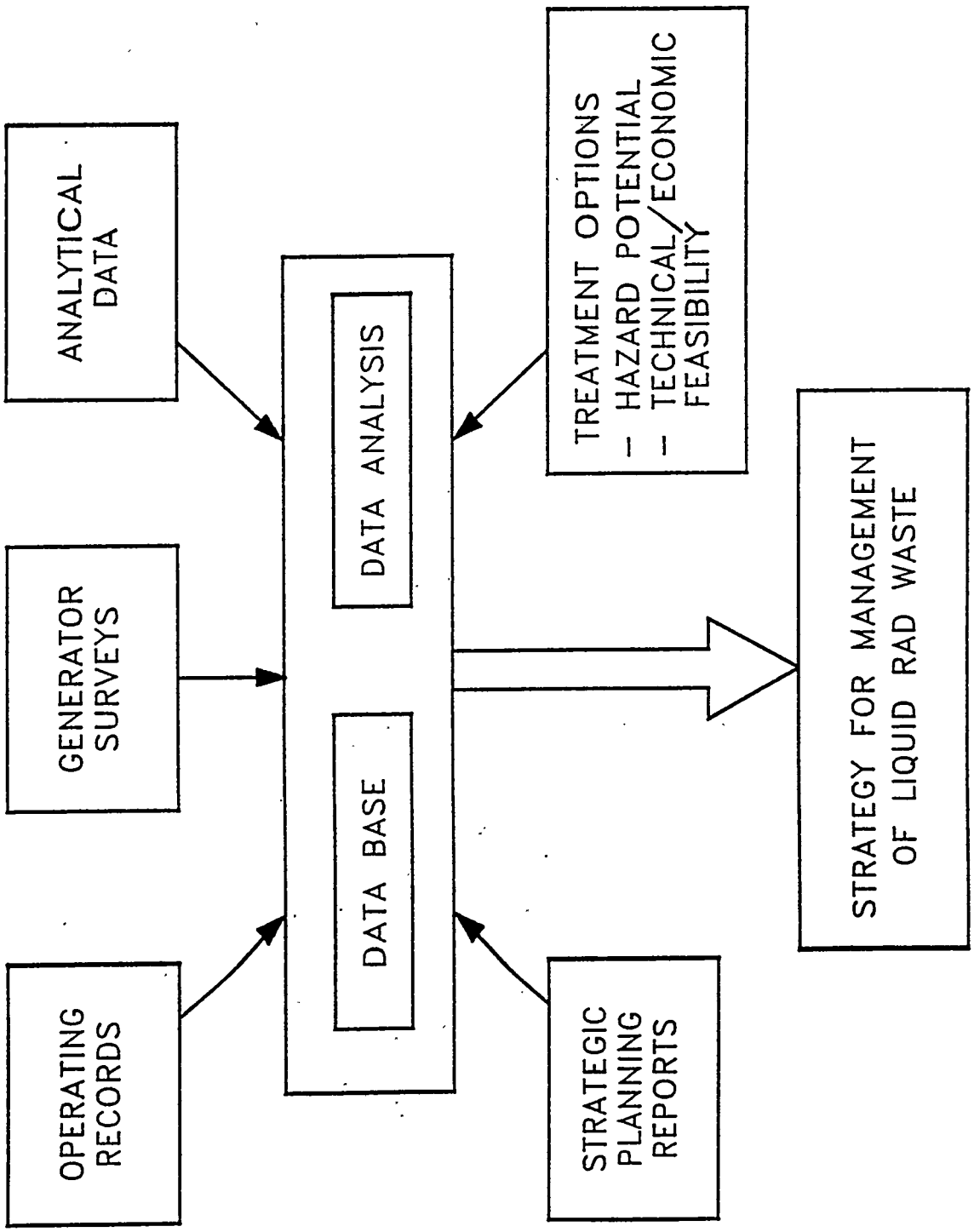


Figure 3. Systems Analysis Approach for the Oak Ridge National Laboratory LLLW System.

Table 1. Average monthly dilute liquid low-level waste generation.

Generator	Monthly generation (gal)			Percent of total		
	1989	1990	1991	1989	1990	1991
Isotopes production facilities[b]	4,068	3,273	2,083	15	12	6
Off-gas scrubber	3,698	3,522	3,501	13	13	10
Fission Products Development Laboratory[b]	1,324	979	1,981	12	4	6
High Flux Isotope Reactor	3,086	6,169	10,449	12	23	31
High-Radiation-Level Examination Laboratory	1,899	1,725	1,277	10	6	4
Radiochemical Engineering Development Center	992	1,066	1,429	7	4	4
4500 General Laboratory complex[b]	1,278	756	1,924	7	3	6
Bethel Valley Reactors[c,b]	2,390	2,433	1,646	6	9	4
Tank W1-A[d,b]	4,067	3,884	3,235	5	14	10
Radiochemical Proc. Pilot Plant	76	95	84	3	1	<1
Process Waste Treatment Plant[e]	521	311	617	3	1	2
Tank WC-8 pump pit[b]	1,366	1,185	358	2	4	1
All others[b]	1,359	1,484	5,008	5	6	16
Total	26,124	26,882	33,591	100	100	100

a. Isotopes include all collections from Isotopes Area collection tank, and Building 3026-C collection tank.

b. Tanks collect waste from nongenerator sources, such as rainwater from vault sumps, filter pit sumps, building floor drains, etc.

c. Reactors included are the Oak Ridge Research Reactor and the Bulk Shielding Reactor.

d. Tank W1-A is inactive.

e. The PWTP also produces a highly concentrated waste stream which is sent directly to storage.

Table 2. Predictions of LLLW concentrate generation rates using systems analysis approach.

Year	Actual (gal/year)	Predicted[a] (gal/year)
1987	37,000	
1988	24,000	
1989	13,000	13,100
1990	12,600	12,500
1991	22,500	17,500

a. Based on generator estimates of dilute waste volume and composition.

Table 3. Major sources of concentrated liquid low-level waste (LLLWC).

Tank and/or source building	1989 LLLW concentrate generation rate (gal/year)	1990 LLLW concentrate generation rate (gal/year)	1991 LLLW concentrate generation rate (gal/year)	1989 contribution (%)	1990 contribution (%)	1991 contribution (%)
Radiochemical Engineering Development Center	4,700	4,300	5,700	30	38	32
Process Waste Treatment Plant	5,950	4,300	7,300	46	38	31
High Flux Isotope Reactor	250[b]	1,200[a]	2,600[a]	2	10	15
High-Radiation-Level Examination Lab	650	750	500	5	6	3
Oak Ridge Research Reactor, Bulk Shielding Reactor	550	500	500	4	4	3
Isotopes Production Facilities	1,000[a]	200[b]	240[b]	7	<1	1
Others	700	750	660	6	4	4
Total	13,100	12,000	17,500			

a. Estimate based on information obtained during operation.

b. Estimate based on information obtained during shutdown.

Table 4. Planned waste minimization projects for major LLLW generators.

Source	Project	Implementation Date
REDC	Operational changes to reduce LLLW volume	1992
	Pretreatment to remove potassium, TRU, and RCRA Land Disposal Restriction constituents	1997
ORR/BSR	Diversion to process waste system	1994
HFIR	Source treatment by organic ion exchange	1997
PWTP	Source treatment by inorganic ion exchange	2001

Pollution Prevention Program for New Projects—Lessons Learned

John Lum
U.S. Department of Energy

PURPOSE

The purpose of this presentation is to relay the experience of the Office of New Production Reactors (NP) in developing and implementing its pollution prevention program.

BACKGROUND

NP was established to plan, design, and construct a new safe and environmentally acceptable nuclear reactor capacity necessary to provide an assured supply of tritium to maintain the nation's long-term deterrent capability. The Program offered the Department of Energy an opportunity to demonstrate its commitment to environmental protection via minimization of environmental releases; new design offers the best opportunity for pollution prevention. The NP pollution prevention program was never fully implemented because NP's tritium production design activity was recently terminated. The information in this paper represented lessons learned from the last three years of NP operation.

CHALLENGES FOR NEW DESIGNS

With the goal of minimizing all environmental releases to as low as reasonably achievable levels, NP established a comprehensive pollution prevention program. NP's pollution prevention program contained the same basic elements as those for existing facilities; the difference was in implementation. The areas that posed the greatest challenge and opportunity included management commitment, establishment of requirements in the very early stage of program, development of comprehensible goals and guidance, culture development, strong oversight and technical interfaces, and integration of pollution prevention with other activities. These challenges and examples of successes are summarized below.

Management Commitment

Management commitment is necessary for success. In the case of NP, top management knew the importance of a rigorous pollution prevention program while middle management support was more sporadic. Like most major projects, the NP program was both resource and schedule constrained; pollution prevention was always competing with other needs. Unless top and middle management is convinced that pollution prevention saves money and facilitates permitting, developing a rigorous pollution prevention program will be an uphill battle. A recent assessment of the NP program indicated that most of the middle management personnel are aware of the benefits of pollution prevention and requested specific budget for its implementation.

Establishment of Requirements

Some design organizations viewed pollution prevention as an environmental requirement and one that should be considered after preliminary design is completed. Unless design requirements documents include consideration of source reduction and recycle/reuse, design organizations will not rigorously implement pollution prevention. NP's trail of pollution prevention requirements included the following: (a) issuance of a pollution prevention/waste minimization policy statement; (b) issuance of environmental requirements document that specifically requires pollution prevention for all NP activities; (c) inclusion of pollution prevention requirements in all technical design requirements documents; and (d) development of the Environmental Compliance Plan that defines NP's pollution prevention program and its relationship with other environmental programs.

Comprehensible Guidance and Direction

Since design and operating engineers are the most qualified people to define source reduction opportunities, the benefits, goals, and processes of pollution prevention assessment must be presented in a form that they understand. Although engineers understand the importance of good public relations and expedited permitting, quantitative factors must be defined to guide their effort. Cost and quantitative reduction goals are examples of these factors. NP developed life cycle costs for pollution prevention assessments that include all the current and future costs of handling and managing waste. NP was developing quantitative reduction goals. While the visionary goal was to eliminate all environmental releases, some engineers found it difficult to accept since it is technically impossible to achieve. Design engineers wanted quantitative reduction goals upon which their performance can be measured. Reduction goals under consideration before termination of the project ranged from 99+% for mixed waste to 50% for municipal waste. The NP process of conducting pollution prevention assessments was not unique. Instead of optimization for cost and performance, the same engineering approach was used to reduce waste generation.

Culture

Some design engineers/project managers had a difficult time accepting process changes for purposes of reducing waste. In many instances, pollution prevention responsibility was assigned to the environmental groups of the DOE and design contractor organizations. The engineering design group(s) must be assigned lead pollution prevention responsibility for their portion of the design if it is to succeed. In addition, the design contractors' award fee must be based in part on their performance in reducing waste. While NP had not fully implemented this concept, the engineering organizations began to seriously considered process modification for purpose of reducing waste. In part, the high life cycle cost of waste management was the reason for this acceptance. Other aspects of culture development such as incentive programs were still being developed when the program terminated.

Technical Interface and Oversight

Technology transfer must be encouraged. While the design contractors have experience in the design of production facilities, their experience in process alternatives to reduce waste in the production and support facilities was not certain. Design engineers do not actively seek outside expertise on a routine basis for pollution prevention. Technology transfer must be encouraged in order to fully define pollution prevention opportunities. NP had some success in this area. It is important that the design staff be aware of environmental requirements; equally important, the environmental oversight personnel must be familiar with design activities and constraints. A mutual understanding and respect among technical and environmental staff is critical to a successful program.

Integrated Program

The success of pollution prevention will impact many environmental compliance activities. Their interrelationship must be understood and considered in the development of the overall environmental program. NP adopted the approach of a consolidated environmental plan entitled Environmental Compliance Plan. This Plan defined five environmental entities: pollution prevention, permitting, monitoring, training, and site specific environmental considerations. The consolidation of these elements into one document will minimize the amount of documentation, consolidate monitoring requirements, and provide a broader perspective in identifying overlaps and potential conflicts. Under such an approach, the full benefits of pollution prevention to general environmental compliance are layout.

Examples of Successes

The NP pollution prevention program identified numerous environmental release reduction opportunities. Although all releases were targeted for reduction, the waste sources were prioritized and more efforts were devoted to reduction of mixed waste, high activity radioactive waste, hazardous solid waste, and

toxic air pollutants. Examples of pollution prevention measures that were considered which will reduce generation of low level waste include:

Process Modifications:

1. Reducing quantity of tritium required
2. Assessment of alternative tritium production technologies (heavy water reactor, modular high temperature gas cooled reactor, light water reactor, and accelerator)
3. Use of heat-only-extraction process for tritium recovery (the crush heat process was the initial process evaluated)
4. Reduction in waste associated with handling, storage, treatment, and production of fuel assembly production via high uranium enrichment and deep burn.

System Design:

1. Equipment arrangement in reactor containment that facilitates maintenance and reduces maintenance requirement
2. Collection systems that reduce commingling of waste streams
3. Design to minimize material exposed to potential contamination such as removal of packaging material prior to entry into reactor containment.

Others:

NP has been examining reuse/recycle options for almost all of its process related streams including argon gas and blowdown from the heavy water processing unit. Final treatments have been identified for most waste streams but they would be applied only if source elimination/reduction and recycle/reuse opportunities are exhausted.

CONCLUSIONS

The NP pollution prevention program identified numerous opportunities for waste reduction and elimination; most of the measures if implemented will result in cost savings, facilitate permitting, improve worker health and safety, enhance public acceptance, and provide other environmental benefits. Pollution prevention measures are most cost effectiveness when included at the design stage.

Low-Level Waste Minimization at the Y-12 Plant

John Koger
Oak Ridge National Laboratory
Oak Ridge, TN 37831

INTRODUCTION

The Oak Ridge Y-12 Plant, located in Oak Ridge, Tennessee, is managed by Martin Marietta Energy Systems, Inc., under contract with the Department of Energy. This is an exciting and yet critical time for the Y-12 Plant. Our mission as a plant and many of our goals and objectives are very different from just one year ago. Although the Y-12 Plant mission is changing, the goals associated with environmental issues and waste minimization are even more important to our future.

These needs are driving changes:

- Y-12 burial ground is closed to uranium
- Uranium and waste storage is the only option today
  - Concentrated wastes: 60,000 ft^3/yr
  - Dilute wastes: 600,000 ft^3/yr
- Uranium personnel protection standards are changing
- Minimal uranium recycle is in use today
- Current technology is available for use today.

Issues in the uranium waste stream:

- Cannot bury uranium
- Cannot do anything with RCRA+U (mixed waste)
- Storage space, large volumes of LLW
- Montreal protocol
- Downsizing—decrease of RAD areas
- Minimize scrap generation
- Increase recycle
- Substitution of less hazardous materials
- Below regulatory concern
- Weapons returns.

The conduct of environmental and waste management programs at the Y-12 Plant demands an integrated approach to a number of different but interrelated activities. The overall goal is full compliance with all current regulations, anticipation and participation in the development of future regulations, and planning for

compliance with future regulations. All environmental projects and programs of the Y-12 Plant are designed to provide comprehensive and effective environmental management and to improve environmental quality while bringing the Y-12 Plant into full compliance with all federal and state laws and regulations, such as the Clean Air Act, Clean Water Act, Comprehensive Environmental Response, Compensation, and Liability Act of 1980 and subsequent Superfund Amendments and Reauthorization Act, the Pollution Prevention Act, National Environmental Policy Act, National Emission standard for Hazardous Air Pollutants, Resource Conservation and Recovery Act (RCRA), and Toxic Substances Control Act.

WASTE MINIMIZATION

Waste minimization is the means by which DOE controls its low-level waste problem and makes major cutbacks in the amount of hazardous, mixed, and radioactive waste destined for storage and disposal. To treat the source rather than the result of waste production, the waste minimization program focuses on avoiding generation of wastes and on recycling as much material as possible. Where waste is unavoidably generated, it will be treated to reduce its volume and to stabilize it by the best technology that can be devised. Waste minimization activity at the Y-12 Plant reduces low-level waste production by process modifications to eliminate the generation of hazardous or radioactive waste, minimizes the hazardous and radioactive constituents in a waste, or minimizes the amount of mixed waste generated. Without this work, waste will continue to be generated at the present rate. This program is an integral part of the environmental and waste management regulation of Tennessee, EPA, and DOE.

The Y-12 Development Waste Minimization Program is used as a basis for defining new technologies and processes that produce minimum low-level wastes (hazardous, mixed, radioactive, and industrial) for the Y-12 Plant in the future and for Complex 21 and that aid in decontamination and decommissioning (D&D) efforts throughout the complex. In the past, the strategy at the Y-12 Plant was to treat the residues from the production processes using chemical treatment, incineration, compaction, and other technologies, which often generated copious quantities of additional wastes and, with the exception of highly valuable materials such as enriched uranium, incorporated very little recycle in the process. Recycle, in this context, is defined as material that is put back into the process before it enters a waste stream. Additionally, there are several new technology drivers that have recently emerged with the changing climate in the Nuclear Weapons Complex such as Complex 21 and D&D technologies and an increasing number of disassemblies. The hierarchies of concern in the waste minimization effort are source reduction, recycle capability, treatment simplicity, and final disposal difficulty with regard to Complex 21, disassembly efforts, D&D, and, to a lesser extent, weapons production. Source reduction can be achieved through substitution of hazardous substances for nonhazardous materials, and process changes that result in less generated waste.

The Waste Stream Program is one initiative in this area. This program involves looking at specific problems in six different waste streams: uranium (primarily enriched), solvents, mixed, miscellaneous, plating, and polymers. The program will reduce wastes and worker exposure at the Y-12 Plant and is being coordinated with work in those waste streams across the Nuclear Weapons Complex.

Another effort, the Depleted Uranium Manufacturing Waste Minimization Program, is focused on defining technologies for use in Complex 21, D&D efforts, and weapons disassemblies. Benefits of the new technologies will be minimization of wastes and worker exposure, reduction of the quantity and hazards of wastes originating from the depleted uranium processing areas, a lower cost per unit of product, and less dependence on uranium bought from the outside. This program was initially funded by the Office of Technology Development, DOE-EM, as an integrated demonstration. The primary emphasis in this program is to reduce wastes by source reduction. Crucial to this approach is the documentation of the current depleted uranium manufacturing flow cycle (process waste assessment) and the use of models to examine the impact of proposed changes on the system as a whole. Results from the process waste assessments have provided critical information on which areas to focus attention.

ONGOING PROJECTS

Air Emission Control Project

When completed, the Air Emission Control Project will further reduce nitrogen oxide emissions from the Y-12 Plant through the installation of scrubber systems on acid pickling baths. Additional air pollution control equipment will be installed for particulate removal and will include mist eliminator, high-efficiency particulate air (HEPA) filters, nitric acid scrubber systems, and other similar equipment.

Stack Emission Reduction and Monitoring Project

The proposed Stack Emission Reduction and Monitoring Project will also reduce nitrogen oxide emissions from the Y-12 Plant through by installing an exhaust gas scrubber from a nitric acid pickling area in a major Y-12 Plant depleted uranium production building. The exhaust gas scrubber will remove entrained nitric acid mists from the exhaust gas stream before it is filtered through in a new HEPA filter to remove uranium particulates.

Ultrasonic Cleaning of Uranium Castings

A development/demonstration project is under way to test ultrasonic cleaning as an alternative to nitric acid pickling of uranium ingots. If successful, this cleaning method would eliminate the need for the scrubber system discussed above.

Machine Hood Exhaust Improvements Project

This proposed project will upgrade exhaust systems used in machine shops to improve particulate capture efficiency and reduce workplace exposure to particulates generated in machining operations. The project will also provide modern exhaust filtration systems to minimize emissions.

Radiological Emission Estimation and Sampling Program

The Y-12 Plant is believed to be well in compliance with the radiological dose standard of 10 millirems. However, the sampling methods and emission estimation methods used at the Y-12 Plant do not fully meet EPA requirements. A compliance plan was developed to document the acceptable estimating and sampling methods to be used at the Y-12 Plant. This plan was submitted to the EPA, and a Federal Facilities Compliance Agreement has been signed.

Hazardous Liquid Waste

A variety of hazardous liquid waste (uranium-contaminated as well as noncontaminated) results from activities associated with metal finishing, plating, uranium recovery, and facility cleaning operations. In addition, a large variety of conventional liquid waste exists such as domestic sewage, steam plant wastewaters, and coal pile run-off. For the purpose of environmental planning, aqueous waste streams may be divided into two categories—those with high nitrate content and those without. With the exception of nitrate content, all the waste streams are amenable to similar treatment to provide pH control and to reduce levels of suspended and dissolved solids. A variety of wastewater treatment facilities are planned or are in place to handle specific waste streams (plating rinsewaters, domestic sewage, high-nitrate streams, etc.) Research and development work have been undertaken in support of these facilities. Several development projects have been completed while others are still underway or planned.

Wastewaters high in nitrate are transported to the West End Tank Farm for neutralization. After neutralization, they are biologically denitrified before undergoing final effluent polishing and discharge at the tank farm. Non-nitrate wastes are treated at one of several facilities on site.

Process Waste Assessments

One key mechanism by which the Y-12 Plant pursues source reduction is by conducting process waste assessments (PWAs) of discreet plant operations and activities. Each PWA is conducted by a core team of individuals, some who offer a unique and detailed knowledge of the particular operation or process being reviewed and others who have experience in waste minimization principles and techniques. The Y-12 Plant intends to continue with the implementation of PWAs across all program elements of the plant to continue to find ways to reduce both hazardous and nonhazardous waste generation.

Waste Characterization and Segregation

An additional activity being pursued by the Y-12 Plant to promote hazardous waste minimization through source reduction is to develop better waste characterization and segregation procedures. The goal of these initiatives is to ensure that RCRA hazardous wastes are not mixed with nonhazardous waste or that nonradiologically contaminated wastes are not mixed with wastes that are contaminated.

This is a very important process since RCRA hazardous wastes are difficult to manage, and wastes that are both RCRA hazardous and radiologically contaminated (mixed wastes) are extremely difficult to manage due to the lack of available treatment and disposal facilities. Improved waste characterization initiatives are being pursued through the improved training of Y-12 Plant personnel in RCRA regulations, including improved training on hazardous waste identification.

In addition, waste generation, accumulation, and waste management practices are undergoing review to identify areas where improved waste segregation could result in smaller quantities of hazardous waste that must be managed.

Sludge Reduction

A process developed at the Y-12 Plant could potentially reduce the volume of RCRA hazardous sludge at the Wet End Tank Farm by approximately 95%. This process would require the neutralization and removal of precipitates as the first step in the tank farm process in order to remove hazardous constituents from the process stream. The material in process would then be free of these components, and solids generated in subsequent steps and operations in the treatment process would be nonhazardous solid waste. While it may still be necessary to manage the front end sludge as hazardous waste, the larger volume of sludge, which is generated later in the process, would be nonhazardous since the hazardous constituents would no longer be present.

LOW-LEVEL WASTE ACCOMPLISHMENTS

- Installed low-level waste monitors in RAD areas for tertiary waste segregation
- Substituted argon heat-treating furnace for salt bath
- Substituted ultrasonic cleaning for acid pickling bath
- Reduced NO_x emissions with scrubber systems on acid pickling bath
- Installed robotics which decreases worker exposure
- Upgraded exhaust systems in machine shops to improve particulate capture efficiency
- Decreased saw fines by use of an arc saw
- HEPA filters are commonly used.

SUMMARY

In looking to the future, we want the Y-12 Plant to be regarded by employees and others as a responsible plant that really cares about how we accomplish our mission, that we not merely use any means to justify the results. Formal planning, both strategic and long-range, helps make Y-12 a responsible plant. The Y-12 Plant Long-Range Environmental and Waste Management Plan establishes and describes programs that challenge Y-12 Plant personnel and that provide guidance for the direction we must take to achieve our presently developing mission.

IGRIS for Characterizing Low-Level Radioactive Waste

C. W. Peters
Nuclear Diagnostic Systems
P.O. Box 726
Springfield, VA 22150

Phillip J. Swanson
Concord Associates
Knoxville, TN

ABSTRACT

A recently developed neutron diagnostic probe system has the potential to noninvasively characterize low-level radioactive waste in bulk soil samples, containers such as 55-gallon barrels, and in pipes, valves, etc. The probe interrogates the target with a low-intensity beam of 14-MeV neutrons produced from the deuterium-tritium reaction in a specially designed sealed-tube neutron-generator (STNG) that incorporates an alpha detector to detect the alpha particle associated with each neutron. These neutrons interact with the nuclei in the target to produce inelastic-, capture-, and decay-gamma rays that are detected by gamma-ray detectors. Time-of-flight methods are used to separate the inelastic-gamma rays from other gamma rays and to determine the origin of each inelastic-gamma ray in three dimensions through Inelastic-Gamma Ray Imaging and Spectroscopy (IGRIS). The capture-gamma ray spectrum is measured simultaneously with the IGRIS measurements. The decay-gamma ray spectrum is measured with the STNG turned off. Laboratory proof-of-concept measurements were used to design prototype systems for Bulk Soil Assay, Barrel Inspection, and Decontamination and Decommissioning and to predict their minimum detectable levels for heavy toxic metals (As, Hg, Cr, Zn, Pb, Ni, and Cd), uranium and transuranics, gamma-ray emitters, and elements such as chlorine, which is found in PCBs and other pollutants. These systems are expected to be complementary and synergistic with other technologies used to characterize low-level radioactive waste.

INTRODUCTION

Nuclear Diagnostic Systems is developing a family of Neutron Diagnostic Probe (NDP) systems based on the Associated-Particle Time-of-Flight (AP TOF) technique. Development of systems for detecting explosives and contraband drugs for physical security applications has reached the commercialization stage. Development of other systems for applications such as Treaty Verification, chemical weapon detection, nonproliferation of Special Nuclear Materials (SNM), cargoscan, airport security, and in vivo medical investigations is being pursued in collaboration with the Argonne National Laboratory,[1,2] BDM International, Phillips Scientific, and the University of Auckland, New Zealand. Systems for characterizing low-level (and high-level) radioactive waste are being pursued in collaboration with Concord Associates, BDM, and Phillips Scientific.

The Argonne National Laboratory sponsored a project to evaluate the use of this AP TOF technique for characterizing low-level radioactive waste.[3] In this project, laboratory measurements were used to predict system performance versus system design parameters. Several kinds of neutron interrogation measurements that can be made with a Nuclear Diagnostic Probe system were studied. The measurement of primary interest is Inelastic-Gamma Ray Imaging and Spectroscopy (IGRIS), which yields a coarse three-dimensional image of the densities of the nuclides in the target. Secondary measurements found to be of interest included Capture-Gamma Ray Spectroscopy (CGRS) and Passive-Gamma Ray Spectroscopy (PGRS). The most promising applications were found to be Bulk Soil Assay, Barrel Inspection, and Decontamination and Decommissioning.

THE AP TOF TECHNIQUE

Inelastic-Gamma Ray Imaging and Spectroscopy

The Associated-Particle Time-of-Flight technique is illustrated in Figure 1. A specially designed sealed-tube neutron-generator (STNG) uses the deuterium-tritium reaction to isotropically generate 14-MeV neutrons from a small diameter spot. This reaction produces a 3.7-MeV alpha particle in the opposite direction from each 14-MeV neutron. A position-sensitive photomultiplier coupled to an alpha scintillator incorporated in the STNG detects those alpha particles within the solid angle subtended by the alpha scintillator. This solid

angle defines the solid angle, or field-of-view, of the 14-MeV neutrons associated with the detection of these alpha particles.

Some of the 14-MeV neutrons will interact with the nuclei in the target to produce inelastic-gamma rays, some of which will be detected by a gamma-ray detector, which is usually a large NaI(Tl) scintillation detector. The time-of-flight (TOF) is the time (T_n) for the 14-MeV neutron with a velocity (v_n) of 5 cm/ns to travel to the reaction site (R_n) in the target plus the time (T_g) for the inelastic-gamma with a velocity (v_g) of 30 cm/ns to travel to the detector (R_g). Typical TOFs are in the 10–20 ns range.

Some of the 14-MeV neutrons associated with detection of an alpha particle will be transmitted through the target and interact with the detector or other materials to produce counts in the gamma-ray detector. However, these events occur at a later time than those from the target and are eliminated by TOF discrimination. Those 14-MeV neutrons not associated with alpha-particle detection, which are produced outside of the field-of-view, can also produce inelastic-gamma rays. Most of these events are eliminated by the TOF requirement and the remainder contributes to the "accidental" background.

The 14-MeV neutrons will eventually be thermalized to produce capture-gamma rays in the target, detector, floors, walls, etc. These capture-gamma rays (indicated by a dashed line in Figure 1) occur from about 5 to 500 microseconds after 14-MeV neutron emission and are easily eliminated by the TOF requirement except for "accidentals."

In addition, fast-neutron and thermal-neutron interactions leave some isotopes in an excited state that decay by gamma-ray emission (indicated by a dashed line in Figure 1) with half-lives varying from micro-seconds to thousands of years. Except for accidentals, these gamma-rays are eliminated by the TOF requirements.

A block diagram of the electronics is shown in Figure 2. The timing pulses from the alpha and gamma-ray detectors are generated by constant fraction discriminators (CFD). The output of the alpha detector is used to start a coincidence circuit and a time-to-amplitude convertor (TAC). The output of the gamma-ray detector is used to stop the coincidence circuit and the TAC. The coincidence circuit is used to eliminate long TAC cycles for alpha events that are not followed by detection of a gamma ray within the TOF requirements. This reduces system deadtime. One output of the TAC enables a linear gate to pass the gamma-ray pulse that stopped the TAC. The outputs of the TAC and the linear gate, which are the TOF and gamma-ray energy, are sent to analog-to-digital convertors (ADC). Their outputs are stored in a micro-computer (PC) for histogramming and data processing and analysis. The x and y outputs of the position-sensitive alpha detector for each event (which are not shown in Figure 2 for simplicity) are also stored in the PC. The output of the alpha detector CFD is sent to a scaler that can be read by the PC.

The x, y, and TOF inputs are converted into three-dimensional coordinates for each event by software. The data is histogrammed to produce displays of inelastic-gamma ray energy spectra and spatial distributions of events within the target. The alpha counts are a precise measurement of the 14-MeV neutrons emitted into the field-of-view and are used for normalization purposes. This system is the Inelastic-Gamma Ray Imaging and Spectroscopy (IGRIS) system.

Capture-Gamma Ray Spectroscopy

If the linear output of the gamma-ray detector is sent to a multi-channel analyzer (MCA) and the output of the coincidence circuit is sent in anti-coincidence to the MCA (indicated by dashed lines in Figure 2), then the MCA will record the energy spectrum of all of the gamma rays except the IGRIS events. This spectrum includes the spectrum of capture-gamma rays produced in the target and the surroundings superimposed on a background spectrum of decay-gammas from the target and surroundings and a small component of inelastic-gamma rays from the target and surroundings that is not time-correlated with alpha particle detection.

This is the Capture-Gamma Ray Spectroscopy (CGRS) system, which is operated simultaneously with IGRIS. The energy spectrum obtained by CGRS is the same as the energy spectrum of the accidental counts observed by IGRIS and, with appropriate normalization, can be used to improve the IGRIS spectra.

Passive-Gamma Ray Spectroscopy

If the STNG is turned off, then the MCA (Figure 2) measures the energy spectrum of the decay-gamma radiation from the target and from the surroundings. The decay-gamma radiation spectrum from the surroundings is measured without a target present. The difference between these two spectra is the energy spectrum of the decay-gamma radiation from the target. This is called Passive Gamma-Ray Spectroscopy (PGRS).

PGRS measurements made before the IGRIS/CGRS measurements are used to determine the gamma-ray activity of the target. If desired, PGRS measurements made before and after IGRIS/CGRS measurements could be used to determine the decay gamma-ray activity induced in the target by fast and thermal neutrons.

SYSTEM DESIGN AND PERFORMANCE

Experimental Results

The results of experimental measurements that were made to obtain a basis for system design are as follows.

IGRIS is capable of detecting heavy metals such as As, Cd, Cr, Hg, Ni, Pb, and Zn; elements such as Cl, C, N, and O that are associated with explosives, PCBs, and other toxic pollutants; and uranium and transuranics (TRU). Uranium and TRU are detected by their prompt-fission gamma rays, which cannot be used to identify isotopes.

CGRS is useful for detecting nuclides with large thermal-neutron cross sections for production of capture-gamma rays with energies greater than 3 MeV because the CGRS background is low above 3 MeV. This criterion applies to elements such as Cl, Cd, Cr, Hg, and Ni. CGRS is also useful to detect nuclides with a large thermal-neutron fission cross section such as U^{235} and Pu^{239}; however, the prompt-fission gamma rays cannot be used to identify isotopes. The sensitivity of CGRS is highly dependent upon the amount of hydrogen in the target needed to thermalize the fast neutrons and "poisons" such as B and Li that have large thermal-neutron absorption cross section.

As expected, PGRS is very sensitive to gamma-ray emitters such as Cs^{137} and Co^{60} and to spontaneously fissionable isotopes such as Pu^{240}. PGRS is capable of identifying certain isotopes of TRU, which produce low-energy gamma rays, provided that the mixture of isotopes does not produce a spectrum that is too complex to be analyzed by NaI scintillators and that shielding does not greatly attenuate their signals.

System Design Considerations

The detection capability of these systems is related to the figure-of-merit (F), which is proportional to the reciprocal of the minimum detectable level (MDL):

$$F = S/B^{1/2},$$

where

S = net signal counts and

B = background counts.

IGRIS

For IGRIS, we find that F approaches a constant as the neutron output (N) of the STNG increases because the background (B) varies with N^2 for large values of N. The maximum useful STNG output depends upon the system design and is usually in the 10^6 to 10^7n/s range.

The alpha count rate equals the associated neutrons/second in the field-of-view of the STNG and is a precise monitor of the incident neutrons, which eliminates this source of experimental error.

The net signal counts are proportional to the product of the mass of an element in the target times its mass absorption coefficient in cm^2/gram. The mass absorption coefficient is proportional to the reciprocal of the cube root of the element's atomic mass, which means that the sensitivity does not vary greatly from element to element. The MDL (in ppm) is equal to the minimum detectable mass of an element divided by the mass of the target normalized to a million grams.

The optimum thickness of a bulk soil sample was found to be about 30 cm or 35 g/cm^3. Hence, the largest signal and lowest MDL are obtained from a bulk soil sample with a thickness of 30 cm that fills the field-of-view of the STNG.

The TOF background is the accidental counts, which are low, typically two orders of magnitude less than the signal from the target.

For homogeneous targets such as a bulk sample of soil, the net signal and the background vary with the number of gamma-ray detectors (n), the STNG output (N), and the measurement time (T). Consequently, tradeoffs in these parameters relative to a reference system with a figure-of-merit of F_o, can be expressed as:

$$F_o/F = MDL/MDL_o = [n_o N_o T_o / nNT]^{1/2}.$$

If the maximum useful STNG output is used, then the MDL improves with the square root of the number of detectors (n) and/or a longer measurement time (T), both of which have practical limits.

For heterogeneous targets in which the element of interest occupies a small volume or voxel, IGRIS background varies with the size (V) of the voxel for voxels larger than about 200 cm^3, which is the spatial resolution of IGRIS. In this case, the figure-of-merit varies with the square root of the ratio, V/V_T, where V_T is the volume of the target.

CGRS

Because of pulse pile-up effects, the CGRS system is limited to gamma-ray count rates of less than about 10^5 c/s, which is not exceeded for STNG outputs in the 10^6 to 10^7 n/s range.

The signal counts vary with the amount of hydrogen in the target because hydrogen is needed to thermalize fast neutrons. The thermal-neutron mass absorption coefficient varies by orders of magnitude from one isotope to another. Hence, the signal counts for a specific nuclide depends upon its mass absorption coefficient and concentration relative to that of other elements in the target. Absolute density calculations are difficult because of the variation of the flux of thermalized neutrons from sample to sample. The result is that only a few elements are easily detected and their relative, but not absolute, densities are readily calculated. One method of determining absolute concentrations from the CGRS spectra is to compare the relative concentrations of the elements detected by CGRS to an element that is easily detected by both CGRS and IGRIS, because IGRIS provides a better absolute measurement.

The background is low for gamma-ray energies greater than about 3 MeV.

CGRS is most useful for detecting a few isotopes with large thermal-neutron cross-sections that produce prompt-fission gamma rays or capture-gamma rays with energies greater than 3 MeV. These measurements are redundant to the IGRIS measurements for certain isotopes and can be used to improve analysis of photopeak interferences in complex IGRIS spectra.

PGRS

In essence, PGRS is conventional gamma-ray spectroscopy with large NaI scintillators, which provide a high sensitivity. If needed, a high-purity germanium (HPGe) detector can be added to analyze samples that produce complex spectra such as mixtures of TRU isotopes that are difficult to analyze with NaI scintillators because of their poor energy resolution.

BULK SOIL ASSAY SYSTEM

The geometry of the Bulk Soil Assay (BSA) system is illustrated in Figure 3. The soil target is shaped to fit the field-of-view of the STNG. An array of rectangular 6 × 6 × 18-in. NaI scintillation detectors are used. If needed, an HPGe detector with a fast-neutron scatter shield to reduce fast-neutron damage of the detector could be added.

Table 1 lists the predicted MDLs for the BSA system. The predicted MDLs for the CGRS measurements are for soils with a moisture content of 20%. These MDLs will be higher for drier soils. The MDLs will also be higher for mixtures of pollutants that produce photopeak interference in the spectra.

The calculated weight of the soil target is 321 kg. The estimated weight of a voxel is 0.5 kg. The calculated minimum detectable amount for the case in which all of a pollutant is located in one voxel is listed in the third column of Table 1.

The measurement time of 10,000 seconds can be decreased to about 20 minutes or the MDLs could be decreased by increasing the STNG output and the number of NaI scintillators.

This system is expected to be useful for characterizing waste and highly-polluted soil excavated from a waste site and for process control. For example, a technique being investigated by Retech[4] is a Plasma Centrifugal Furnace to treat soils contaminated by metals and organic pollutants. The organics are thermally destroyed. The metals are melted in the soil to form a hard, glass-like, nonleachable mass.

A demonstration was performed on a mixture of No. 2 diesel oil and metal-bearing soil from the Silver Bow Creek Superfund site. This mixture was spiked with zinc oxide and hexachlorobenzene. The concentrations of elements with significant concentrations measured by Retech before and after treatment are listed in columns two and three of Table 2. The data for chlorine are estimated by the authors. The minimum detectable levels of the BSA system from Table 1 are listed in the fourth column for comparison purposes. Comments on the utility of the BSA system are listed in the fifth column.

For this demonstration, the Bulk Soil Assay system appears to be useful for detecting the significant pollutants, except for arsenic and lead, in the soil either before or after treatment and for both for the case of zinc.

BARREL INSPECTION SYSTEM

The geometry of the Barrel Inspection system is illustrated in Figure 4. The barrel is rotated to obtain uniform sensitivity with respect to its radius.

The predicted MDLs for the homogeneous and heterogeneous cases are listed in Table 2. If the barrel does not contain hydrogenous materials, then the CGRS MDLs will be higher than shown in Table 2.

The weight of the barrel is assumed to be 200 kg and filled with material similar to soil for neutron and gamma-ray attenuation. The weight of a voxel is 0.3 kg. The measurement time of 10,000 seconds or the MDLs could be reduced by adding more detectors and/or increasing the neutron output of the STNG.

The tradeoff between reducing the measurement time (which reduces costs) or the minimum detectable levels depends upon the information needed to make environmental decisions in regard to the contents of the barrel. In essence, these decisions are deciding what to do with the contents of the barrel and how, when, and where to do it. These decisions depend upon the chemical, nuclear, and physical nature of the contents of the barrel. Unfortunately, no single inspection method is likely to provide all of this information.

Examination of the records, if available, may describe what was put into the barrel but may not describe the current nature of the contents because of chemical and physical effects that may have occurred since the barrel was filled. In any event, the recorded contents should be verified.

To avoid unpleasant surprises, the records should be examined and noninvasive measurements should be made before invasive measurements. Noninvasive measurements include (a) x-rays, which provide a detailed image of the contents that can be used to identify certain objects and some physical characteristics such as liquid or solid form and variations in density; (b) neutron interrogation such as IGRIS, CGRS, and PGRS, which provide a coarse image of the contents, density variations, concentrations of elements and certain isotopes, and detection of gamma-ray activity; and (c) other measurements, such as acoustical or thermal, might provide some useful characteristics of the physical nature of the contents. However, none of these methods measures the chemical nature of the contents.

Invasive measurements, such as x-ray fluorescence and/or specific-ion probes and/or chemical analyses of gas samples and grab samples are needed to determine the chemical content. The question that arises for invasive methods is whether a representative sample of the contents has been measured.

These barrel inspection methods are complementary because each provides information not available from the others, and they are synergistic because additional information can be obtained by combining the results of the individual methods. For example, the IGRIS measurements could be used with the chemical analysis of a grab sample to estimate the distribution of chemicals in a barrel containing a nonhomogeneous mixture.

This leads to the concept of a multi-sensor approach with data fusion from the different measurements to characterize the contents of barrels containing low-level radioactive waste.

A multi-sensor approach should be cost effective. Except for the chemical analyses, the results are timely because they are available at the end of the measurement. On the other hand, the chemical analyses are the most accurate. The more that is known about the contents of a barrel before it is opened for invasive measurements, the less the danger of a hazardous surprise. The chemical analyses are the most costly and anything that can be measured by the other methods to reduce the frequency of grab samples and to reduce their analysis cost would save costs.

The next step is to demonstrate the cost effectiveness of this multi-sensor approach for characterizing barrels of low-level radioactive waste by field tests.

DECOMMISSIONING AND DECONTAMINATION SYSTEM

This system is to be used to detect pollutants in pipes, valves, and other inaccessible locations that cannot be detected by other methods. An example of the geometry for detecting a pollutant in a pipe is depicted in Figure 5. Proof-of-concept has been shown for a similar problem, which was the detection of tens of milligrams/cm^2 of corrodents such as Na and Cl on steam turbine blades.

The expected performance of the IGRIS measurement for this application is expected to be better than that shown in Table 3 for the one voxel case depending upon how many detectors can be used and the presence of significant (several inches) shielding.

POTENTIAL IMPROVEMENTS

The major improvements are expected to be in software. For example, Gamma-Ray Coincidence Spectroscopy (CGRS) could be used to analyze complex spectra because some of the gamma-rays are produced in cascades. On average, about eight prompt-fission gamma rays are produced per fission and Gamma-Ray Coincidence Spectroscopy could be used to estimate gamma-ray attenuation coefficients.

SUMMARY

A neutron interrogation system based on the associated-particle time-of-flight technique has been investigated for characterizing low-level radioactive wastes. This system is used for passive gamma-ray spectroscopy, capture-gamma ray spectroscopy, and inelastic-gamma ray spectroscopy, which provides a unique three-dimensional measurement of the concentrations of elements.

The results of experimental measurements were used to design systems and to predict their performance for bulk soil assay, barrel inspection, and decommissioning and decontamination applications. A multi-sensor approach, in which the measured results are combined with those obtained from other sources, is expected to be the most cost effective.

The next step will be to demonstrate the utility of these systems for applications, such as:

- Characterization and process control of excavated waste and soil
- Characterization of the contents of barrels and other containers stored at facilities or excavated from burial sites
- Verification of the contents of radwaste containers received at a disposal site
- Detection of pollutants deposited in pipes, valves, etc.

ACKNOWLEDGMENTS

The contributions of A. H. Aitken, C. C. Blackmon and C. J. Henderson of Nuclear Diagnostics Systems, who conducted the experimental measurements and their analysis, are deeply appreciated. The support of R. E. Williams, Chairman, and W. Jones, President of Nuclear Diagnostic Systems; P. Haas, President, Concord Associates; T. Phillips, President, Phillips Scientific; and M. D. Erickson, Associate Director, R&D PCO Office, Chemical Technology Division, Argonne National Laboratory is greatly appreciated.

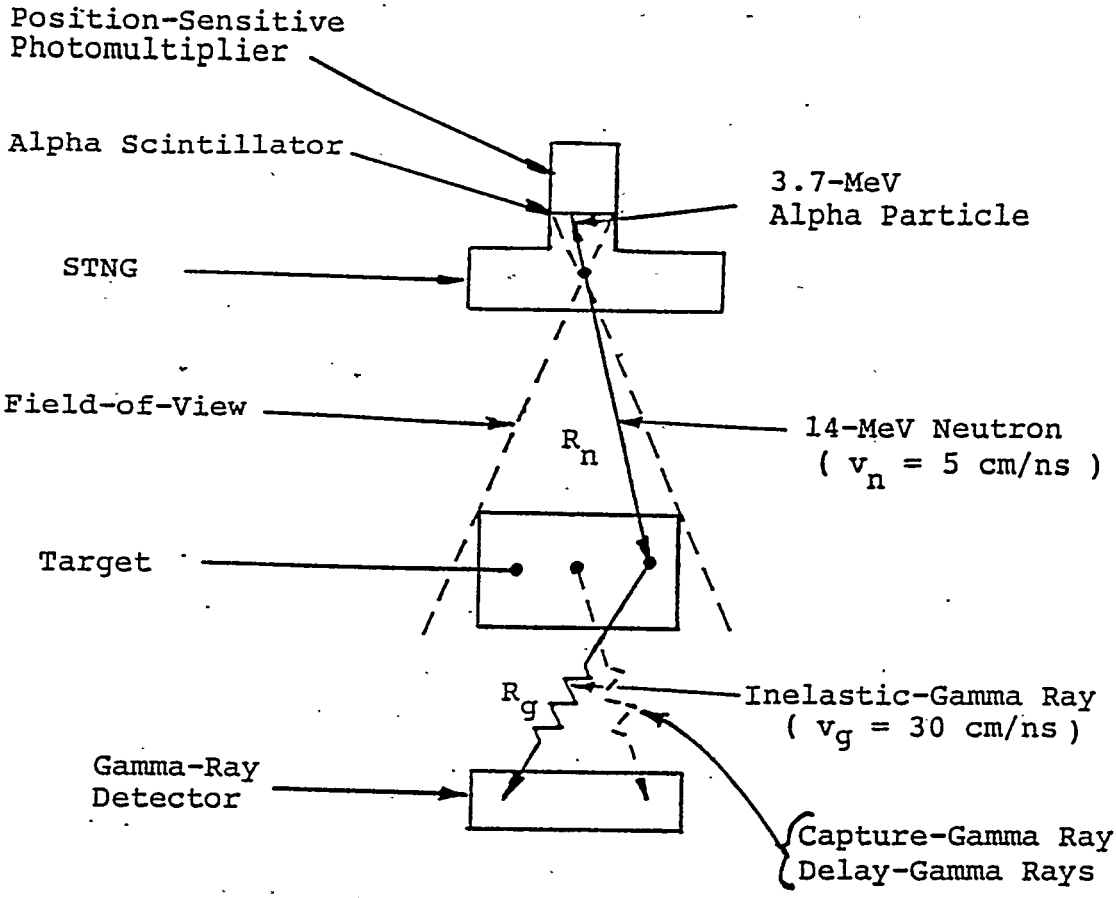
REFERENCES

1. E. Rhodes and C. W. Peters, "APSTNG: Neutron Interrogation for Detection of Explosives and Drugs and Nuclear and CW Materials," SPIE 1992 Symposium on Optical Applied Science and Engineering, San Diego, CA, 19-24 July, 1992.

2. E. Rhodes and C. W. Peters, "APSTNG: Neutron Interrogation for Detection of Drugs and Other Contraband," Contraband and Cargo Inspection Technology International Symposium, Washington, D.C., 28-30 October, 1992.

3. A. H. Aitken and C. W. Peters, "Predicted Performance of Systems for Bulk Soil Assay, Barrel Inspection and Decommissioning," DOE/CH-9210 Bulk Soil Assay System, April 1992.

4. Retech, Inc., "Plasma Centrifugal Furnace," EPA/540/A5-91/007, June 1992.



$$H^3 + H^2 \rightarrow He^4(3.7\ MeV) + n^1(14\ MeV)$$

$$TOF = T_N + T_g = \frac{Rn}{v_n} + \frac{Rg}{v_g} = \frac{Rn}{5} + \frac{Rg}{30} \approx 10 \text{ to } 20 \text{ ns}$$

Figure 1. The Associated-Particle Time-of-Flight technique.

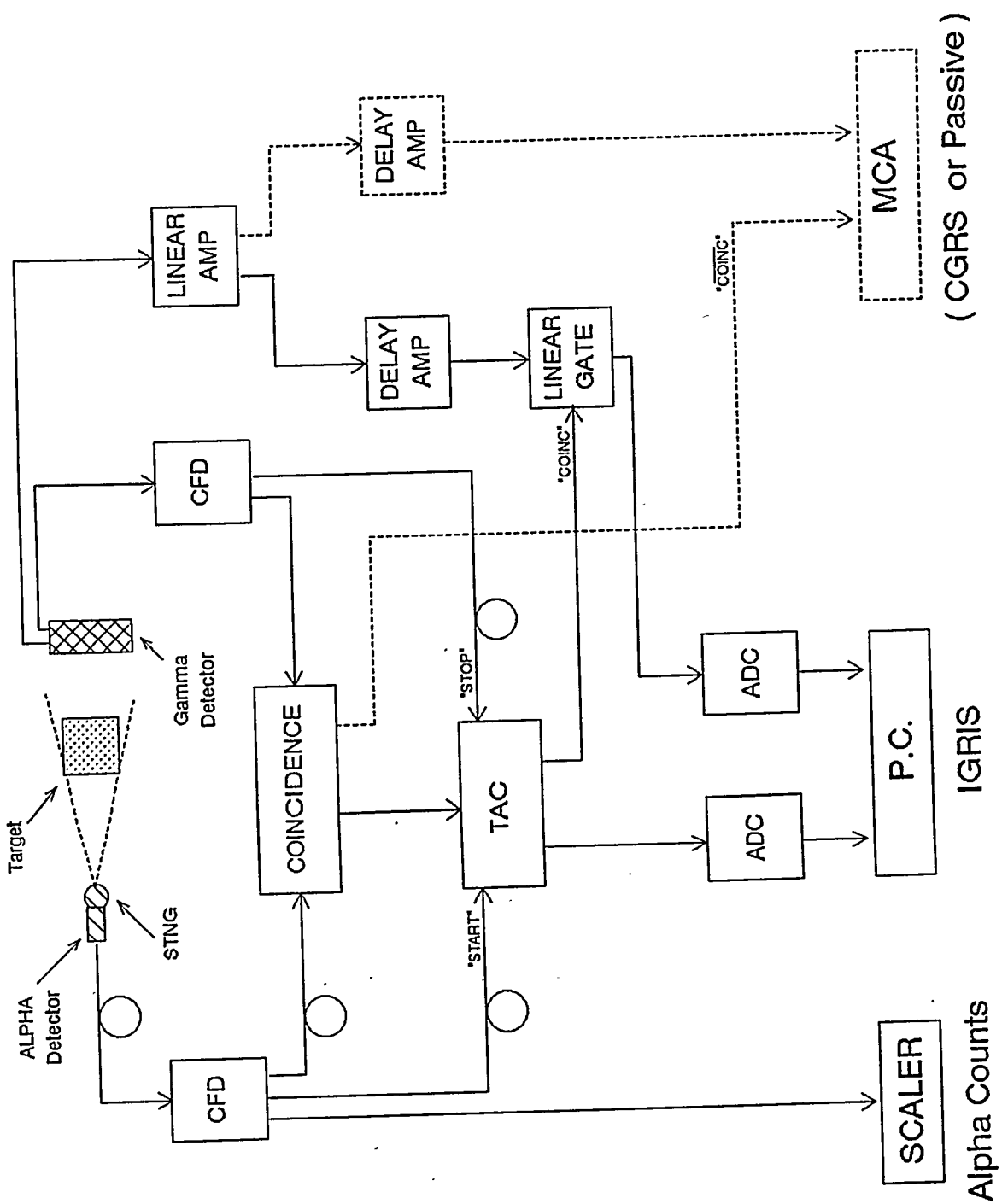


Figure 2. Block diagram of electronics.

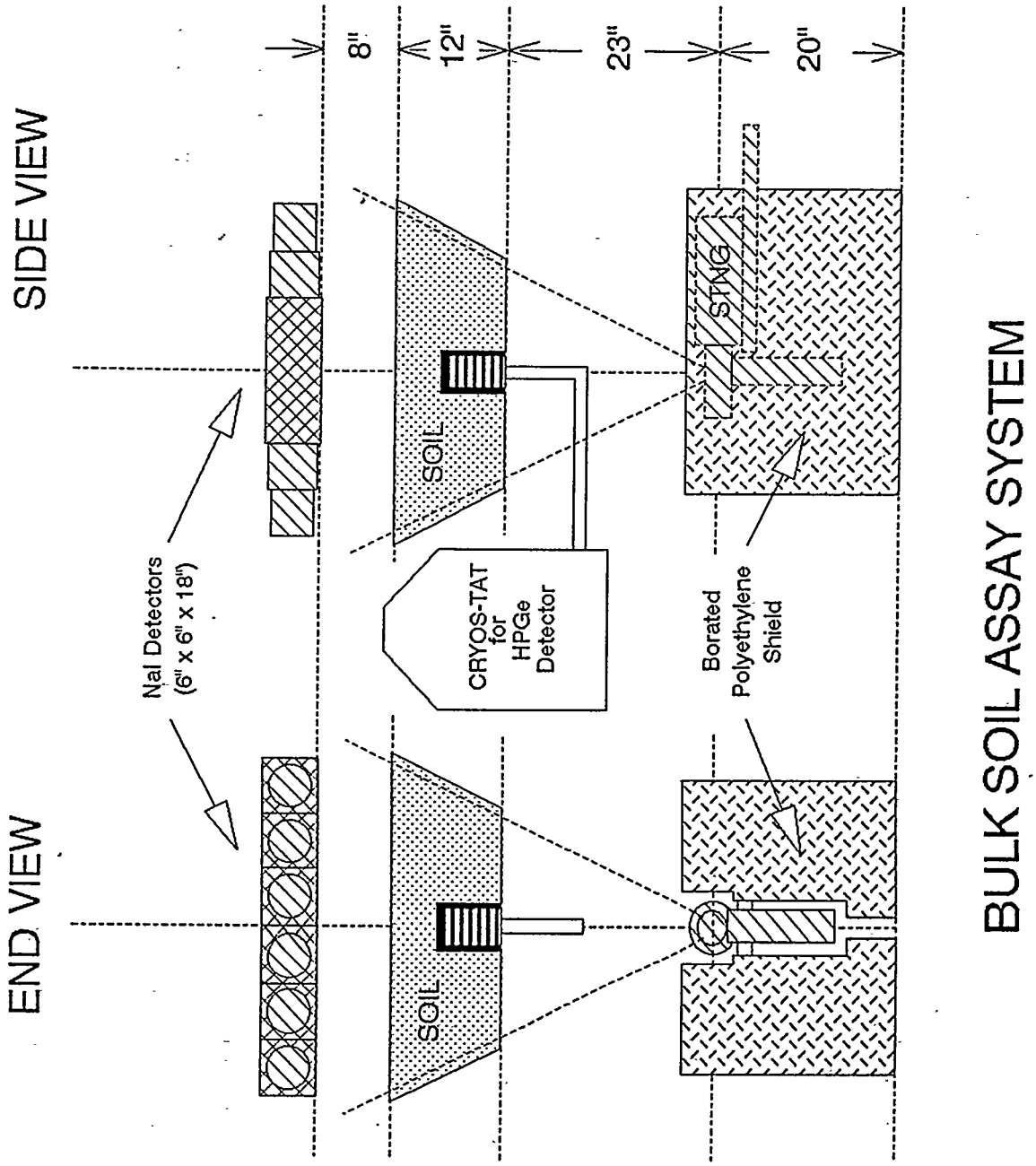


Figure 3. Illustration of proposed Bulk Soil Assay System.

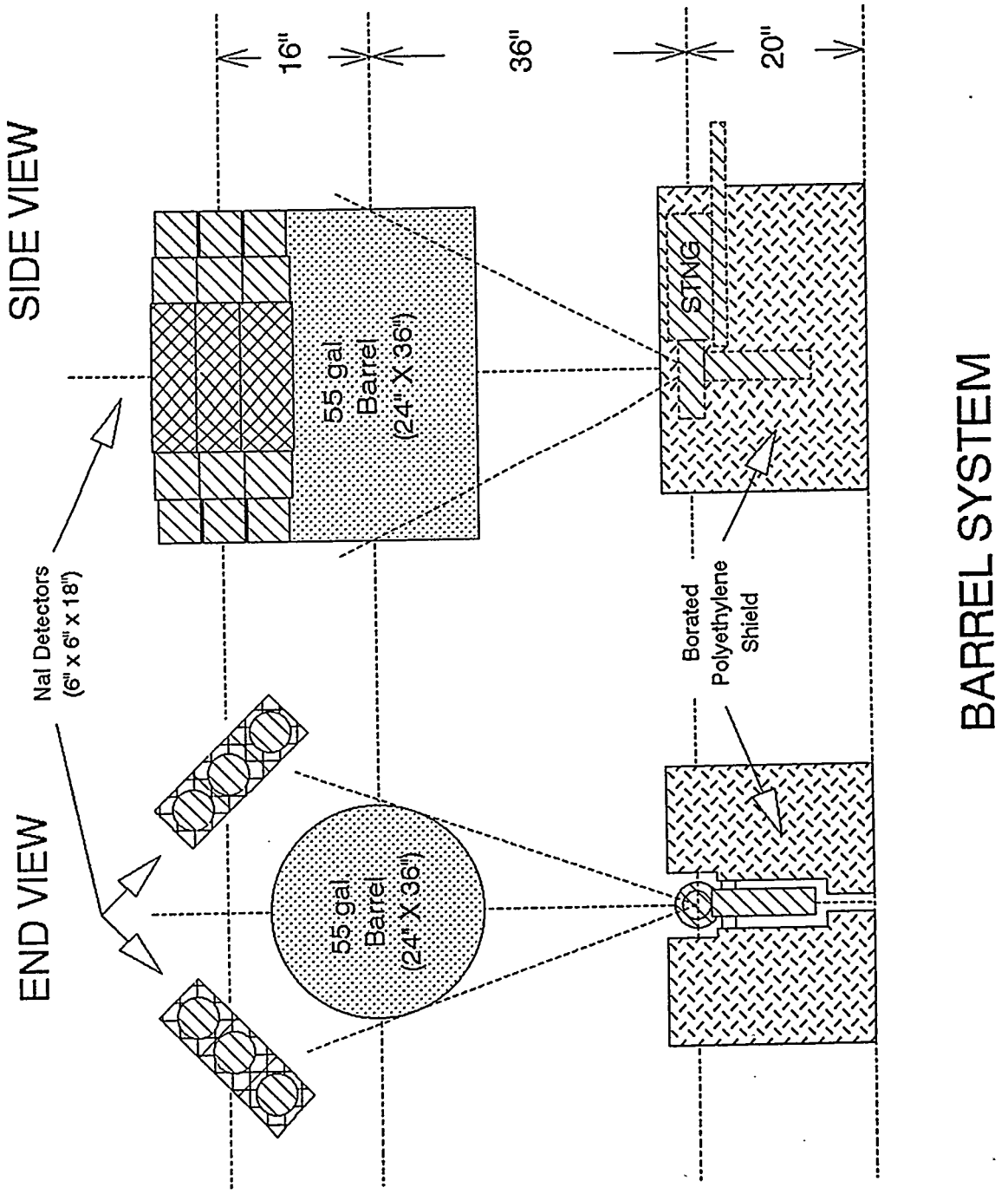


Figure 4. Illustration of proposed Barrel Inspection system.

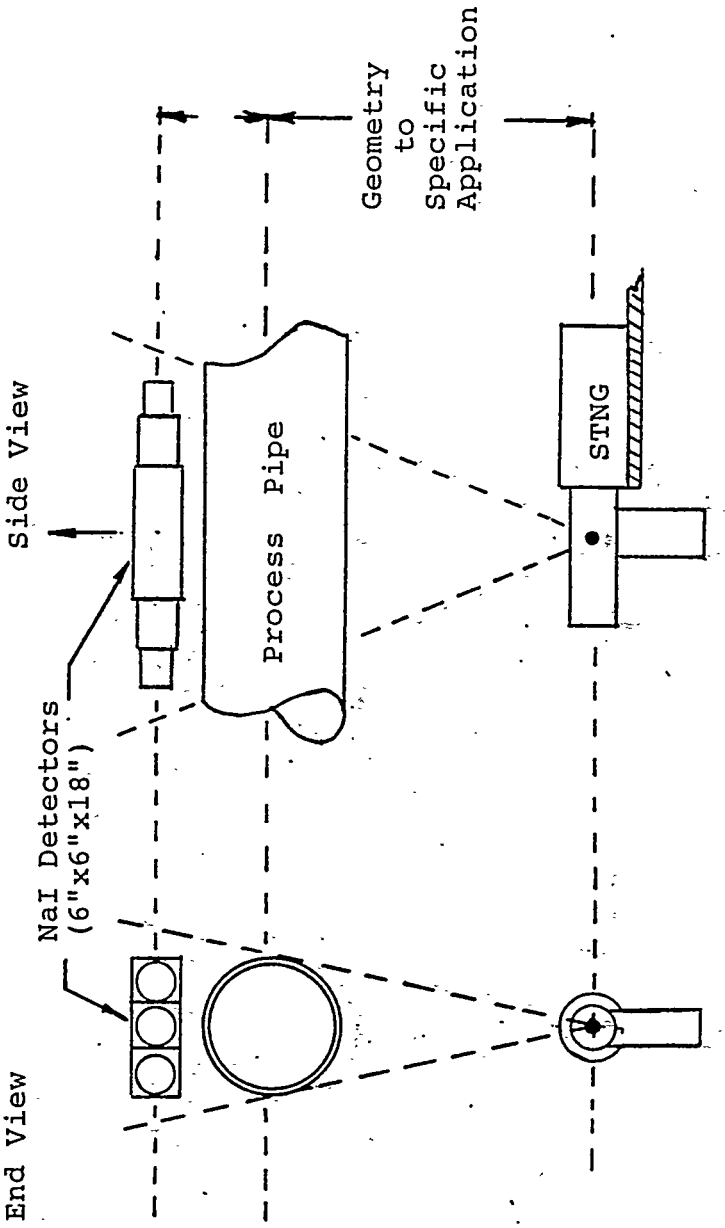


Figure 5. Illustration of proposed Decommissioning System.

Table 1. Examples of predicted minimum detectable levels for the Buld Soil Assay system.

Measurement Time = 10,000 seconds. Increasing Detectors from 6 to 12 and STNG output from $2x10^6$ to $8x10^6$ n/s Decreases T to 1,250 seconds.

MODE	HOMOGENEOUS TARGET	POLLUTANT IN ONE VOXEL
element/isotope	MDL	MDL
A. PGRS:		
Cs-137	0.0078 picoCi/g	2.5 nanoCi
Co-60	0.0031 picoCi/g	1.0 nanoCi
Pu-238	79 nanoCi/g	25,254 microCi
Pu-240	6.5 nanoCi/g	2,071 microCi
Pu-242	0.037 nanoCi/g	11.8 microCi
Cm-242	0.00036 nanoCi/g	0.1 microCi
Z>95	0.00032 nanoCi/g	0.1 microCi
B. CGRS:		
Cl	139 ppm	45 grams
Cr	193 ppm	62 grams
Ni	108 ppm	35 grams
Hg	61 ppm	20 grams
Cd	15 ppm	5 grams
U-235	11 ppm	3 grams
PU-239	8 ppm	3 grams
C. IGRIS:		
Cl	4,264 ppm	55 grams
Pb	2,480 ppm	32 grams
Zn	541 ppm	7 grams
As	2,824 ppm	36 grams
Cr	232 ppm	3 grams
Ni	363 ppm	5 grams
Hg	1,722 ppm	22 grams
Cd	658 ppm	8 grams
U-235	0.017 ppm	0.22 milligrams
U,U-238	0.034 ppm	0.44 milligrams
TRU	0.017 ppm	0.22 milligrams

NOTES: nanoCi for TRU is for alpha activity. Weight of Soil=321 kg. Weight of a voxel=0.5 kg. MDLs are for one element and vary with $1/T^{(1/2)}$. The MDLs for a mixture of elements and TRU may be higher depending upon spectral interferences, which may be improved by Gamma-Ray Coincidence Spectroscopy. Prompt-gamma rays from fission are used to detect U and TRU and does NOT identify the radionuclides. Passive gamma-ray spectroscopy is used to identify and measure the concentrations of TRU radionuclides needed to calculate the TRU alpha activity. The addition of an HPGe detector may improve the analysis of mixtures of TRU and other elements.

Table 2. Process control with IGRIS.

Example of a Potential Use with a Plasma Centrifugal Furnace [(a)] to Treat Soil

ELEMENT	FEED SOIL (ppm)	TREATED SOIL (ppm)	BSA MDL (ppm)	COMMENTS ON IGRIS UTILITY
*Cl	~300	NA	139	before treatment
As	201	12	2824	too high
Cr	25	500	193	after treatment
Pb	426	98	480	too high
Ni	NA	270	108	after treatment
Zn	23,214	6,475	541	both

NA - Not Analyzed

ND -Not Detectable

(a) Retech, Inc, Plasma Centifugal Furnace (June 1992), EPA/540/A5-91/007

* Chlorine concentrations estimated by authors.

Table 3. Examples of predicted minimum detectable levels for the 55-gal Barrel Inspection system.

Measurement Time = 10,000 seconds. Increasing Detectors from 6 to 12 and STNG output from $2x10^6$ to $8x10^6$ n/s decreases T to 1,250 seconds.

MODE	HOMOGENEOUS TARGET	POLLUTANT IN ONE VOXEL
element/isotope	MDL	MDL
A. PGRS:		
Cs-137	0.0091 picoCi/g	1.8 nanoCi
Co-60	0.0036 picoCi/g	0.73 nanoCi
Pu-238	92 nanoCi/g	18,357 microCi
Pu-240	7.5 nanoCi/g	1,505 microCi
Pu-242	0.043 nanoCi/g	8.6 microCi
Cm-242	0.00042 nanoCi/g	0.085 microCi
Z>95	0.00038 nanoCi/g	0.076 microCi
B. CGRS:		
Cl	163 ppm	33 grams
As	2,828 ppm	566 grams
Cr	225 ppm	45 grams
Ni	126 ppm	25 grams
Hg	71 ppm	14 grams
Cd	18 ppm	3.5 grams
U-235	13 ppm	2.5 grams
PU-239	10 ppm	2.0 grams
C. IGRIS:		
Cl	4,974 ppm	39.8 grams
Pb	2,893 ppm	23.1 grams
Zn	631 ppm	5.0 grams
As	3,294 ppm	26.4 grams
Cr	270 ppm	2.2 grams
Ni	424 ppm	3.4 g rams
Hg	2,009 ppm	16.1grams
Cd	767 ppm	6.1 grams
U-235	0.020 ppm	0.16 milligrams
U,U-238	0.040 ppm	0.32 milligrams
TRU	0.020 ppm	0.16 milligrams

NOTES: nanoCi for TRU is for alpha activity. Weight of 55-gal. barrel = 200 kg. Weight of a voxel = 0.3 kg. MDLs are for one element and vary with $T^{-1/2}$. The MDLs for a mixture of elements and TRU may be higher depending upon spectral interferences, which may be improved by Gamma-Ray Coincidence Spectroscopy. Prompt-gamma rays from fission are used to detect U and TRU and do NOT identify the radionuclides. Passive gamma-ray spectroscopy is used to identify and measure the concentrations of TRU radionuclides needed to calculate the TRU alpha activity. The addition of an HPGe detector may improve the analysis of mixtures of TRU and other elements.

Electrokinetics for Removal of Low-Level Radioactivity from Soil

Sibel Pamukcu, Ph.D.
Department of Civil Eng.
Fritz Engineering Laboratory
Lehigh University
Bethlehem, PA

J. Kenneth Wittle, Ph.D.
Electro-Petroleum, Inc.
Old Eagle School Road
Wayne, PA

ABSTRACT

The electrokinetic process is an emerging technology for in situ soil decontamination in which chemical species, both ionic and nonionic, are transported to an electrode site in soil. These products are subsequently removed from the ground via collection systems engineered for each specific application. Electrokinetics refers to the movement of water, ions, and charged particles relative to one another under the action of an applied direct current electric field. In a porous compact matrix of surface charged particles such as soil, the ion containing pore fluid may be made to flow to collection sites under the applied field. The process was demonstrated in the laboratory to show the viability of the electrokinetic treatment to move "contamination" through soil types of hydraulic conductivity as low as 10-8 cm/s to a directed location.

The work presented here describes part of the effort undertaken to investigate electrokinetically enhanced transport of soil contaminants in synthetic systems. These systems consisted of clay or clay-sand mixtures containing known concentrations of a selected heavy-metal salt solution. These metals included surrogate radionuclides such as Sr, Cs and U, and an anionic species of Cr. Degree of removal of these metals from soil by the electrokinetic treatment process was assessed through the metal concentration profiles generated across the soil between the electrodes. Removals of some metal species up to 99% were achieved at the anode or cathode end of the soil upon 24 to 48 hours of treatment or a maximum of 1 pore volume of water displacement toward the cathode compartment. Transient pH change through the soil had an effect on the metal movement, as evidenced by accumulation of the metals at the discharge ends of the soil specimens. This accumulation was attributed to the precipitation of the metal and increased cation retention capacity of the clay in high pH environment at the cathode end. In general, the reduced mobility and dissociation of the ionic species as they encounter areas of higher ionic concentration in their path of migration resulted in the accumulation of the metals at the discharge ends of the soil specimens.

The results of the laboratory study presented here indicate that electrokinetic enhancement of contaminant transport in soils is a viable technology of soil decontamination. The development of this technology for a wide range of applications hinges upon better understanding of the transient chemical and physical processes during application of current through soil/contaminant systems. The testing has clarified the need for site-specific design and control of the treatment operation so that once the contaminant is mobilized, it is kept in motion until transported out of the soil to a collection system in the most efficient manner. Chemical (pH control, complexing agents, etc.) and physical enhancement methods may be necessary in some situations to accomplish this goal.

INTRODUCTION

Electrokinetically enhanced transport of contaminants is perhaps one of the most promising in situ decontamination processes capable of feasibly removing heavy metals and organic contaminants from soils, sludges, and lagoons. The significance of the technology appears to be in its projected low operation cost and its potential applicability to a wide range of contamination situations. It is also viewed by researchers and industry as potential "problem solver" when all else appears nonworkable or fails to remediate a site. Present day urgency to develop feasible technologies to clean up soils and groundwater makes it germane to spend the time and effort necessary to look at the fundamental mechanisms associated with the technology and to develop it into a well-engineered and reasonably predictable process for field applications.

In this work, successful application of the technique was demonstrated on pure soil-contaminant-mixtures in the laboratory. The results of the work presented here also indicated that further development of the technology for a wide range of applications in the field hinges upon the better understanding of the transient processes during application of a DC current through soil. Some of these processes, such as net electroosmotic water flux and transient acid-base distributions, have been studied in the past and were confirmed in this study. The simultaneous interactions between different transient and physical processes that may take place in a complex system of soil, water, and contaminant are discussed. These processes have been identified as the physical and chemical interactions between soil components and the contaminants, soil surface physico-chemistry and its variation with pore fluid chemistry, and speciation and distribution of the contaminants.

A study of five soil types with 11 heavy metal elements and six organic compounds confirmed that electrokinetic treatment of soils is a promising decontamination process that is capable of removing contaminants from clayey soils. The degree of success of decontamination appeared to be parameter-specific, more dependent on the type of the contaminant to be removed than the type of the medium contaminated. Those contaminants whose chemistry was least affected by the transient chemical and physical processes during electrokinetics exhibited a significantly higher degree of removal than those that were affected. This trend was consistent despite the variations in soil type and properties. The contaminant levels selected in this program were typical of levels found at various DOE sites. The results of the full laboratory investigation can be found in other publications (Pamukcu and Wittle, 1992 and Wittle and Pamukcu, 1993). This paper deals with the radioactive cationic species of general interest: uranium, strontium, and cesium. In addition, experimental results for chromium are presented as an example of migratory trend of an anionic species for comparison.

BACKGROUND

Historical Development of Electroosmosis Theory in Soils

Electroosmotic phenomenon was first discovered by Reuses in 1808. The phenomenon was first treated analytically by Helmholtz in 1879, which later was modified by Pellat in 1904 and Smoluchowski in 1921. This theory is widely known as Helmholtz-Smoluchowski (H-S) theory, which relates electroosmotic velocity of a fluid of certain viscosity and di-electric constant, through a surface-charged porous medium of electrokinetic potential, ζ (zeta potential), under an electric gradient. The theoretical computation of electroosmotic water transport by this theory does not always agree well with experimental observations. The electrokinetic potential term in the H-S theory varies with pH and ionic concentration of the pore fluid, which is not a constant during electrokinetic treatment. Similarly, electric gradient is not constant in time and space due to the changing resistivity and oxidation/reduction state of the soil and also the aqueous solution near the electrodes.

A notable approach to electrokinetic process in porous medium was made by Spiegler (1958). He considered the interactions of the mobile components of soil (water and ions) on each other and the frictional interactions of these components with the pore walls. The true electroosmotic flow was expressed as the difference between the measured water transport and the ion hydration in moles per Faraday. This quantity was suggested to be directly proportional to concentration of free water in the soil pores and indirectly proportional to the concentration of mobile counterions in moles per volume. This suggested the phenomenon of water transport in the opposite direction of electroosmotic flow by the electromigration of the anions. Therefore, at any time during electrokinetic treatment, if the concentration of anionic species in the free water exceeds the cationic species, the opposite flow may retard the net water flow toward the cathode.

Gray and Mitchell (1967) showed experimentally that the electroosmotic flow increases with increasing water content of most soils, but decreases with increasing electrolyte concentration of the pore fluid. This electrolyte concentration effect is more evident in clays with high anion retention capacity, such as kaolinite, as opposed to montmorillonite (Bohn, 1985). Therefore, high electroosmotic flows are observed in kaolinite than montmorillonite types of clays at the same concentration of dilute solutions of electrolytes. This is consistent with the prediction of electroosmotic water transport according to Donnan concept.

Khan (1991) proposed a modified theory of electroosmotic flow through soil. In this theory the true electroosmotic flow is directly proportional to the current carried by the surface of the charged solid constituents of soil. The slipping plane potential (electrokinetic potential) used in H-S theory of electroosmotic flow is replaced by a constant surface potential that is invariable with electrolyte concentration. Hence, true electroosmotic flow becomes independent of electrolyte concentration in the pore fluid. The measured values agree well with the predicted flow using this modified theory. It also agrees with Speigler's formulation and much earlier observations of Napier in 1846 who stated that ". . . the measurable endosmose (electroosmosis) seems to be greatest when the current has greatest difficulty to pass through, and when the decomposition (of water) was least." This follows that the true electroosmotic flow is large when ratio of the surface current to the electrolytic current (carried by the ions in the pore fluid) is large due to reduced concentration of ions in the pore fluid.

Definitions and Some Theoretical Aspects of Electrokinetics

Electrokinetic treatment of soils invokes three electrokinetic processes: electroosmosis, electrolytic migration of ionic and polar species, electrophoresis and electrophoretic migration of colloidal electrolytes or ionic micelles.

Electroosmosis produces a rapid flow of water in low permeability soils and probably contributes significantly to the decontamination process in clay soils by advection transport. The current efficiency or the time rate of volume of water flow per current in electroosmosis is given by the following equation, where the surface conductivity, λs, of capillary surfaces in soil medium is considered (Hunter 1984):

$$V/i = -\epsilon_o \theta \xi / \eta (\lambda_o + 2\lambda_s / r) \qquad (1)$$

where

V = volume of water flow per time

i = current

r = radius of the capillary

λ_O = specific conductance of the bulk liquid

λ_s = surface conductance of the capillary

ϵ_o = permitivity in free space

θ = di-electric constant of the medium

η = viscosity of the medium

ξ = electrokinetic potential.

Surface current is due to the ionic motion in a region close to the solid surface called the diffuse layer. In narrow capillaries with low ionic concentrations and thick diffuse layers, a disproportionate fraction of the current flows in this layer due to the low conductivity of the bulk fluid and high conductivity of the diffuse layer. Experimental evidence shows that current efficiency decreases with increasing ionic concentration in the bulk fluid. This can be explained readily from Equation 1, since, and λ_o, is expected to increase with increasing fraction of ions in the solution. There is also evidence that ζ and θ/η decrease with increasing ionic concentration. The surface conductance also changes with ionic concentration. As the fraction of ions in the bulk liquid increase, the diffuse double layer shrinks toward the particle. The shear plane where the electrokinetic potential is measured, shifts away from the particle surface so that majority of the charge is now compensated by an immobile layer of ions in the diffuse double layer called the Helmholtz layer. Therefore

the charge density in the mobile portion of the diffuse double layer decrease, giving rise to a lower surface conductivity, λ_s. As a result of this lowered conductivity a smaller portion of the current flows on the capillary surface. In contrast, in presence of low ionic concentration the diffuse double layer is swollen and much of the charge is compensated by the ions in the mobile portion of the diffuse double layer. Therefore, the capillary surface conductivity is high and so is the fraction of the current that is transmitted on the surface. A detailed study of the significance of surface conductance on the prediction of electroosmotic flow as it relates to contaminant transport in soils is presented by Khan and Pamukcu [Khan (1991). and Khan et al. (1993)].

Electrolytic migration of ions is perhaps the major cause of conduction of current through a porous medium containing moderately concentrated aqueous solution of electrolytes. The ions migrate toward the electrode opposite to their charge. Their net velocity of migration, v_i, can be determined by superpositioning of three velocity components, $v_{i,\infty}$, $v_{i,\ relaxation}$, and $v_{i,\ electrophoresis}$, as given by the following equation (Kortum and Bockris, 1951):

$$v_i = v_{i,\infty} + v_{i,relaxation} + v_{i,electrophoresis} \qquad (2)$$

where, $v_{i,\infty}$ is the velocity of ion type $_i$ in infinite dilution, $v_{i,relaxation}$ and $v_{i,electrophoresis}$ are the retardation effects due to non uniform distribution of charge density around the moving ion and viscous drag of the counter ions moving in the opposite direction, respectively. These effects arise from the ionic atmosphere structure that develops in ionic solutions. Owing to electrostatic interaction and thermal motion, in a time average, there will be more negative ions than positive ions in the region of a positive ion, and vice versa. This region of ions (regarded spherical in shape) carrying a charge density of sign opposite to that of the central ion is called the ionic atmosphere of the central ion. The potential of an ion then depends on the interaction between the ion and its surrounding atmosphere.

Debye-Huckel (1923) calculated the potential, ψ, of the central ion with respect to its surrounding ionic atmosphere at a distance of closest approach to the ion. Accordingly:

$$\psi = (z_i\, e_O/\theta a) - (z_i\, e_O/\theta)(\kappa/(1+\kappa a) \qquad (3)$$

where, z_i = valence of central ion, e_O = electronic charge, κ = Debye-Huckel parameter; θ = di-electric constant of the medium inside the ionic atmosphere sphere, and a = distance of closest approach to the central ion or sum of the radii of the oppositely charged ions in contact. The first term on the right hand side is the potential at the surface of the ion and it is solely due to the charge of the ion itself. The second term is dependent on the ionic concentration and it is due to the ionic atmosphere surrounding the central ion. The inverse of κ, or $1/\kappa$, is taken as the thickness of the spherical ionic atmosphere.

If an external potential gradient is applied on a solution of a selected ion, it will tend to migrate with a velocity, $v_{i,\infty}$, determined by its characteristic ionic mobility and independent of the presence of other ions. The ionic atmosphere, however, being oppositely charged to the central ion, will tend to migrate in the opposite direction, taking with them their solvent tights. The central ion therefore travels against a medium moving in the opposite direction, which results in an additional viscous drag on the ion. This phenomenon is called the electrophoretic effect. Another effect that retards the ionic velocity is the relaxation effect (Onsager 1928). This phenomenon comes about as the central ion is suddenly moved in its atmosphere, the atmosphere will tend to attain an asymmetrical shape about the central ion due to time lapse between the responses of the central ion and the ionic atmosphere. If the central ion moves steadily in the applied electric field, the effect of a permanent distortion of the ionic atmosphere will tend to retard the ionic velocity. The average charge density will tend to decrease in front of the moving ion and it will decrease behind it. The excess charge behind the ion exercises an electrostatic retardation on the moving ion. The magnitudes of retardation of the electrophoretic and the relaxation effects are directly proportional to the ionic concentration. As the ionic concentration increases, the charge density of the ionic atmosphere increases; therefore, the forces associated with the electrophoretic and electrostatic retardation increase.

Electrophoresis is the migration of charged colloids in soil-liquid mixture. In a compact system of porous plug, electrophoresis of should be of less importance since the solid phase is restrained from movement. In

some cases, however, electrophoresis of clay colloids may play a role in decontamination if the migrating colloids have the chemical species of interest adsorbed on them. An important contribution of electrophoretic movement to contaminant transport may be when the contaminants are in the form of *colloidal electrolytes* or *ionic micelles*. Colloids that are made up of ionizable groups attached to large organic molecules, macro molecules, aggregate of ions belong to a class of substances known as colloidal electrolytes or ionic micelles. Ionic micelles form by aggregation of particles of like sign when the attractive dispersive forces are greater than the coulombic repulsive forces between the groups (Kortum and Bockris 1951). Micelle formation is promoted as the concentrations of the aggregating groups increase. Ionic micelles often carry a high charge owing to the many ions they contain. Although they are large and exhibit higher frictional drag in motion, the high charge will tend to increase their mobility at a greater rate than the frictional drag would tend to reduce. Therefore, ionic micelles often exhibit high conductance in dilution.

The conductance of ionic micelle solutions increases with increasing concentration owing to build up of charge with further aggregation. However, with many systems there is a sudden and sharp decrease of conductance at a critical concentration, which is attributed to (a) increasing association of the ionic colloids, which results in increased fraction of neutral colloids, and (b) retarding interionic forces (electrophoretic and relaxation effects), which could be especially powerful with the large charges that these ionic micelles carry. At high electrolyte concentrations of the bulk liquid, the double layer around the micelle shrinks causing the ratio of the particle radius to its diffuse layer thickness, (κa), to increase. This reduction signifies an appreciable compensation of the charge on the micelle so that at small distances the electrostatic repulsion is reduced. As a result the micelles tend to coagulate; thus, their mobilities are retarded. A numerical solution provided by O'Brien and White (1978) shows the variation of electrophoretic mobilities with electrokinetic potential (ζ) and κa. They show that, for large κa values ($\kappa a > 3$) increasing electrokinetic potential beyond a threshold value actually results in reduced mobility for ionic micelles and colloidal electrolytes.

Other Electrokinetic Processes in Soils

One of the important aspects of electrokinetics in soil-water systems is the transient migration of an acid front from the anode site to the cathode site during treatment (Acar et al. 1990, Shapiro et al. 1989). When water decomposes, it is reduced to hydrogen gas at the cathode and oxidized to oxygen gas at the anode. This results in progressive reduction of pH at the anode site, and increase of pH at the cathode site. Subsequently the hydronium ions produced at the anode migrate toward the cathode, whereas the hydroxide ions produced at the cathode migrate toward the anode. The ionic mobility of the hydronium ion is nearly twice as high as that of the hydroxide ion and its migration is further enhanced by the electroosmotic flow of water toward the cathode. The benefits of increased hydrogen ion concentration would be most evident in extraction of metals, since hydrogen ion will tend to exchange with metal ions held on clay surfaces and low pH condition is favorable for the dissolution of most metal precipitates making them available to migrate or be transported. In natural soils, however, the buffering capacity is often high, which would tend to neutralize the acid front and maintain a higher pH environment.

The transient and spatial variation of pH affect soil surface properties such as cation exchange capacity, ion (cation and anion) adsorption capacity, and magnitude of electrokinetic potential, ζ, and its sign. Furthermore, speciation and solubility of the contaminants are often pH dependent. The distribution of these contaminants would be transient and spatially varied with pH and redox potential during electrokinetic treatment. The pH-redox conditions at a point at any time during the treatment would determine the solubility and speciation of most heavy metal constituents. These conditions may limit or enhance the movement of the metals to an electrode site.

Extraction of contaminants by electrokinetic method is based on the assumption that the contaminant is in liquid phase in the soil pores. Electroosmotic advection should be able to transport non-ionic as well as ionic species through soil toward the cathode. This is perhaps best achieved when the state of the material (dissolved, suspended, emulsified, etc.) is suitable for the flowing water to carry it through the tight pores of soil without causing an immovable plug of concentrated material to accumulate at some distance from the anode. Polar organic molecules, ionic micelles, and colloidal electrolytes should migrate under the influence of field as well as being transported by the water. The size of these molecules or micelles and their tendency

to agglomerate or be adsorbed on to soil surfaces are probably the main factors that control their removal from soil pores by electrokinetics. Removal of cationic species on the other hand, should be enhanced with the electroosmotic flow of water as they migrate toward the cathode electrode by the applied potential. It is yet unclear the relative magnitude of contribution of either process (electroosmosis and electrolytic migration) to decontamination under a given set of initial and boundary conditions determined by the soil and contaminant type and also their interaction. However, recent findings indicate that at low concentrations of cations, electroosmotic water flow may contribute a significant percentage, if not all, to the overall decontamination process (Khan 1991). At high concentrations of the ionic species, electrolytic migration, intensity of electrochemical reactions, auxiliary water movement by frictional dragging of water by ions (cations and anions) may play more important roles than electroosmosis in the decontamination process.

One of the indicators often used to characterize electroosmotic process is the *current efficiency*, or the time rate of volume of water flow per current. Experimental as well as analytical treatment (Equation 1) of the matter shows that the current efficiency decreases with the ionic concentration of the soil pore water (Renaud and Probstein 1987, Gray and Mitchell 1967, and Pamukcu and Wittle 1992). Current efficiency increases with decreasing ionic concentration as the conductivity of the soil surface increases and the water flow is primarily controlled by the mobile layer of ions in the diffuse double layer of the clay capillary, rather than the frictional dragging of the migrating ions in the bulk fluid. This type of flow is probably closer to true electroosmotic flow in which the contribution of ionic motion in the bulk fluid to the overall flow is minimum. Additional evidence to support this finding was presented by Pamukcu and Wittle (1992, 1993) where the ionic concentration effect on the measured current efficiency appeared to be most pronounced in clays with high anion retention capacity. At the same concentrations of dilute solutions of electrolytes, kaolinite clay with higher anion retention capacity showed consistently higher electroosmotic flow than montmorillonite clay with lower anion retention capacity. This observation suggested that the anionic dragging of water toward anode diminished the net flow toward the cathode compartment in the montmorillonite clay. This also provided an explanation to the lower current efficiency observed in these clays in contrast to that observed in kaolinite clays.

Application of Electrokinetics to Soil Decontamination

Electrokinetics have been used for dewatering of soils and sludges since the first recorded use in the field by Casagrande in 1939. Work and subsequent research in electrokinetic decontamination of soils have been accelerated in recent years, probably after the report of the detection of high concentrations of metals and organics in electroosmotically drained water of a dredged sludge in the field by Segall and coworkers in 1980. Other field work (Lageman 1989, Banerjee et al. 1988) has been conducted since then with reasonable success of heavy metal transport.

Hamnett (1980) performed laboratory studies on electrically induced movement of ions in sand. In evaluating the electrolytic migration of ions of different salts, he found that smaller ions (e.g., Na) were more mobile than larger ions (e.g., K, Ca, Ni). Acar et al. (1991) and Hamed et al. (1991) showed that the migration of an acid front from the anode toward the cathode is significant in the removal of heavy metals from clay soils. Shapiro and coworkers (1989) developed a model for electroosmosis to predict transient behavior of concentration profiles for chemical species in solution. The model agreed well with experimental results of acetic acid removal from soil via electrokinetics.

A simple prediction method was suggested by Khan (1991). The theoretical approach developed for electroosmotic flow was used to predict the contaminant removal from soil when the contaminants were either present at low concentrations in the soil pores or they were not adsorbed onto the charged surfaces, so that the true electroosmotic flow was the dominant mechanism for their migration. Tracer experiments in kaolinite clay utilizing O-Nitrophenol and zinc as representative contaminants were conducted. O-Nitrophenol represents a poorly adsorbed organic compound, the adsorption of which was measured on the order of 0.01 mg/g of soil. The zinc concentration used was 325 mg/kg of dry soil, which was slightly over than the typical maximum concentration of naturally occurring zinc (10–300 mg/kg) in soils. There was good agreement between the measured removal of the contaminant and the predicted removal using electroosmotic flux of water based on clay surface current. Experiments with higher concentrations of zinc showed clearly the effect

of speciation and precipitation on the efficiency of the electrokinetic transport of metals (Pamukcu et al. 1991).

INVESTIGATION

Experimental Procedures

An laboratory program was undertaken to investigate the feasibility of electrokinetic treatment of clay mixtures containing heavy metals. The test matrices were prepared in the laboratory by compressing slurries of clay to compact saturated soil samples. Each clay slurry was mixed with solution of one heavy metal salt of a predetermined concentration. The mixing water of the slurries was also changed to distilled water, a solution of a humus product representing humic acids in natural soils, and water with dissolved salts representing the ionic constituents of a selected groundwater type. Each specimen type (clay, pore solution and metal type) was prepared in triplicate and tested under the same conditions, but with variable duration of treatment for some of the triplicate sets. A matrix of metals and soil types constituted the materials for producing artificial contaminated soil systems in the laboratory. Metals evaluated in the program were representative of those found at a majority of DOE sites. They included the classes of metals (Cd, Hg, Pb, Ni, Zn), surrogate radionuclides (Co, Cs, Sr, U), anions (HAsO4, Cr_2O_7). Five soil types were studied: kaolinite clay, Na-montmorillonite clay, sand with 10% Na-montmorillonite, kaolinite clay with simulated groundwater, and kaolinite clay with humic substances solution. The minimum test duration was 24 hours in general. A number of the replicate tests were extended into longer periods (up to 48 hours) to investigate the transient behavior of the transport. During each test, the systems were monitored for voltage, current, inflow and outflow of liquid through the soil. After the test, the soil samples were analyzed to construct metal and organic contaminant concentration and also pH profiles along the length of the sample to assess the success of decontamination.

In this paper, only the results pertaining to the surrogate radionuclides (Cs, Sr, U) and an anionic species, Cr_2O_7, are presented and discussed.

Materials

The clays used in preparing the soil matrices were kaolinite (Georgia kaolinite) and Na-montmorillonite (bentonite), both obtained commercially. The sand specimens were prepared with washed beach sand passing No. 40 sieve and retained on No. 100 sieve. This variation in soil mineral matrix was intended to investigate the process in so assumed difficult situations of remediation when the ionic species are strongly held on the clay surface (Na-montmorillonite case), or when the electroosmotic flow efficiency might be reduced due to reduced surface charge density (sand case). The sand matrix was prepared with the clean beach sand mixed homogeneously with 10% Na-montmorillonite by dry weight.

The pore solutions were distilled water, humic solution and simulated groundwater. The humic solution was prepared by dissolving a commercially obtained humus product in distilled water at a concentration of 900 ppm. The organic carbon content of this stock solution was 257 as measured in mg C/l. This corresponded to DOC values typically measured in groundwaters associated with very high organic carbon fields, such as oil fields. The pH of this solution was 9.4. The simulated groundwater was prepared following an approximate formula of the groundwater salt constituents typically found in the Jefferson County of Idaho State. The pH of groundwater sampled in that region was measured at 8.2, and contained a substantial amount of (212 ppm) bicarbonate. The simulated groundwater did not contain this component and its pH was measured as 7.9.

The salts used in preparing solutions of the four metals and the metal concentration of each resulting solution as well as the resulting concentration of the metal in soil and the soil slurry pH prior to electrokinetic treatment are given in given in Table 1. In general the pHs of the mixtures were moderately acidic or near neutral.

Procedures

The slurries would be mixed at 100% water content of the kaolinite clay, 50% water content of the sand mixture, and 200 - 300% water content of Na- montmorillonite clay, all by dry weight of the solid components. The mixing would be done in large batches (2-3 gallons) with a tall hand-held mixer. Then the slurry would be poured into individual compression units referred to as "consolidometers" as shown in Figure 1. The operation of these units is presented elsewhere (Khan 1991). The main features of the consolidometers are that they are capable of applying small increments of sustained stress (pneumatically) while allowing for the excess fluid to drain out slowly. This procedure creates homogeneous, near-saturated soil matrices compacted to a constant density and pressure. The most beneficial aspect of these custom manufactured units is that at the end of the consolidation process, the densified soil sample is packed into a cylindrical soil chamber (3.556 cm ID and 7.62 cm long), which can be detached from the unit and installed into the electrokinetic cell used in this investigation (Figure 2). As a result, the soil specimen is not disturbed by handling such as trimming and placement.

All the specimens were consolidated to 200 kPa pressure. Although there is evidence, from this work and also others, that electroosmotic flow increases with consolidation pressure in clay soils, it is not well known to what extent the increased flow contributes to decontamination when the contaminant migration is not governed by electroosmosis. The average initial and final dry densities and water contents of the five artificial soil types are given in Table 2. The average water contents increased from the initial state to after electrokinetic treatment state by about 3 to 20%, whereas the bulk densities showed reduction by about 0.5 to 9%. These changes indicated that during the treatment, the electroosmotic water flow did not cause any volume contraction of the soil; on the contrary, the degree of saturation increased and some particulate material was lost to the water chambers due to electrophoretic migration.

At the completion of each consolidation period, the tube containing the packed soil would be removed, and the top extruding portion would be trimmed and stored for quantitative chemical and water content analysis. Samples of the waters extracted during consolidation were also taken for chemical analysis to assess the degree of metal retention by clays. The approximate period of consolidation to 200 kPa pressure was around 24 hours for the kaolinite slurries and it was around 7 days for the Na-montmorillonite clays slurries. This period was much less for the bentonite mixed sand specimens, but the pressure increment periods for these were kept similar to that of the kaolinite specimens for consistency. When the soil cylinder was removed from the consolidometer, weighted and sampled, it would be ready for mounting on the electrokinetic apparatus, the schematic diagram of which is given in Figure 2.

The details of the electrokinetic apparatus used in this study are also provided elsewhere (Khan 1991). It should be noted that there is no standard apparatus for measuring electrokinetic water flow in soils. The ones that are used in similar work elsewhere have been shown to produce consistent results. The equipment used in this particular program was developed with attention given to a few concerns. These were addressed by providing larger electrode surfaces than soil surface to achieve low current density, by isolating the electrodes from soil surfaces to minimize electrode reactions at these boundaries, and by providing convenient ports for gas expulsion from the electrode sites and also for extracting inflow (anode site) and outflow (cathode site) water samples for analysis. The main features of these units are the electrodes reside in watertight chambers that are connected to measuring burettes at one end and to the soil specimen cylinder at the other end. The soil specimen is separated from these water-filled chambers by carborandum porous stones. This allows the contaminants to come out into the liquid phase and not be deposited on the electrodes. These units can be operated under constant potential or constant current. The time-dependent water movement through the soil can be measured on the inflow (anode side) and outflow (cathode side) tubes on individual control panels. These panels are each equipped with a pressure regulator and gauge for hydraulic potential application capability. The control panels also carry small pumps to drain the electrode chamber periodically as necessary to remove the extracted material and alleviate concentration polarization.

The tests, results of which are reported here, were conducted under a constant potential of 30 VDC across electrodes. The voltage in soil and the current generated were measured simultaneously with the flow measurements. The tests were continued for at least 24 hours. For a number of randomly selected

combinations of soil, pore fluid, and metal, the termination times were varied between the triplicate samples from 24 hours to up to 48 hours. For a number of extended hours of treatment, the electrode chambers (both anode and cathode) were drained at around 24 hours and refilled with the appropriate pore water used in the soil specimen. This was done to alleviate concentration polarization and the high pH gradients created between the chambers, which was thought to reduce water flow rate originally. However, this practice did not prove to be effective for increased contaminant removal or water flow rate, since the pH in the electrode compartment waters build up to their previous levels in a matter of minutes.

At the termination of each experiment, the electrode chamber waters would be collected. These water samples were analyzed for the particular metal extracted and their pHs were measured. The cathode water pHs ranged from around 10 to 12, whereas the anode water pHs ranged from 2 to 3 in general. The cathode chamber water was acidified to solubilize the metal precipitates created at the high pH environment in that chamber. The soil specimen would then be extracted, pH measurements taken at the anode end, center and the cathode end. Specimens from each one of these locations were collected for chemical analysis of the particular metal extracted.

Results

The analysis of the data showed metal migration in all soil specimens. Considering the lowest concentration of a particular metal achieved at one of the three locations (anode end, center, cathode end) of the soil cylinder, the metal removal success was up to 99% for the durations of treatment that did not exceed 50 Hs. This removal is computed as 1 minus the ratio of the remaining concentration to the original concentration of the metal. Table 3 summarizes the average of percentage of metal concentration reduction for three replicate specimens at the location of lowest concentration measurement after 24 to 48 hours of electrokinetic (E-K) treatment. Also shown in Table 3 is the average cumulative fraction of pore volume of water transported through the specimens toward the cathode compartment during the treatments. The variations in these concentration reduction percentages appeared to depend on soil matrix, the metal and pore fluid type. They appeared to have little or no correlation with the volume of flow achieved during treatment.

As observed from Table 3, for the cationic species, the volume of water represented as the fraction of pore volume for each soil specimen ranged between 0.25 and near 1.00. The flow for the anionic form of Cr was consistently lower that of the cationic species. This demonstrated the effect of water dragging action of migrating ions on the net flow toward cathode. In the case of Cr_2O_7, as the anion migrates toward the anode, it drags along with it sufficient amount of water to measurably reduce the net flow toward the cathode, which is the electroosmotic flow.

Figures 3 through 6 show the fraction of metal with respect to its original quantity in soil, found at different locations in the cylindrical soil specimen as well as in the anode and cathode compartment waters. These graphs represent the average data for three replicate specimens for each soil type. It should be noted here that the metal concentration analyses across the soil specimens were made by sampling only three points along each specimen. The actual concentration profile at the time of sampling may not be well represented by the linear or best fit distributions assumed between the consecutive points. Therefore, it is not possible to predict degree of removal of the contaminant from the areas under the concentration curves, neither it is possible to arrive at an accurate mass-balance prediction. Nevertheless, the data presented are consistent and show a clear trend of metal migration toward an electrode site in each case.

As observed from the first three figures (Sr, Cs, U), the cations are transported to the cathode end of the soil where they tend to accumulate. The transport mechanism is probably all governed by electromigration since there appears to be very little or no correlation between the measured fraction of the metals in the cathode chamber or the fraction gradient in the soil and the quantity of water transported (see Table 3). In Figure 6, chromate is removed into the anode chamber and a majority of it has accumulated on the anode end of the soil. This migration took place in the opposite direction of water flow, since a net water flow was measured toward the cathode for all the chromate contaminated specimens.

All the metals, both anionic and cationic, accumulated at their discharge locations, creating zones of high concentrations of metal (sometimes over that of the original). These zones are perhaps very narrow residing at the interface between the soil and the electrode chamber, which is analogous of depositing the metal on an electrode if it was in contact with soil. In the case of cations, the production of hydroxide in the cathode chamber is one of the major causes of the phenomena. As the hydroxide ions migrate into the soil, they create a high pH zone in the soil before they encounter the oncoming hydronium ions and be neutralized. This zone may lessen in thickness as the acidic front penetrates more toward the cathode end of the soil; however, as long as there is a high pH gradient at this discharge end, the metals would tend to form hydroxide complexes and start to precipitate from solution in a thin zone of soil at the interface of electrode chamber water. Another effect of high pH is on the adsorption capacity of the clay soils. Hydroxide ions are potential makers, which subsequently cause the cation adsorption capacity of the soil to increase. Therefore, at high pH, the surface potential will increase, leading to thicker diffuse layers and increased surface conductivity. Since the bulk liquid conductivity would be reduced with precipitation, the combined effect should actually signal increased electroosmotic water transport and current efficiency. This suggests that with extended duration of treatment, the accumulated metal may be transported into the electrode chamber by the steady but slower action of electroosmotic advection.

A similar accumulation is observed with the chromate ion, which migrates toward a low pH area (Figure 6). This occurrence demonstrates the effect of another important phenomenon that delays the metal discharge from soil by electrokinetics. If a triggering mechanism, such as increased adsorption, precipitation, starts delaying the removal at the discharge location, the metal concentration will quickly build up there as more of the ions migrate into the area. When the ions encounter the high concentrations, their velocities decrease due to the electrophoretic and relaxation effects discussed above. In the case of chromate, increased potential for anion adsorption of the clay at low pH may have triggered the accumulation of the metal at the anode end. Nevertheless, it is remarkable to observe the relatively high removal of Cr into the anode chamber in the presence of opposing water flow.

Strontium

Strontium remains a divalent ion for a large range of pH values. Figure 7 shows the average pH distribution from anode to cathode end of three replicate specimens of five soil types. The pH ranges from about 2 to 10, through which Sr is expected to remain a divalent ion. Figure 8 shows typically, the normalized concentration profiles of Sr for the three specimens of kaolinite and distilled water soil. Specimen labeled as KGSrHM1 showed a slight accumulation of the metal at the cathode end by the end of 24 hours of treatment. The pore volume fraction of water transported for this specimen was measured to be approximately 0.4. When the duration of treatment was increased beyond two days, the cathode end concentration diminished resulting with a more or less uniform distribution of the metal throughout soil. The pore volume fraction of water for this specimen labeled as KGSrHM3 was 0.6. Long-term tests on Sr contaminated kaolinite soil with distilled water showed nearly complete removal of the metal after about 4 pore volumes of water transport (Wilkowe 1992). This suggests that the removal rate is not constant and decreases with duration of treatment depending upon the interactions between the soil and the metal. The accumulation of the metal at the cathode end (Figure 3) is attributed initially to the increased ion retention capacity of the soil, which subsequently triggers the concentration increase and deceleration of the migrating ions at this end. However, with extended treatment, the electroosmotic flow enhances the removal at a steady but slower rate. Figure 9 shows the steady state flow achieved for up to 18 pore volume of water flow through Sr contaminated kaolinite soil. As observed, after about 4 pore volume of flow, (by which nearly all Sr was removed from soil) the measured current dropped to a constant value of 0.5 mA and stayed constant throughout the treatment. This shows depletion of the bulk current carriers and mobilization of the surface conductance of the clay, which is now constant at constant ionic concentration.

Cesium

Cesium is a monovalent cation that is a strong exchanger in most clays. Similar results were observed with Cs as those of Sr. In the Cs case, however, the rate of removal appeared to be slower than the Sr case. This is perhaps due to the lower ionic mobility and larger ionic atmosphere of Cs, which resulted in lowered

electromigration velocity. The affinity of the clay to Cs may have also contributed to the delayed response. It is interesting to note the reduced initial Cs concentration with the humic solution in the pore fluid. In making the slurry specimens, the humic solution was first mixed with the cesium salt before adding the clay to make the slurry. It appears that most of the cesium was retained on the organic component of the humic solution that was drained out during the consolidation of the slurry. The affinity of the humic solution to Cs is also evident in Figure 4, in which there is a significant fraction of Cs removed into the cathode chamber in kaolinite clay with humic solution as the pore fluid and also as the permeant. During the period of tests (24 to 48 hours), more than 40% of the metal was transported into the cathode chamber of the kaolinite soils, as can be seen in Figure 4.

Figures 10 through 13 show the post E-K concentration profiles of Cs achieved in replicate specimens of 4 soil types. In general, the concentration profiles shifted down in a uniform manner with increasing duration of treatment. The repeatability of data for similar durations of treatment and similar initial concentrations of Cs was good.

Uranium

Uranium removal was not as efficient as that of Sr and Cs, however, there was definite migration of the metal toward the cathode end where it accumulated at concentrations higher than the original (Figure 5). Uranium was introduced into the soil as the uranyl salt from a series of hydroxide complexes. Below the pH of 6 they are cationic in nature. At approximately pH 6, the $UO_2(OH)_2.H_2O$ precipitate. At higher pHs, the anion hydroxide species such as, $UO_2(OH)_3$- and $UO2(OH)_4$-2 occur which would than migrate in the opposite direction of electroosmotic water flow. These species may not be able to travel to the anode chamber since they would encounter a low pH environment on the way and tend to change form and sign. However, as long as a high pH gradient prevail at the interface of the soil and water at the cathode end, the uranium would be difficult to transport into the water phase by electromigration. Therefore very little fraction of the metal is encountered in the cathode chamber, which probably was transported prior to the high pH build up, and by electroosmotic advection and diffusion. The effect of diffusion is also evident in the anode chamber, in which there is nearly as much Uranium as there is in the cathode chamber. Migration of anionic species might have contributed to removal into the anionic chamber also.

Chromium

Figures 14 and 15 show typical migration of chromate toward the anode. Chromate (chromium in the hexavalent oxidation state) is an anion that carries a negative 2 charge. As observed, the concentration profiles shift downward with increased duration of treatment with slight accumulation at the anode end of the soil. Figure 6 shows that, approximately 30% of the Cr is extracted into the anode chamber by the end of 24 to 48 Hs of treatment. As discussed before, the remarkable aspect is that the electromigration of the ion takes place regardless of the water flow in the opposite direction. Also owing to the water dragging action of the migrating anion, the flow measured at the cathode end was consistently less than that of cationic transport cases. The concentration gradients across the soils for the Cr cases were less than the others, signaling the retarding effect of the electroosmotic flow in the opposite direction. Once again, there was accumulation of the metal at the discharge end due to anion retention and deceleration of the ionic motion due to electrophoteric and relaxation effects.

CONCLUSIONS

The main conclusion of this research has been that electrokinetics promises to be a viable technology to remove contaminants from soils. The interaction of various processes that take place simultaneously is yet to be understood to better predict the efficiency of the process in a variety of soil-contaminant situations. The results presented in this paper shed light on the influence of electrochemistry and physico-chemistry of the soil-contaminant system on the process. The transient acid front movement in soil from anode site to cathode is beneficial for metal desorption and dissolution, which in turn contributes to the removal process. However, the transient pH condition causes formation of complex species of some metals that may hinder the process, or in some cases may enhance it. pH also affects the surface charge characteristics of clay soils, either

enhancing desorption or adsorption. Therefore pH control at both ends (anode and cathode) should create suitable environments for the metal ions to remain in solution and in the bulk pore liquid, so that they can be extracted in a feasible manner. If these factors that trigger ion concentration build up at the discharge ends of a soil-electrode system can be controlled or alleviated, then electromigration alone should be sufficient to remove metal contaminants from soil with minimum water flow.

This study demonstrated that substantial migration of the surrogate radioactive metals such as Sr, Cs, and U is achieved by electrokinetics in short durations of treatment in which the water flow through the soil was on the order of half the total volume of pores in the soil matrices. For Sr and Cs, total removal of the metals up to 80% into the cathode water chamber was achieved for the short durations of treatment. Substantial migration and cathode end accumulation of uranium occurred in all soil types tested. Little removal of U (less than 20%) into the electrode chamber waters was achieved due to precipitation and speciation of the metal in the soil. However, substantial reduction of the metal was achieved at the anode side half of the soil. Cr, as an anionic species, moved toward anode against the electroosmotic water flow. In this case, up to 30% total removal of Cr was achieved for net water flows of less than 0.2 fraction of pore volume of the soil specimens.

ACKNOWLEDGMENTS

This research was funded by the Office of Technology Development, Office of Environmental Restoration and Waste Management, U.S. Department of Energy, managed by Argonne National Laboratory, Contract No. 2112406.

REFERENCES

Acar, Y. B., Gale, R.J, Putnam, G., Hamed, J., and Wong, R., (1990), "Electro Chemical Processing of Soils: Theory of pH Gradient Development by Diffusion and Linear Convection," *J. Envir. Sci. and Health, Part (a); Envir. Sci. and Engrg,, 25 (6).*

Acar, Y. B., Hamed, J., Gale, R.J., and Putnam, G., (1991), "Acid/Base Distributions in Electroosmosis," *Transportation Research Record No. 1288*, pp. 23-34, TRB, Washington, D.C.

Banerjee S, Horng, J, Ferguson, J.F, and Nelson, P.O., (1988), *Field Scale Feasibility Study of Electrokinetic Remediation Report*, USEPA, Risk Reduction Laboratory, Cincinnati, OH.

Bohn, H. L., McNeal, B.L. and O'Connor, G.A., (1985), *Soil Chemistry*, John-Wiley & Sons, New York.

Casagrande, L., (1949), "Electro-Osmosis in Soils," *Geotechnique*, London, England, Vol. 1, No. 3, p. 159.

Debye, P., and Huckel, E., (1923) , *Physik*, Z., 24, 185, 305.

Gray, D. H., and Mitchell, J.K, (1967), "Fundamental Aspects of Electro-Osmosis in Soil", *J. of the Soil Mech. and Found. Div.*, ASCE, SM 6, pp. 209-236.

Hamed, J., Acar, Y.B. and Gale, R.J., (1991), Pb(II) "Removal From Kaolinite by Electrokinetics," *J. of Geotech. Eng. Div.*, ASCE, Vol 117, No. 2, pp. 241-271.

Hamnett, R., (1980), *A Study of the Processes Involved In Electro-Reclamation of Contaminated Soils*, Dissertation, University of Manchaster, England.

Hunter, J. H., (1984), "Double Layers in Colloidal Systems," Ch 9 in *Comprehensive Treatise of Electrochemistry, Vol 1: The Double Layer*, eds. Bockris, Conway and Yeager, Plenium Press, New York and London.

Khan, L. I., (1991), *Study of Electroosmosis in Soil: A Modified Theory and Its Application in Soil Decontamination*, Dissertation, Lehigh University, Bethlehem, PA.

Khan, L.I., Pamukcu, S., and Fang, H.Y., (1993), "A Modified Theory for Electroosmosis in Soil," *J. of the Geotechnical Eng. Div.*, ASCE, New York, (revised, working paper).

Kortum, G. and Bockris, J.O'M., (1951), *Textbook of Electrochemistry*, Vol I &II, Elsevier Publishing Co., New York, Amsterdam.

Lageman R., (1989), "Theory and Practice of Electro-Reclamation," *NATO Pilot Study: Demonstration and Remedial Action Technologies for Contaminated Land and Groundwater*, NATO/CCMS, Copenhagen, Denmark.

Napier, (1846) *J. Phil. Mag.*, 29(10).

O'Brien, R.W. and White, L.R., (1978), *J. Chem. Soc.* Faraday Trans. II 74, 1607.

Onsager, L. (1928), *Physik.*, Z., 28, 277

Pamukcu, S., Khan, L.I. and Fang, H.Y., (1991), *Zinc Detoxification of Soils by Electro-Osmosis, Transportation Research Record No. 1288*, pp. 41-46, TRB, Washington, D.C.

Pamukcu, S. and Wittle, J.K. (1992), "Electrokinetic Removal of Selected Heavy Metals From Soil," *Environmental Progress*, Vol 11, No.3, pp. 241-250, American Institute of Chemical Engineers.

Wittle, J.K. and Pamukcu S., (1993), *Electrokinetic Treatment of Contaminated Soils Sludges and Lagoons*, DOE/CH-9206, Argonne National Laboratory, Chicago, IL.

Renaud, P.O., and Probstein, R.F, (1987), "Electro-Osmotic Control of Hazardous Waste," *Physico Chemical Hydrodynamics*, 9(1/2), pp. 345-360.

Segal, B.A., O'Bannon, C.E. and Matthias, J.A., (1980), "Electro-Osmosis Chemistry and Water Quality," *J. of the Geotech. Eng. Div.*, ASCE, Vol. 106, No. GT10, pp. 1143-1147.

Shapiro, A.P., Renaud, P.C., and Probstein, R.F., (1989), "Preliminary Studies on the Removal of Chemical Species from Saturated Porous Media by Electro-Osmosis," *Physico Chemical Hydrodynamics*, 11 (5/6).

Spiegler, K.S., (1958), "Transport Process in Ionic Membranes," *Transactions of the Faraday Society*, Vol. 54, Part 9, p. 1408-1428.

Wilkowe, A., (1992), *Modeling of Electrokinetic Decontamination of Soils*, Thesis, Department of Civil Engineering, Lehigh University. Bethlehem, PA.

Table 1. Some Chemical Properties of the Contaminated Soil Specimens Used In E-K

Sample Code ①	Metal	Salt Formula	Initial Solution Concentration mg/l	Initial Soil Concentration mg/kg②	Initial pH of Soil Slurry
KS	Blank	...	...	...	4.36
	Cs	$CsNO_3$	1000	693	
	Cr	$H_2Cr_2O_7$	3000	1850	4.91
	Sr	$SrCl_2.6H_2O$	1000	686	4.31
	U	in 2% HNO_3	100	51	2.44
KH	Blank	...	...	...	6.26
	Cs	$CsNO_3$	1000	197	...
	Cr	$H_2Cr_2O_7$	3000	1320	5.42
	Sr	$SrCl_2.6H_2O$	1000	703	5.96
	U	in 2% HNO_3	100	90	3.25
KG	Blank	...	...	...	5.37
	Cs	$CsNO_3$	1000	915	5.98
	Cr	$H_2Cr_2O_7$	3000	1482	4.14
	Sr	$SrCl_2.6H_2O$	1000	564	5.97
	U	in 2% HNO_3	100	59	2.50
MS	Blank	...	...	...	7.94
	Cs	$CsNO_3$	1000	6886	...
	Cr	$H_2Cr_2O_7$	3000	5639	5.92
	Sr	$SrCl_2.6H_2O$	1000	4432	7.83
	U	in 2% HNO_3	100	1108	8.42
SS	Blank	...	...	...	7.34
	Cs	$CsNO_3$	1000	853	...
	Cr	$H_2Cr_2O_7$	3000	972	6.79
	Sr	$SrCl_2.6H_2O$	1000	463	8.2
	U	in 2% HNO_3	100	98	7.56

① KS: Kaolinite/distilled water; KH: Kaolinite/humic solution; KG: Kaolinite/ground water
MS: Na-montmorillonite/distilled water; SS: Sand /10% Na-montmorillonite/dist. water

② Average of three replicate samples

Table 2. Average Water Content and Dry Density of Specimens Before and After Electrokinetic Treatment

Sample Code	Before E-K		After E-K	
	Water Content %	Bulk Density g/cm^3	Water Content %	Bulk Density g/cm^3
KS	47.3	1.64	56.2	1.62
KH	51.4	1.66	54.0	1.54
KG	32.8	1.83	39.5	1.73
MS	271.8	1.14	321.6	1.03
SS	51.3	1.67	53.0	1.66

Table 3. Average Percent Reduction of Metal Concentration (at the lowest concentration location) and Pore Volume Fraction of Water Transported Toward Cathode Chamber

Metal	KS		KH		KG		MS		SS	
	% Rem	PV③	% Rem	PV	% Rem	PV	% Rem	PV	% Rem	PV
Cr	93	0.18	97	0.15	95	0.23	95	0.12	97	0.12
Cs	72	0.65	74	0.30	77	0.64	55	0.96	89	0.30
Sr	98	0.41	96	0.88	99	0.44	92	0.53	99	0.63
U	79	0.35	70	0.69	85	0.25	44	0.77	33	0.64

③ PV: Pore volume of water transported to the cathode chamber during treatment

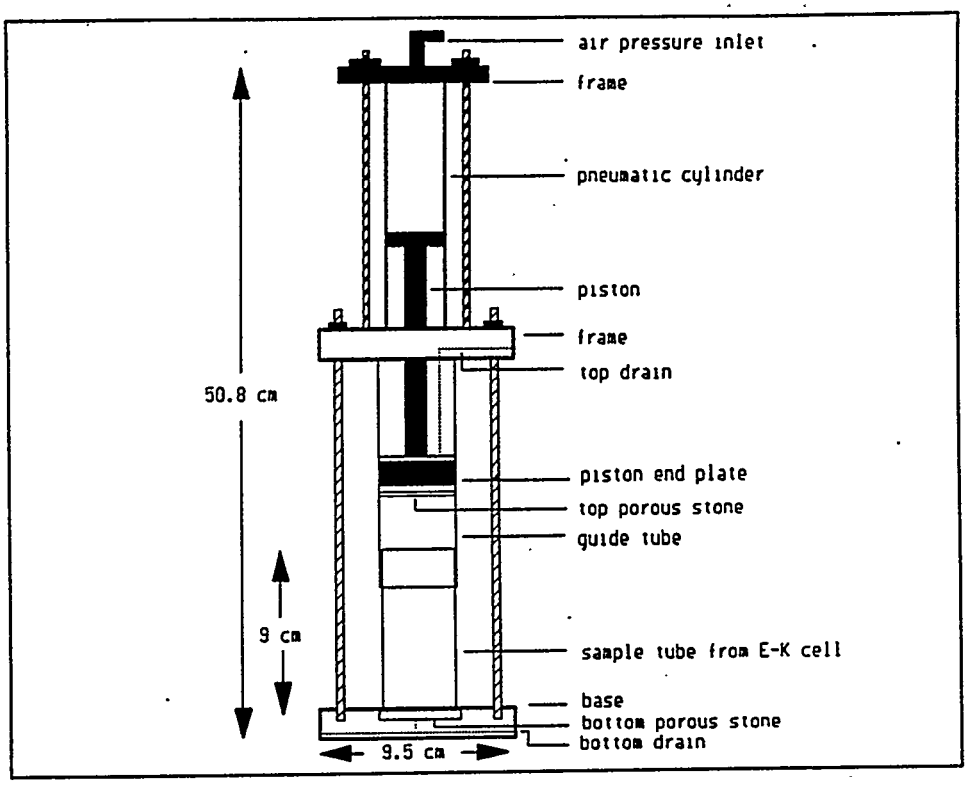


Figure 1. Consolidation Apparatus to Compress Soil Slurry

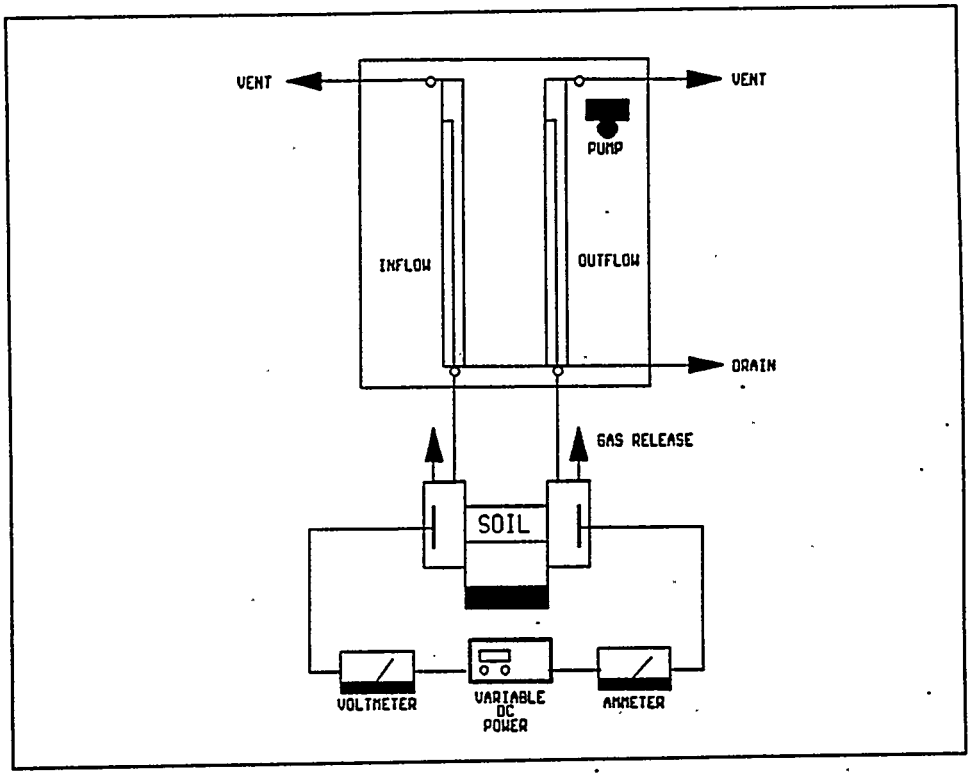


Figure 2. Schematic Diagram of the Electrokinetic Apparatus and Control Panel

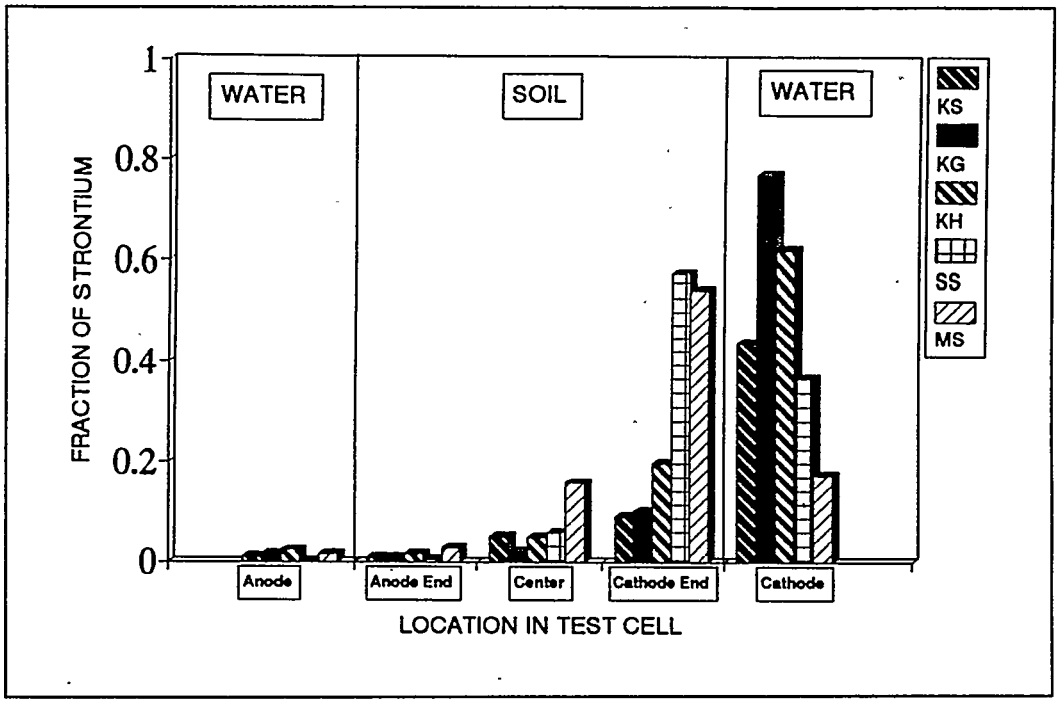


Figure 3. Average Distribution of Fraction of **Strontium** in Soil and Electrode Chamber Waters After E-K

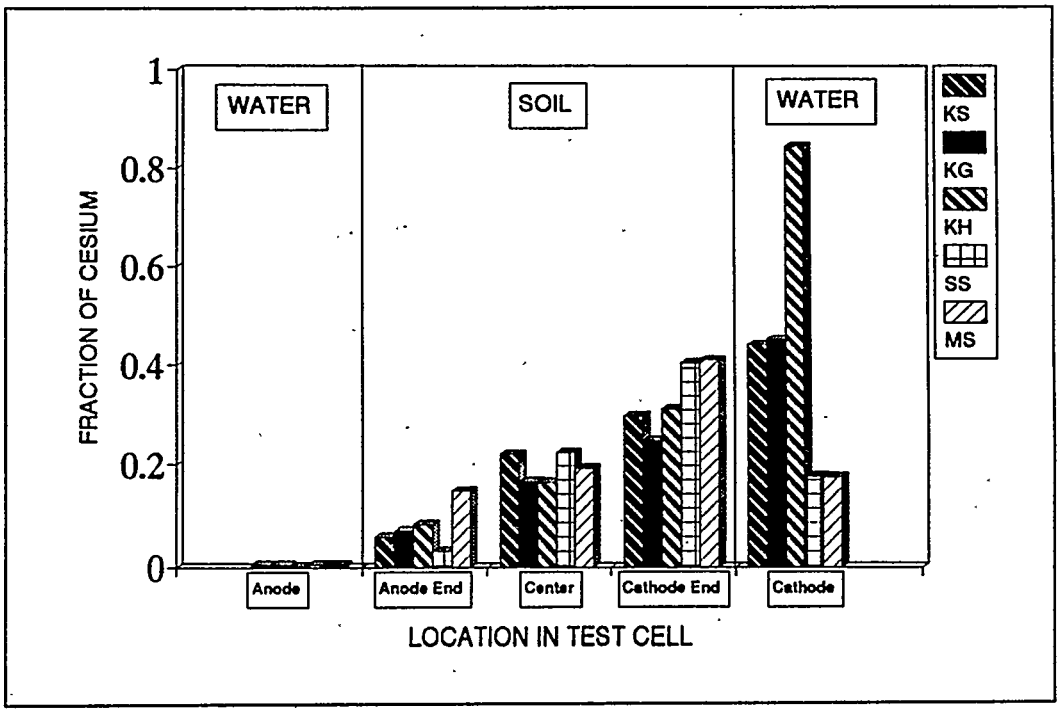


Figure 4. Average Distribution of Fraction of **Cesium** in Soil and Electrode Chamber Waters After E-K

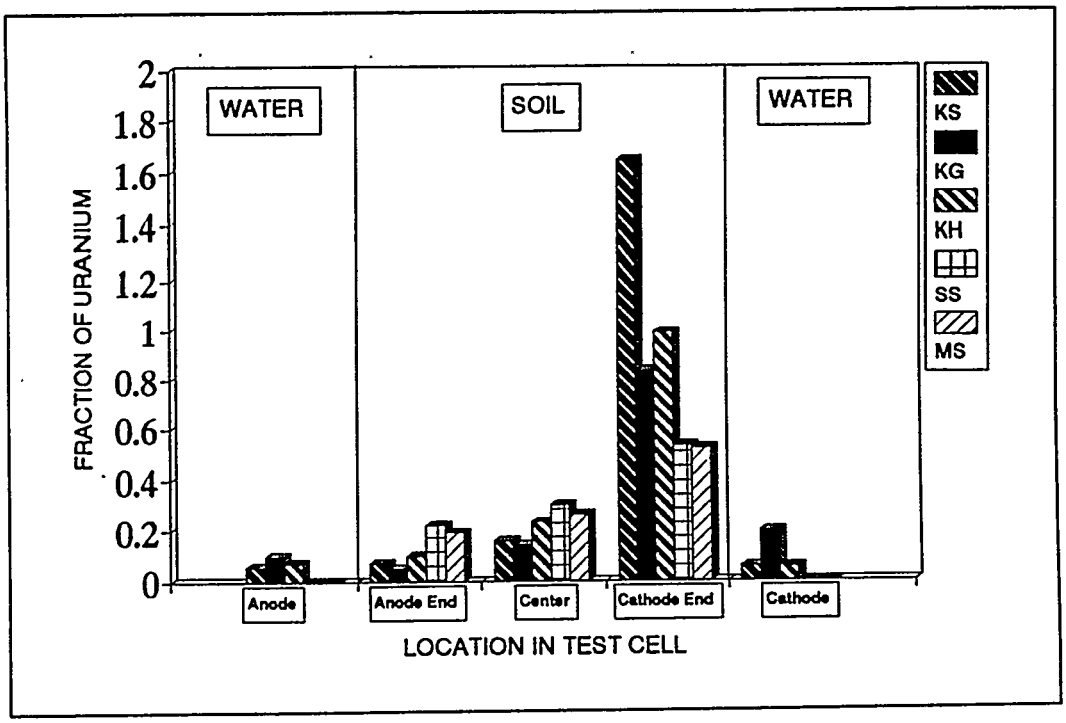


Figure 5. Average Distribution of Fraction of **Uranium** in Soil and Electrode Chamber Waters After E-K

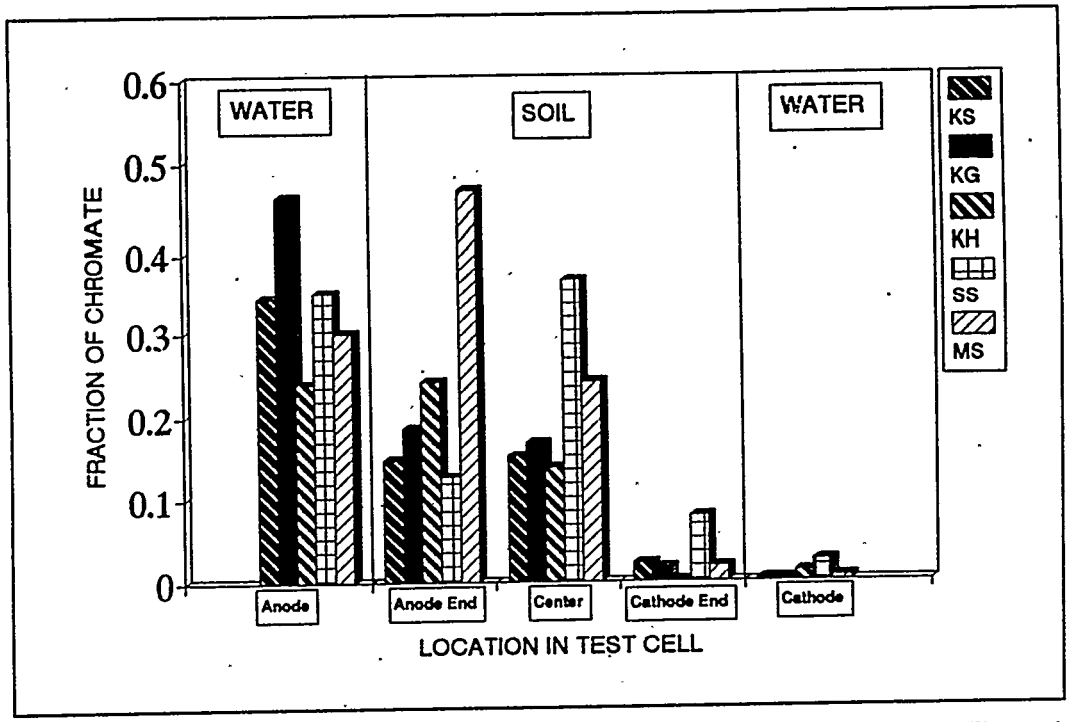


Figure 6. Average Distribution of Fraction of **Chromium** (anionic form) in Soil and Electrode Chamber Waters After E-K

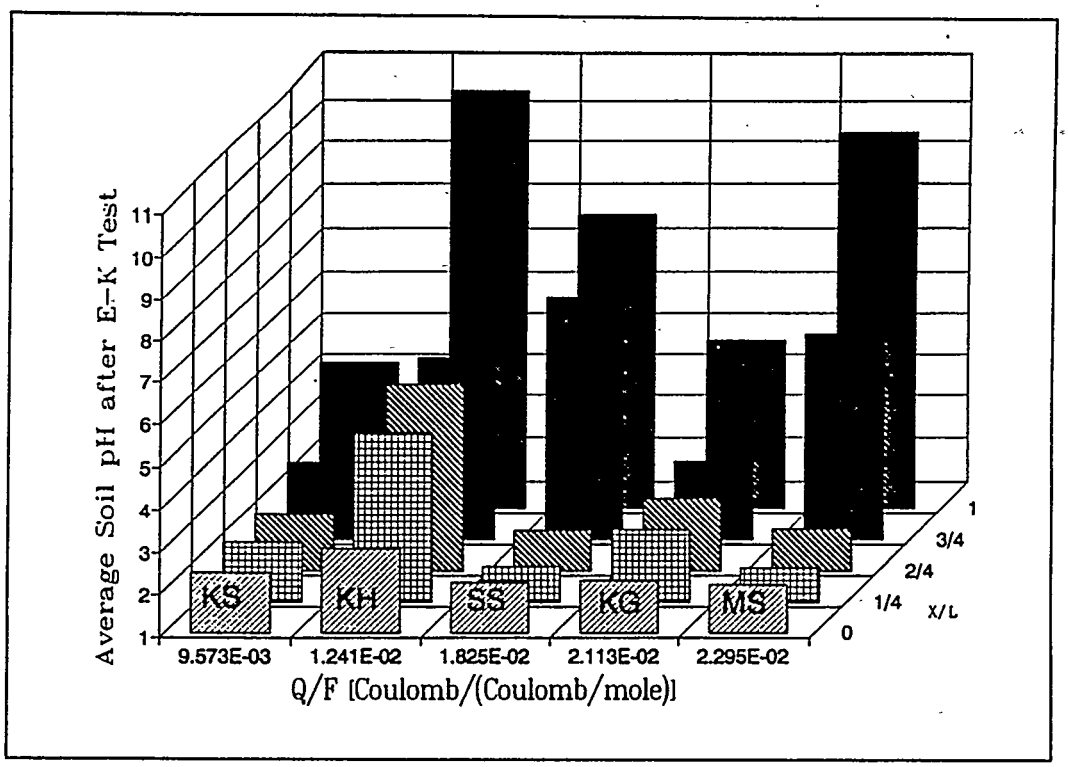


Figure 7. Average pH Distribution in **Strontium** Contaminated Soils

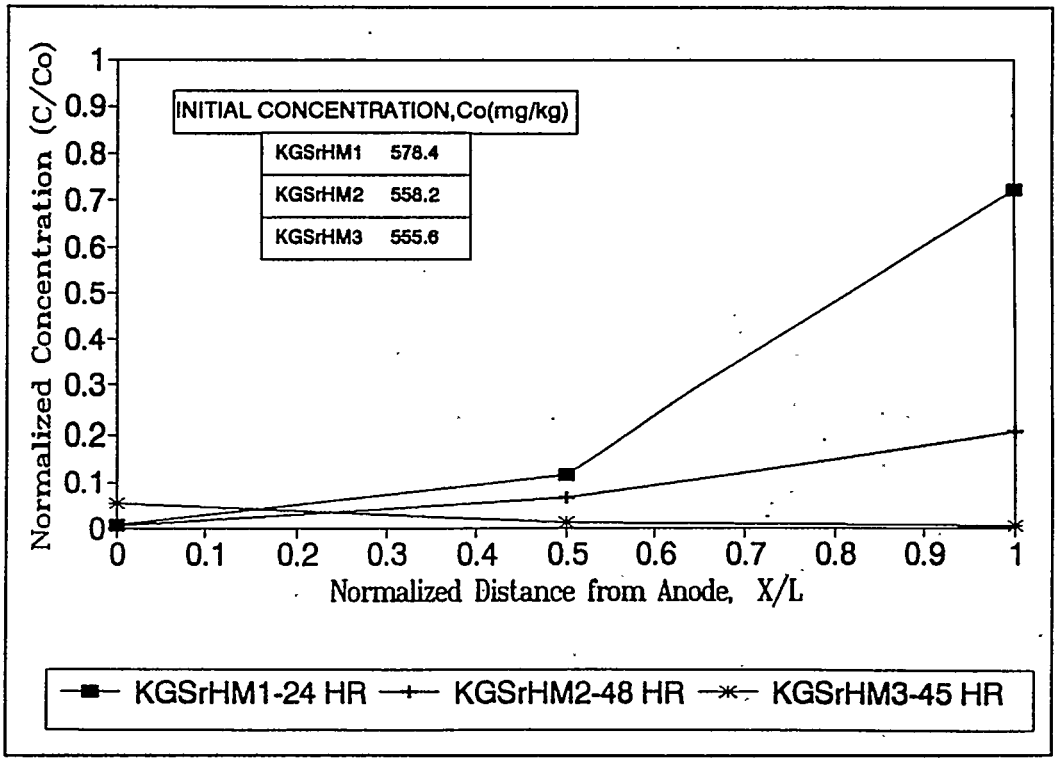


Figure 8. Concentration Profiles of **Sr** in Kaolinite/Groundwater Soil Samples After E-K

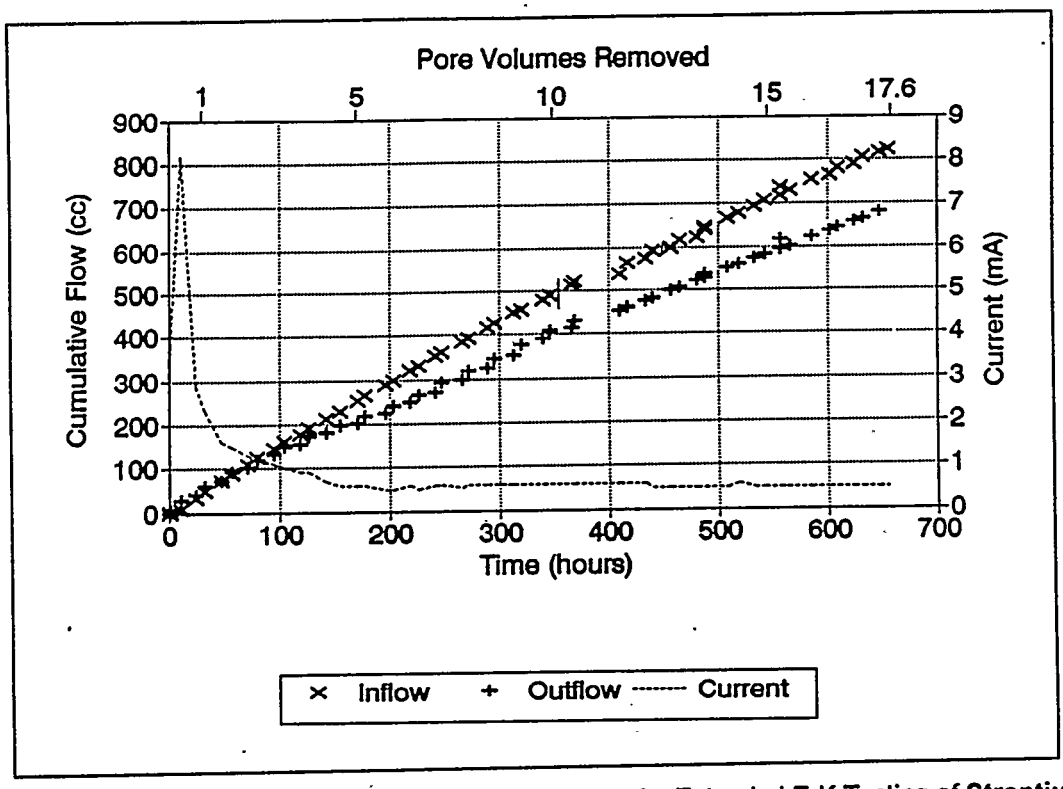


Figure 9. Electroosmotic Flow and Current Versus Time for Extended E-K Testing of **Strontium** Contaminated Kaolinite/Distilled Water Soil Sample

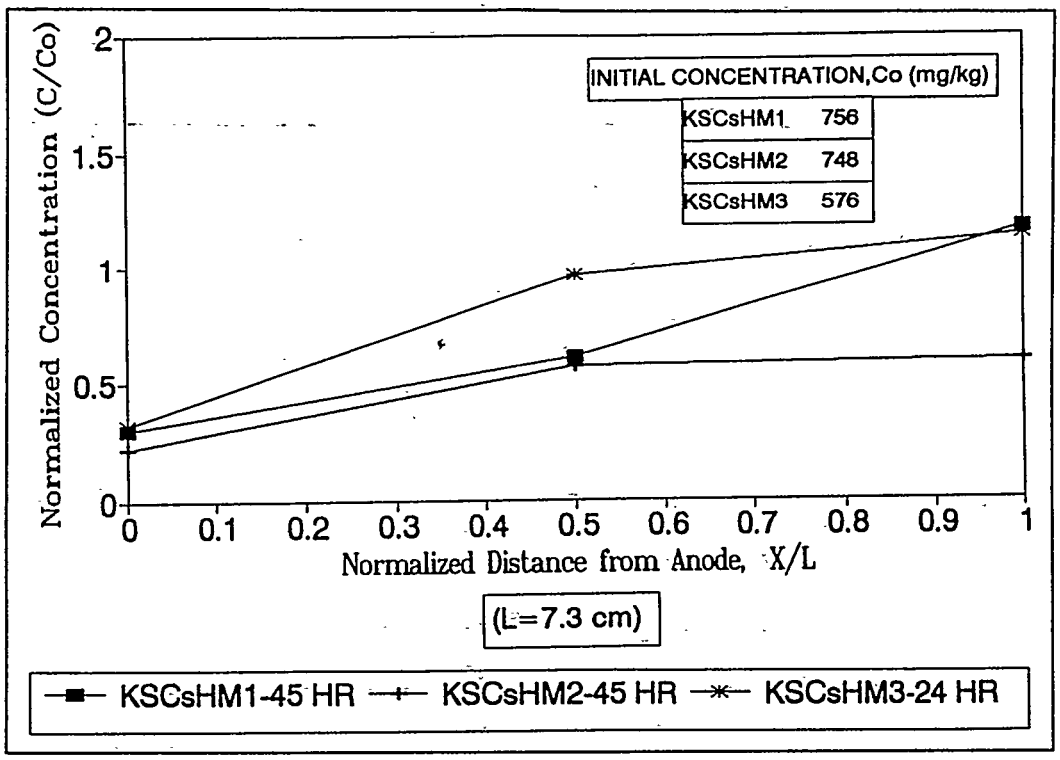


Figure 10. Concentration Profiles of Cs in Kaolinite/Distilled Water Soil Samples After E-K

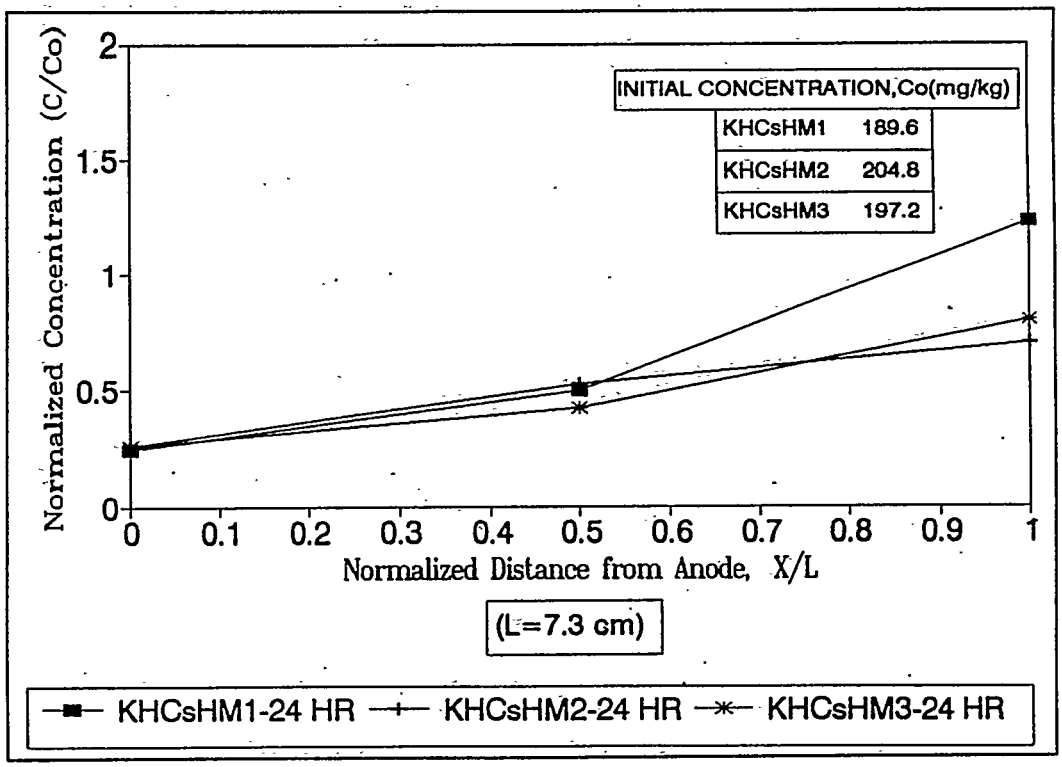


Figure 11. Concentration Profiles of Cs in Kaolinite/Humic Sol. Soil Samples After E-K

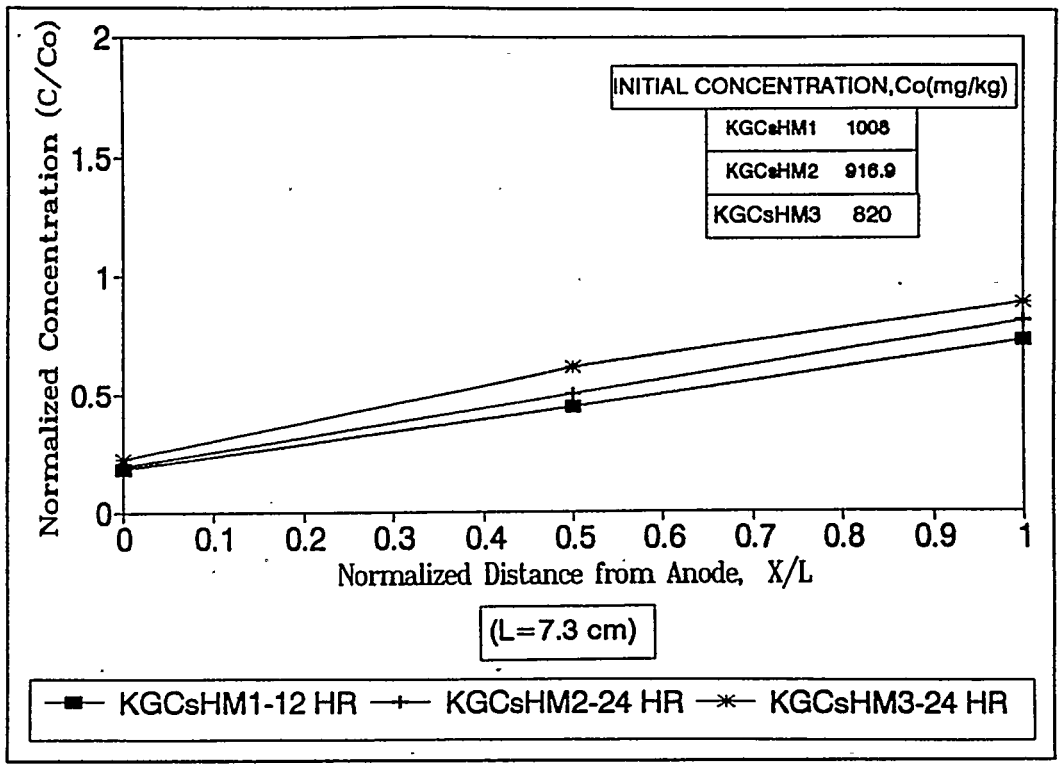


Figure 12. Concentration Profiles of Cs in Kaolinite/Groundwater Soil Samples After E-K

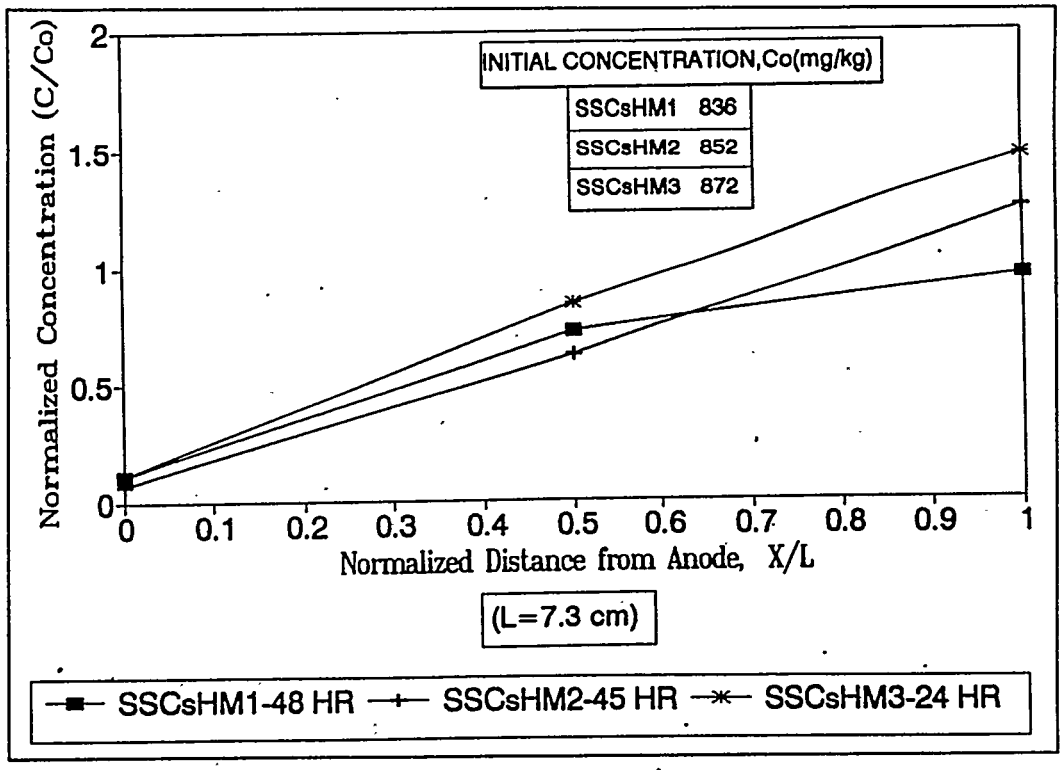


Figure 13. Concentration Profiles of Cs in Sand/Na-Montmorillonite/Distilled Water Soil Samples After E-K

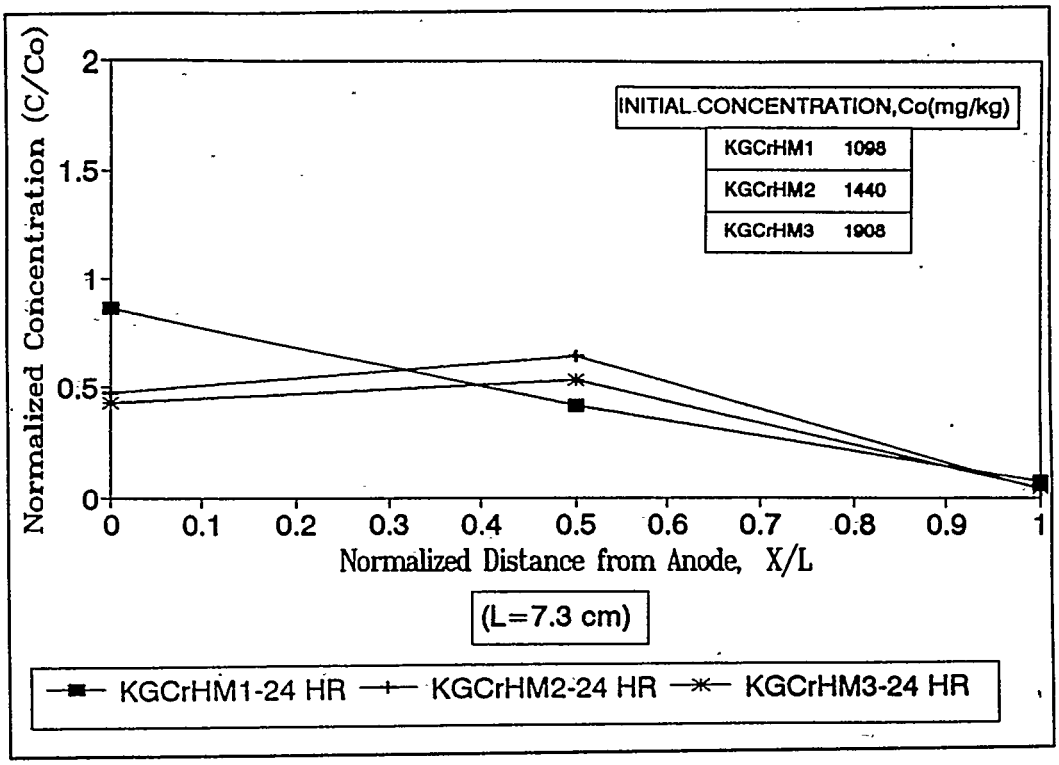


Figure 14. Concentration Profiles of Cr in Kaolinite/Groundwater Soil Samples After E-K

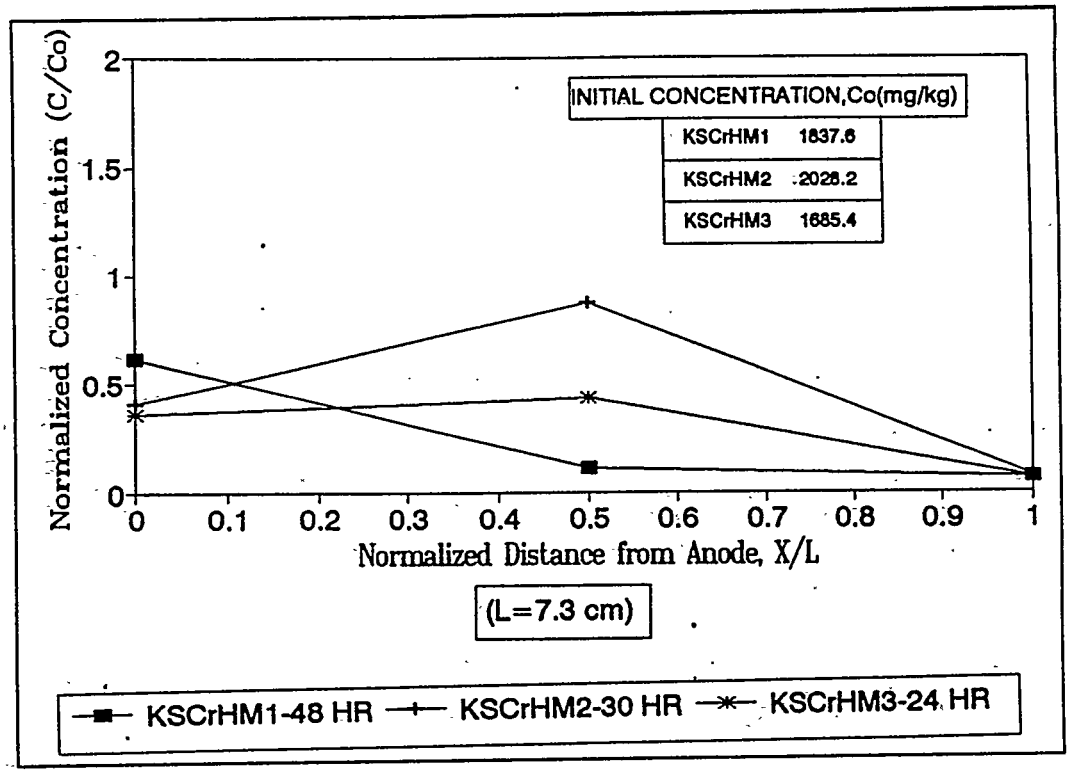


Figure 15. Concentration Profiles of Cr in Kaolinite/Distilled Water Soil Samples After E-K

Application of Neural Networks to Waste Site Screening

Ali E. Dabiri, Tim Kraft, and Jeffrey M. Hilton
Science Applications International Corporation
San Diego, CA 92121

INTRODUCTION

Waste site screening requires knowledge of the actual concentrations of hazardous materials and rates of flow around and below the site with time. The present approach to site screening consists primarily of drilling boreholes near contaminated sites and chemically analyzing the extracted physical samples and processing the data. In addition, hydraulic and geochemical soil properties are obtained so that numerical simulation models can be used to interpret and extrapolate the field data.

Drilling is expensive, as are the physical sample analyses. Furthermore, the standard numerical simulations can also be costly, both in personnel and computer time. Current techniques use finite difference or finite element methods to solve the convective dispersion equations that govern the transport of hazardous wastes. The highly nonlinear equations associated with the saturated/unsaturated soils are particularly difficult to solve, requiring significant computer resources and expertise to obtain a defensible result. Spatial and temporal variations in data describing the subsurface input parameters place further demands on these simulation calculations.

Collection and processing of the data are required to interpolate between points and times and to extrapolate to other distant points and future times. The less precise the data processing methods used, the more physical data must be collected to calibrate the numerical model. Conversely, if the modeling techniques are better, less physical data need to be collected. Thus, there is a tradeoff between the cost of data collection and the cost of development of better numerical model.

The objective of this work is to investigate the feasibility of using neural network techniques to reduce the cost of waste site screening. A successful technique may lead to an ability to reduce the number of boreholes and the number of samples analyzed from each borehole to properly screen the waste site. The analytic tool development described here is inexpensive because it makes use of neural network techniques that can interpolate rapidly and which can "learn" how to analyze data rather than having to be explicitly programmed.

In the following sections, data collection and data analyses will be described, followed by a section on different neural network techniques used. The results will be presented and compared with mathematical model. Finally, the last section will summarize the research work performed and make several recommendations for future work.

DATA COLLECTION

The first step was to determine what data were available and evaluate it for use in the project. A site was selected after meeting and discussions with Westinghouse Hanford Corporation (WHC) scientists. The site is located in the 200 East area of the Hanford/Purex waste disposal reservation. This site was used by Sisson and Lu[1] for the field calibrations of their mathematical flow prediction model.

A system consisting of a central injection well surrounded by an array of 32 observation wells were constructed at the site. There were four observation wells in each radial direction with eight radial positions equally spaced, as shown in Figure 1.

Over the course of four months, 11 injections of approximately 4000 liters of water each were made into the central injection well. The first 10 injections were made at weekly intervals while the 11th injection was made at the 18th week. Moisture measurements were obtained by lowering a neutron-neutron moisture meter into an observation well to a specified depth and recording a value in counts/sec for 15 seconds. This value

was then converted into the percentage of water by volume (moisture concentration). A minimum number of measurements that were sufficient to capture the extent of the moisture plume were made. Therefore, these measurements were restricted to the central core of soil immediately surrounding the injection site. This core extends out to a distance of 5 meters radially (at four radial positions, the observation wells are in 2-meter increments starting at 1-meter radius. At the other four radial positions they are in 2-meter increments starting at 2-meter radius) and from a depth of 3.0 meters to 18.0 meters vertically (in 0.3-meter increments).

Sisson and Lu[1] observed a strong dependence between the initial moisture content and the soil hydraulic properties. For this reason they used four soil types in their flow prediction modeling. The hydraulic properties for these soil types were estimated from field and laboratory data obtained at sites approximately 5 miles from the test site.

ANALYSIS OF DATA

Analyses of the measured data revealed that the flow is not symmetrical. This could be attributed to numerous causes, including slanted soil stratification. Looking at the data regarding depth, one can clearly see that the soil is stratified. This stratification affects the flow of moisture within the system.

The data are very sparse at further distances from the injection site, and the amplitude of the moisture plume peak decreases with distance from the injection site. The sparsity of the data is attributed to the fact that only a minimum number of measurements at further distances were performed to ensure that the extent of the moisture plume was captured.

The following variables were available for input to the neural network:

- Radial direction
- Radial distance from injection site
- Depth below injection site
- Time since injection start
- Time since injection end
- Moisture level at each point as function of time after injection
- Soil hydraulic properties.

NEURAL NETWORKS TECHNIQUES

A neural network is an interconnected collection of "units" that behave similarly to neurons in the brain. Each unit receives multiple normalized input signals (activations) and generates a single output signal. The output from each unit is typically connected as inputs to other units in the network. The connections are weighted so that the output of a unit is the weighted sum of the activation signals passed through a nonlinear threshold function. A subset of the units receives inputs from external sources and another subset of units generates outputs for the network, such that the entire neural network can be viewed as a nonlinear mapping between a vector of input activations to a vector of output values.

The connection weights among the units represent the nonlinear mapping function for the neural network. The weights are determined through a process called training, where the weights are incrementally adjusted over multiple training cycles. For the supervised learning techniques used in this paper, a training cycle consists of applying an input activation vector and propagating the signals through the network to generate an output value vector. For training, the output vector is compared to a desired target output vector

and the errors are backpropagated through the network to adjust the weights. This is repeated until the errors at the output are reduced to an arbitrary small amount.

Once the neural network has been trained, it is capable of recalling the mapping by simply feeding the input activation forward through the network to the output. The neural network is capable of generalizing the mapping such that accurate results can be obtained for input patterns on which it was not specifically trained. In practice, the success of the training and its subsequent application to a problem depends upon constructing training sets of input and target activation vectors that are representative of the problem domain that is being mapped. Often, because the mapping is nonlinear or the data have not been sufficiently analyzed, the formation of the training sets is more art than science. However, the application of neural networks to a problem will lead to a better understanding of the relational properties of the data and appreciation of the holistic character of the system being observed.

In the case of the waste site screening, the basic physics of migration of "liquid" waste through soil is known indicating strong correlations among the cells defining the site. Because of the inherent hazards at the site, the ability to fully instrument the site to support the physical model is difficult at best. Therefore, the problem addressed by the neural network is to determine whether satisfactory models of the site can be constructed from a more sparse set of measurements.

The neural network approach has potentially two advantages over analytical models. First, the neural network attempts to capture the large-scale behavior of the process and progresses to the fine scale behavior if the information is available. Analytical models are typically constructed bottom-up, extending the micro model (usually linear) in steps to a macro model description of the site. The second advantage is once a neural network has successfully been applied at one site, the same process can be used to screen other sites. In other words, the neural network approach is adaptable and can be "tuned" to a specific site.

The approach for development of a tool suitable for site screening using the neural network technique is presented in Figure 2. After suitable processing, the data set is divided into a training data set and a validation data set. The neural network is trained by satisfying certain training measures, as shown in Figure 2. The trained network is then validated with the validation data set. This validation should satisfy some specific validation measures as indicated in Figure 2. The training process is refined until the desired validation measures are satisfied.

The types of units, the connection topology among the units, the propagation of signals through the network, and the learning algorithm is defined by the selected neural network paradigm. For this paper, two different paradigms, back propagation and fully recurrent neural networks, were used to investigate their applicability to waste site screening. Each technique will be briefly discussed below.

Backpropagation

The backpropagation network[2] is an effective mapping function if the relationship between the input activation vector and the output activation vector is a continuous nonlinear mapping. Applying the network to data indicates the degree of direct correlation between the input and output vector values. This methodology was used to evaluate the moisture data collected at the test site. Various networks were developed using subsets of the data to determine the completeness of the data and its general application to site screening.

Fully Recurrent

The fully recurrent network[3] effectively maps multiple time series sequences at the input to one or more output sequences at the output. The units are fully connected within the network such that each unit receives the output from all other units as well as the input activation vector as shown in Figure 3. To achieve an accurate prediction of moisture content as a sequence over time, the collection of input and output activations must be strongly correlated and representative of the time series behavior (patterns) of the system. The combination of sequences represents a closed set of processes defining the site. In other words, each sequence

can be derived from some continuous nonlinear combination of the other sequences in the set. The resulting connection weights represent the correlation strengths or codependencies among the sensor measurements.

Since the present data is sparse, a three-dimensional model, which would be the most useful and accurate model, could not be trained to any reasonable precision. A two dimensional model, however, was a good approximation. The effective moisture values for the 2-D model were obtained at each depth from the surface and distance from the injection site. This reduced the space to two dimensions, depth and distance from the source.

RESULTS

Backpropagation

The initial set of networks used only the moisture values in the neighboring cells to predict the moisture value in the test cell. In this case, the backpropagation network is learning how moisture content in neighboring cells at time t directly maps to the moisture content in the test cell at time t + 1. This technique assumes that the relationship is independent of time. At any arbitrary time, t, the neural network should accurately determine the moisture content at time, t + 1, regardless of the previous moisture history of the neighboring cells or the test cell. The initial networks could predict moisture at a specific test cell but had difficulty generalizing the learning to other sites using the same learned network weights. This is understandable, since other measured parameters, such as soil conductivity, are required to screen a site.

When soil type, related to soil conductivity, was added as a reference input, the backpropagation network was able to generalize the connection weights to other cells not included in the initial training set. The training set required samples distributed over various soil types, injection events, and injection times to generate predictions within 10% of actual measurements. These results indicated that there were significant correlations in the collected data, but did not support the objective of screening a site with reduced data collection. The training required data collected throughout the site, and still required time since last injection as an input.

Time is a problematic measurement in screening a site. Except for controlled experiments, the injection time and rate of injection are not known. Even in the controlled experiments, the sampling time between measurements may vary and not be sufficient to capture significant events such as the peak moisture at a cell or initial start of a rise in moisture content. Through analyses of the backpropagation network performance, time since last injection was used primarily to differentiate periods of increasing or decreasing moisture. To remove direct dependency on the time, coarse shaping parameters were introduced. The shaping parameters indicated the direction of the moisture change over the previous three measurements. These allowed the network to bifurcate the predictions for rising and falling moisture content, and improved accuracy in predicting peak moisture following an injection.

The best results obtained used a network with input moistures and soil type for each neighboring cell and three input shaping parameters feeding to five hidden units resulting in one prediction output for the moisture content of the test cell as shown in Figure 4. During training, the average RMS error was 0.78% with a maximum output error of 5%. During validation recall, the average and maximum errors were 1.1% and 6% respectively, indicating acceptable generalization. The size of the sample was about 700 of which 90% was used for training and the remaining 10% was used during validation. These results are well within the requirements of accurate site screening. However, the primary problem is that the resulting neural network cannot be applied to other sites and still requires extensive sampling of the site to adapt to that site. It does not reduce the number of core samples that must be collected nor the length of time that a site must be observed.

Fully Recurrent Network

The backpropagation network results indicate that the combination of moisture content, soil characteristics, and previous moisture history is sufficient to describe the dynamics at a site. The advantage

of the fully recurrent network over feedforward networks (such as the backpropagation network) is that the recurrent network is learning a set of recurrent mapping equations rather than direct mapping functions. The fully recurrent network is therefore able to incorporate previous history in the screening of the site. Though the data must be presented as a time sequence, the network can generalize over varying sample rates and effectively become independent of specific time and sample rates to screen the site.

Figure 5 presents the fully recurrent network architecture using the same measurement data used in developing the backpropagation networks. In an array of nine cells, moisture values of three cells are used as input to predict the moisture values of six cells at different levels. Because data was collected more extensively with depth than with radius from the injection site, the network was set up to predict the moisture content with depth. The same approach could be used to screen the site radially from the injection point, reducing the number of bore sites required to screen the site.

The networks were trained with inputs from six different depths (540, 600, 660, 750, 810, and 900 cm) and predicted the moisture content for cells at +30 and +60 cm from the input depth. The various networks were trained until the total RMS error achieved was 0.5% (~3400 training cycles). During training the output from the network was replaced by the actual measurement values before recycling for the next output. This is referred to as forced training. During recall validation processing, the output from the neural network is recycled (called free recall) such that the network only receives the initial state for all cells and the input moisture value for the three input cells for each subsequent time step. This tests the stability of the network to errors in the output over extended times.

Figure 6 gives the results of the moisture values for the first output cell at 570 cm depth at the 1 m radial given the moisture values at the 540 cm depth. The network was trained on only the data in the third injection and validated over all five injections. The total number of data set for training on the third injection was about 234, which represented 20% of the total data set for five injections. The figure shows a comparison of the actual measurements, the neural network predictions, and the mathematical model predictions for the cell. Figure 7 shows similar results for the same depth but along a different radial from the injection site. As can be seen, the results of the neural network are comparable to the results of the mathematical model. The degree of agreement indicates that the neural network is capturing the same dynamics incorporated in the mathematical model. The ability of the network to predict moisture over multiple injections indicates stability of the network to output error that can be credited to the strength of the correlations among the cell measurements. In fact, predictions remain accurate (1% RMS x 5% maximum error) for the different cells even when the predominate injection peak is not present (see Figures 8 and 9) at larger radial distances.

The differences between the neural network prediction and the actual measurement, sometimes referred to as innovations, represent information not captured by the neural network during training. The innovations or deviations from modeled behavior can be due to a number of causes including systematic measurement error, such as undersampling and measurement calibration or bias errors; particular soil conditions such as rock stratification or soil moisture conduits; or processes not observed in the original training samples. Because the neural network has been derived independent of the mathematical model, the network, in this configuration, can be used to validate the original data measurements or suggest novelty from normal learned behavior.

The connection weights for a fully connected recurrent backpropagation network have several features that differentiate it from normal backpropagation. The connection weights represent the correlation strength or codependencies among the input and output measurements. Unlike backpropagation networks, the weights are well ordered such that the same weights can be derived from different initial states and even different training data for the same process. Therefore the weights represent the combination of the nominal model for the site independent of specific soil conditions and a local model, which changes the weights to account for conditions specific to the cell neighborhood being predicted. This suggests that there is a relationship between soil conditions and the connection weights and that it may be possible to change the weights to adapt the recurrent network to the site without extensive training for the new site. This observation is the basis for the current set of experiments to develop a general adaptive tool for waste site screening.

The results of the application of the fully recurrent neural network to site data are promising for a general purpose site screening tool. To date, recurrent neural networks have been developed that are able to capture the dynamics at different depths and radii from the injection site, to generalize to different radials, to account for local variations in soil conditions, and are independent of injection time and rate. In its current configuration, the recurrent network reduces the number of test bore sites by extending the accuracy of the predictions over more widely spaced test sites. The stability of the network in the presence of deviations from normal behavior would indicate that through diagnosis of the innovations in the measurement data can be used to further screen the site—for example, identifying areas where moisture flow is higher or lower than normal indicating areas of anomalous geological, hydrological, or soil conditions.

CONCLUSIONS

The present approach to site screening is expensive and time consuming. The feasibility of using neural network techniques to reduce the cost of waste site screening was investigated. The networks were trained with data received from Westinghouse Hanford Corporation. The results indicate that the network trained with the fully recurrent technique show satisfactory generalization capability. The predicted results are close to results obtained from mathematical flow prediction model. It is possible to develop a new tool to predict the waste plume through space and time, reducing substantially the number of the bore holes and number of samplings.

ACKNOWLEDGMENT

The authors would like to thank Dr. Mike Garrett for technical discussions and guidance and Mr. Mark Hammersveld for data reduction during the initial phase of the project. This work was supported by DOE under Subcontract No. C90-132746.

REFERENCES

1. J. B. Sisson and A. H. Lu, *Field Calibration of Computer Models for Application to Buried Liquid Discharges: A Status Report*, Rockwell International, RHO-ST-46, August 1984.

2. Rumelhart, D. E., Hinton, G. E., and Williams, R.J., "Learning Internal Representations by Error Propagation," in Rumelhart, D.E. and McClelland, J. L. [eds.], *Parallel Distributed Processing: Exploration in the Microstructure of Cognition*, 1, 318-362, MIT Press, Cambridge, MA, 1986.

3. Williams, R. J. and Zipser, D. (1989) "A Learning Algorithm for Continually Running Fully Recurrent Networks," *Neural Computation*, 1, 270-280.

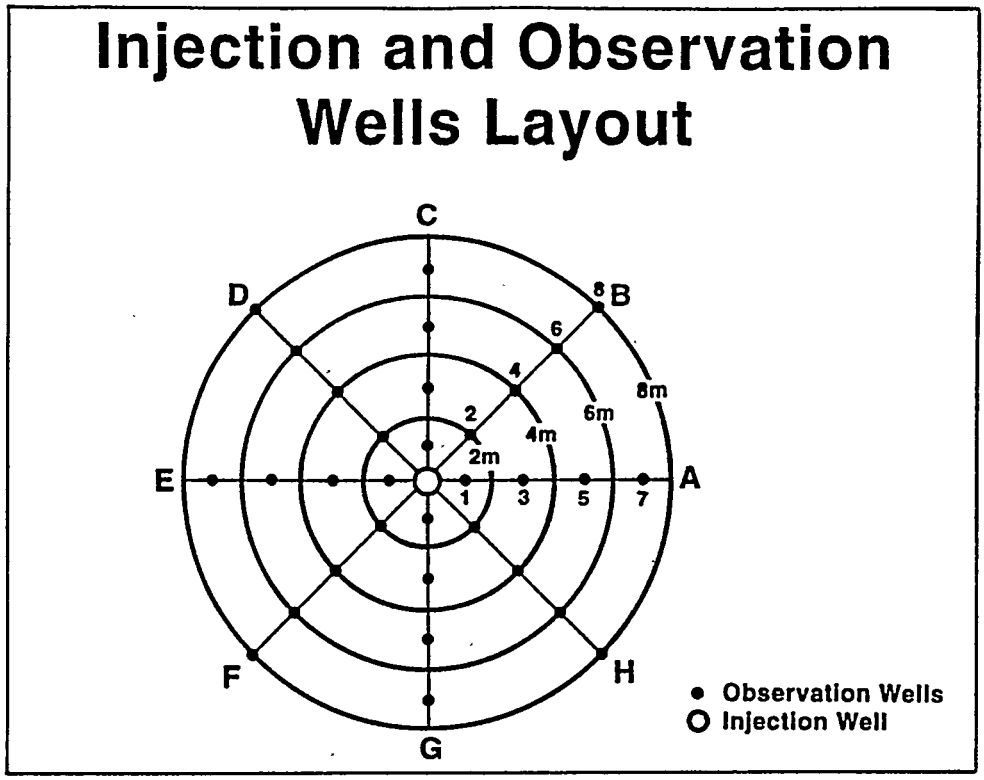


Figure 1.

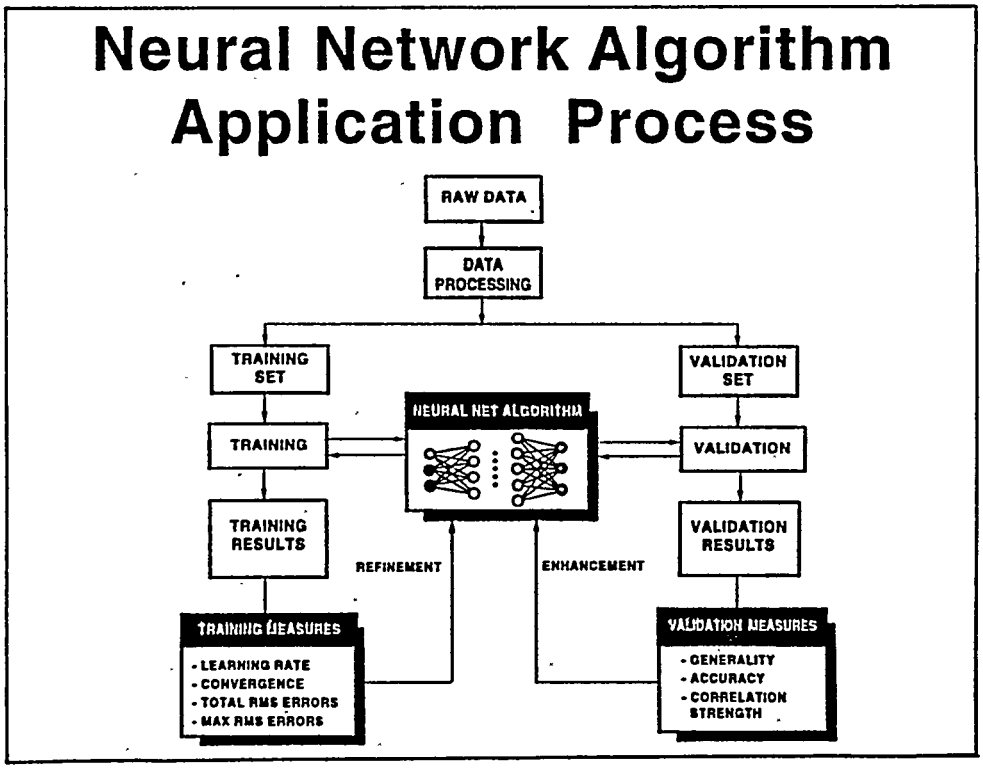


Figure 2.

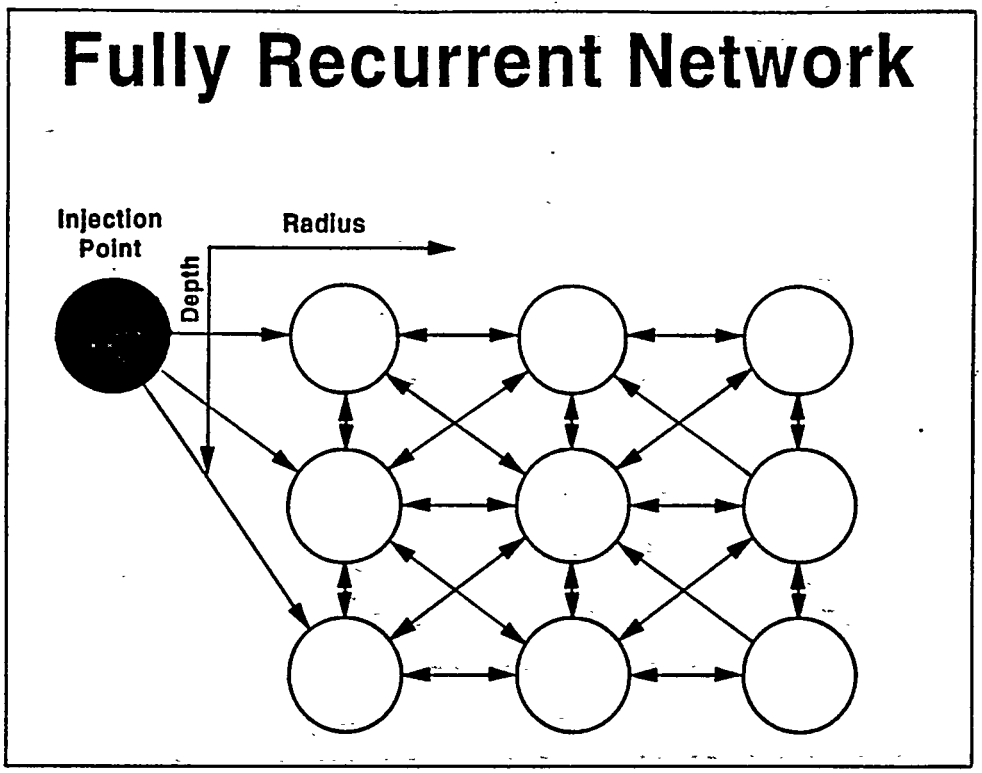


Figure 3.

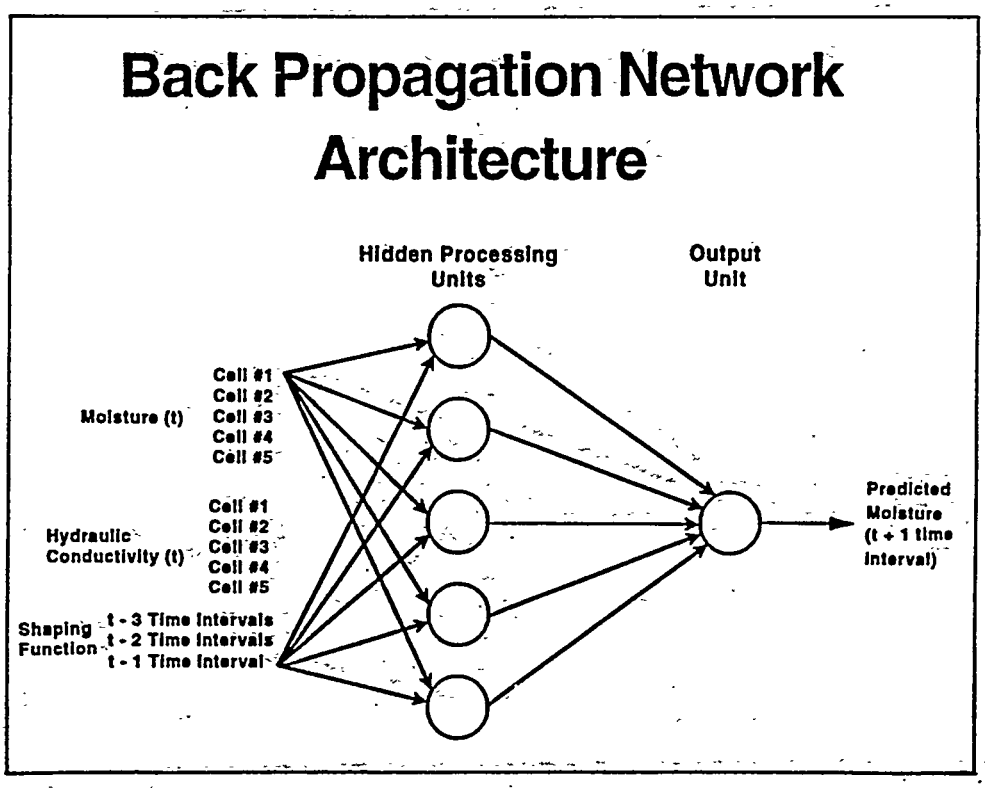


Figure 4.

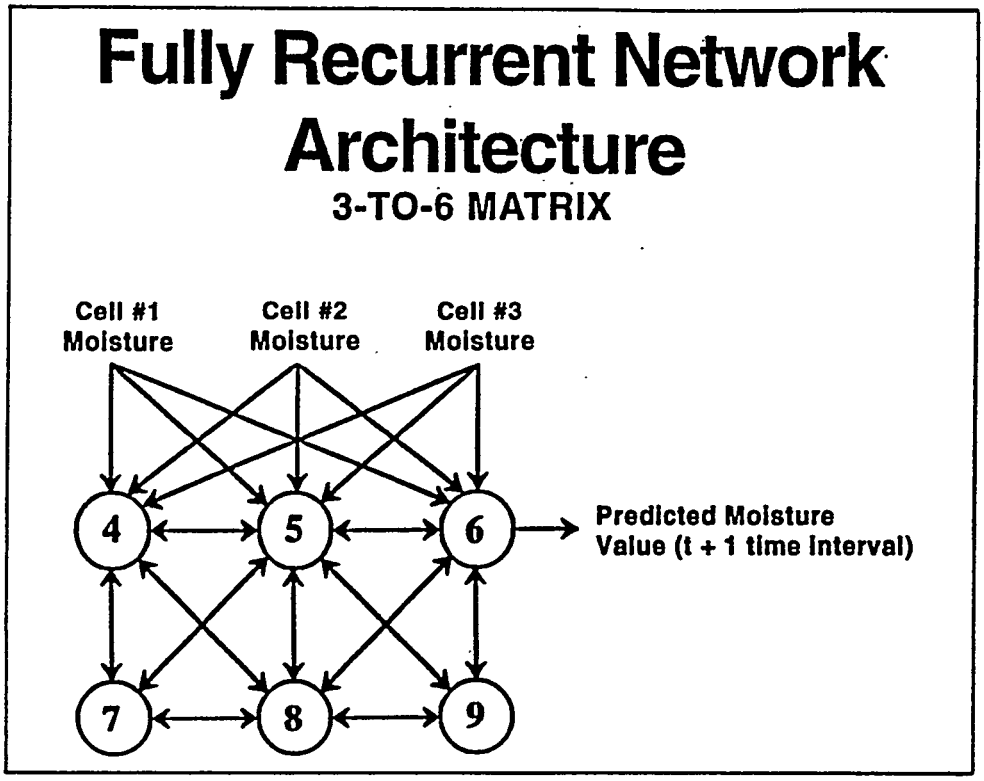


Figure 5.

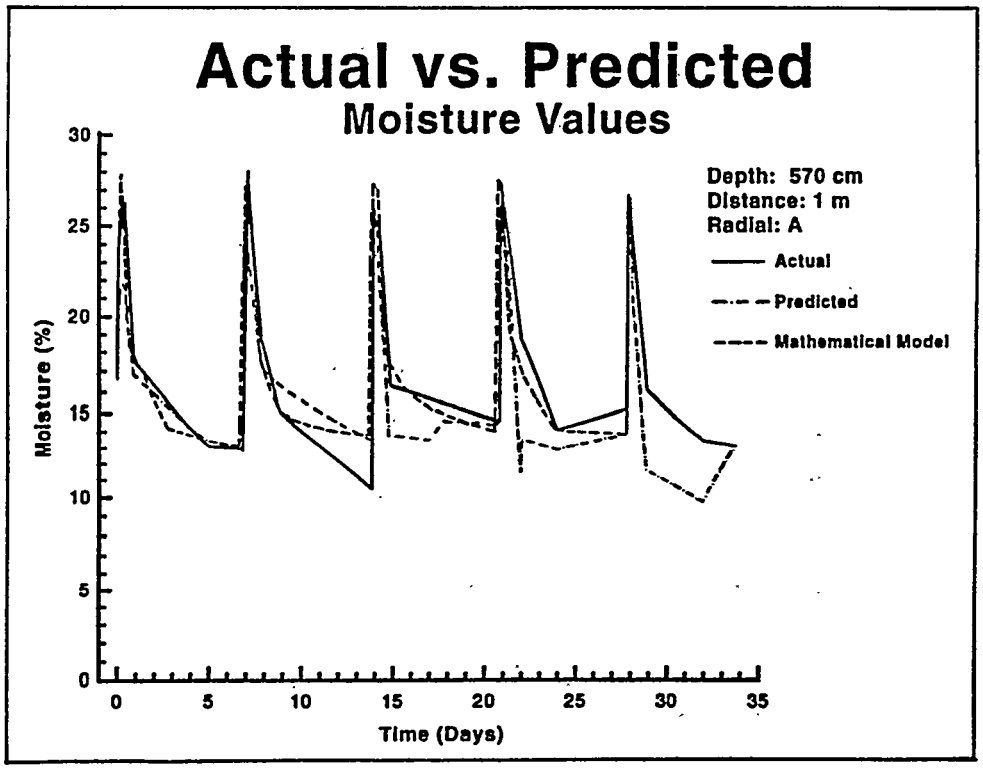


Figure 6.

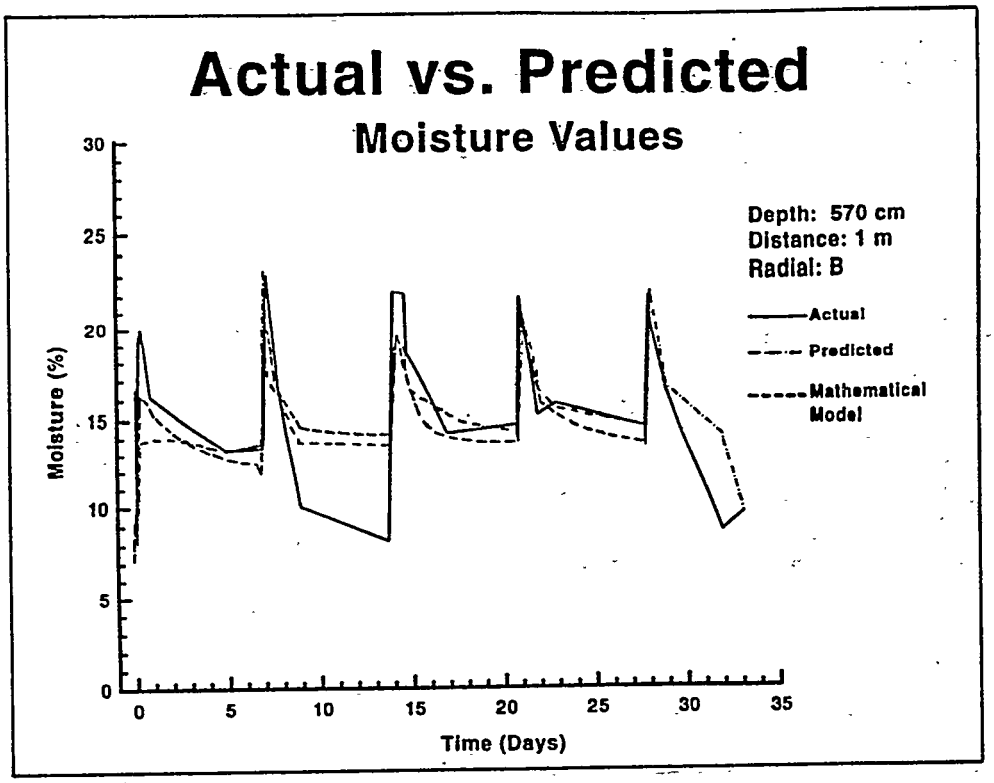


Figure 7.

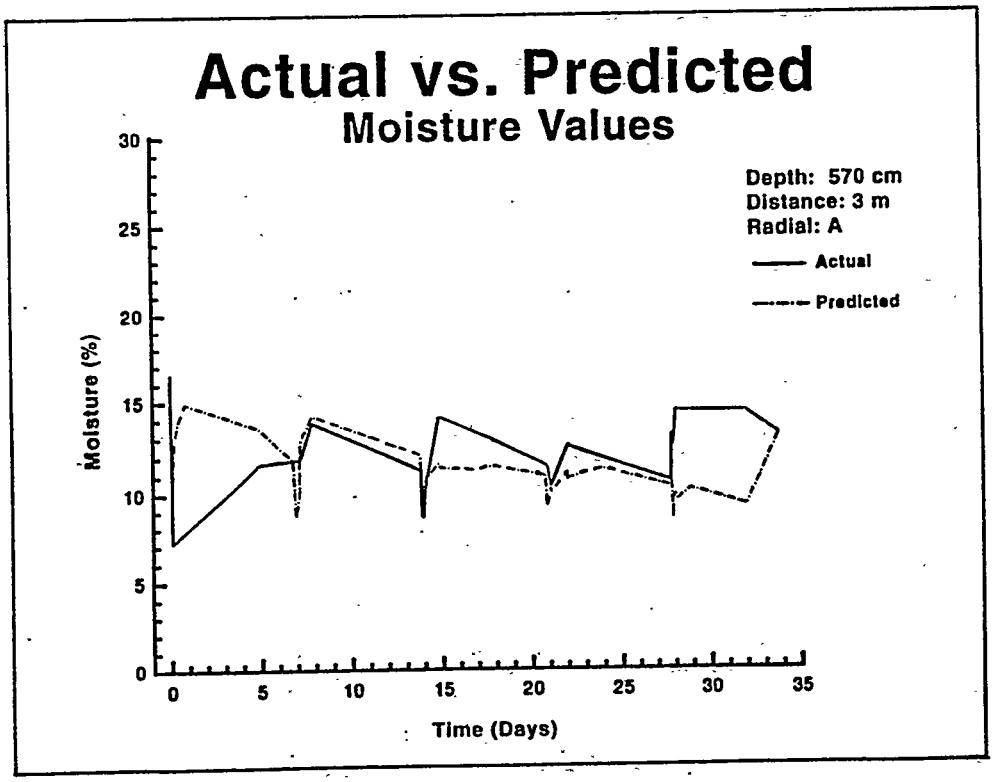


Figure 8.

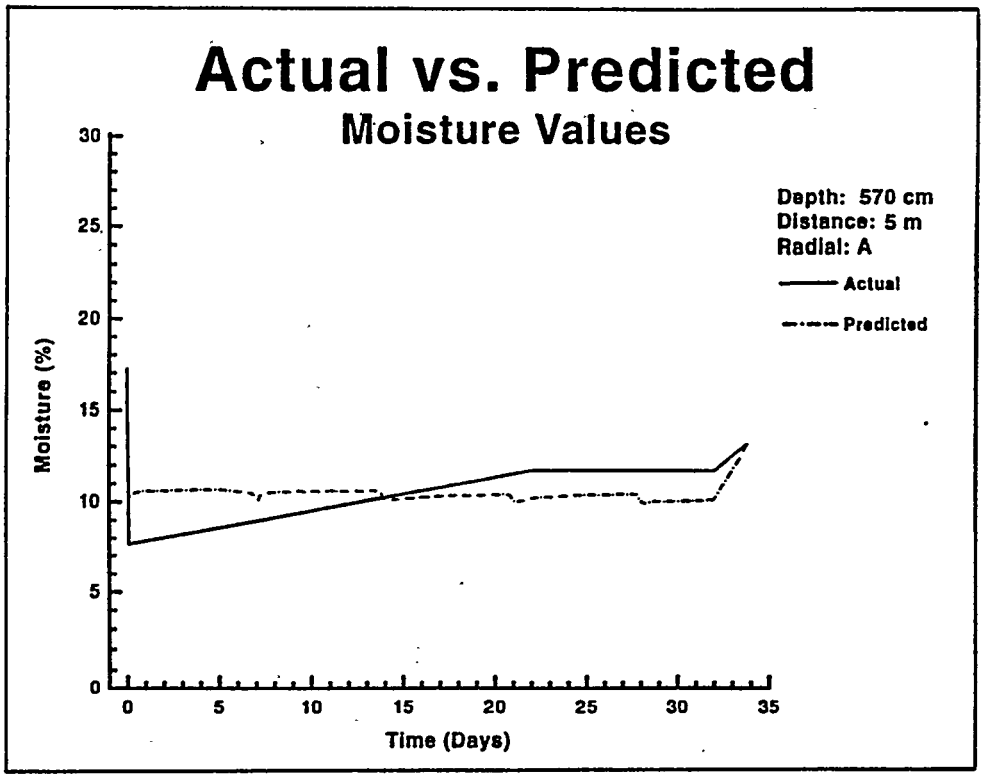

Actual vs. Predicted
Moisture Values
Depth: 570 cm
Distance: 5 m
Radial: A
Actual
Predicted
Moisture (%)
30
25
20
15
10
5
0
0
5
10
15
20
25
30
35
Time (Days)

Figure 9.

Russian Low-Level Waste Disposal Program

Linda Lehman
L. Lehman & Associates, Inc.
1103 W. Burnsville Parkway, Suite 209
Burnsville, MN 55337

INTRODUCTION

The strategy for disposal of low-level radioactive waste in Russia differs from that employed in the U.S. In Russia, there are separate authorities and facilities for wastes generated by nuclear power plants, defense wastes, and hospital/small generator/research wastes. The reactor wastes and the defense wastes are generally processed onsite and disposed of either onsite, or nearby. Treating these waste streams utilizes such volume reduction techniques as compaction and incineration. The Russians also employ methods such as bitumenization, cementation, and vitrification for waste treatment before burial. Shallow land trench burial is the most commonly used technique.

Hospital and research waste is centrally regulated by the Moscow Council of Deputies. Plans are made in cooperation with the Ministry of Atomic Energy. Currently the former Soviet Union has a network of low-level disposal sites located near large cities. Figure 1 shows the general location of these 34 sites. Fifteen disposal sites are located in the Federal Republic of Russia, six are in the Ukraine, and one is located in each of the remaining 13 republics. Like the U.S., each republic is in charge of management of the facilities within their borders. The sites are all similarly designed, being modeled after the RADON site near Moscow.

Figure 2 shows the location of reactors within the former Soviet Union. Currently in Russia 28 operational reactor units exist within nine plants. Twelve are VVER's, similar to PWR's, and 11 are RBMK's, or the Chernobyl-type units. The others are breeder reactors or research reactors.

LAW

The Supreme Soviet has established a subcommittee on Radioactive Safety. This subcommittee is in charge of drafting a law on State Policy For Handling Nuclear Waste. The Chairman and Deputy Chairman of this Committee are environmentalists and have asked an American group to assist them in the development of the law. An organization entitled "Toward a Safer Nuclear World" from the University of California at Irvine in collaboration with the Natural Resources Defense Council has been reviewing the Russian drafts. Other U.S. participants in this process have been Dr. Terry Lash, former Director of the Illinois Department of Nuclear Safety, Dr. John Ahearne, former Chairman, U.S. NRC, and Dan Berkovitz, U.S. Senate Committee on Environment and Public Works. Some of these group members testified at a public hearing of this law in September, 1992, at the Russian "White House."

This law is intended to insure the people's safety and the environment's protection through safe isolation of radioactive waste. The law attempts to: (a) regulate safety, (b) define functions, rights, obligations and authorities, (c) guarantee legal protection and compensation of personnel and citizens, (d) guarantee citizen participation, and (e) regulate international cooperation in waste handling.

The law is very broad in scope and regulates all activity, including military, having to do with the handling of radioactive wastes from creation through burial. This includes collection, storage, treatment, transportation, repository operations, and disarmament of weapons. It includes ALARA concepts for radiation worker doses.

In actuality, the law is little more than an outline at this point. But it seeks to incorporate the following principles:

1. The separation of monitoring and oversight from economic activity (i.e., gain) and, included in this principle, the creation of administrative branches that are independent of each other. The

monitoring and oversight agencies should be answerable to the President, while the economic structure should be answerable to the government.

2. The creation of layers of environmental protection that are subordinate to a proposed "new agency," financed independently from local governments.

3. Absolute compliance with Russian environmental laws.

The law does seem to give a lot of overlapping authority to various Republics, regional and local entities in the area of environmental assessments and monitoring. But it is unclear where the financial support will come from. The underlying plan is to create a new "State Agency for Radioactive Waste" as the basic authority for handling all waste in Russia. This would essentially remove the existing authorities given to Ministry of Atomic Energy and the Military-Industrial Complex producers, who have demonstrated poor handling practices in the past.

The law currently charges this new agency with forming and realizing state programs for handling, monitoring, and financing all activities. They are also to develop the siting process and organize departmental reviews of the programs, as well as guarantee safe labor practices and write all rules and regulations. (The rules and regulations would be drafted in concurrence with the Ministry of Ecology.)

The people currently in charge, such as the Ministry of Atomic Energy and the Military-Industrial Complex, oppose this new law. There is also opposition within the Supreme Soviet. The future viability this arrangement is questionable because authority has already been granted and review organizations have been established (such as GOSATOMNAZOR, the Russian equivalent to the NRC). A recent decree by President Yeltsin in October may further hinder this law. GOSATOMNAZOR was established several years ago as an independent agency outside of the Council of Ministers so that the industry would not be self-regulating. The new Yeltsin decree would place it back under the control of the Ministry of Atomic Energy.

SITING AND REGULATIONS

The Soviets have indicated that they have developed siting criteria for low-level waste facilities and have adopted health-based standards as recommended by International Council on Radiation Protection (ICRP) and the International Atomic Energy Agency (IAEA). The Institute of Science and Technology located at the RADON facility is to have a regulatory review role in the licensing of new low-level waste facilities. In its review process, it will look at three main topics: the release rate, accident scenarios including transportation, and the possible consequences of a large catastrophe. Officials admitted that Chernobyl convinced them that they were not ready to respond quickly. Since the new law envisions the participation of the Ministry of Ecology in developing these regulations in conjunction with the new "State Agency for Radioactive Waste," the Institute of Science and Technology's future role is unclear.

Despite these administrative advancements, however, the siting of a low-level waste repository is becoming more difficult. The USSR is experiencing a strong environmental movement. The most active party is a group called GREENS. For the Soviets, it now seems more difficult to site a waste facility than a reactor because the people can understand the benefits from reactors. They have planned a few low-level waste sites, but they have been unsuccessful in this process because the people stage strikes and demonstrations. The GREENS had a strong presence at the public hearing of the new law.

TREATMENT

Low-level waste is currently being treated in several different ways. First, it is usually stored onsite until treated. Liquid waste is usually stored in stainless steel casks, then transported to double-walled tanks. Solid wastes are also stored onsite in concrete containers.

Treatment methods for liquid wastes include volume reduction, primarily through evaporation and reverse osmosis. Reverse osmosis is used to extract radionuclides from wash water and detergents used in

decontamination. Regeneration of spent solvents by distillation has been developed to the industrial level, but has not yet been applied.

Volume reduction for solid waste streams is accomplished through compaction or incineration. The most common form of incineration utilizes a liquid fuel which achieves temperatures of 1000°C in a dual-chambered furnace. Offgases are filtered, often using a multi-stage gas capture system with metal and ceramic filters. These filters, also referred to as "absolute" filters, may be similar to HEPA filters. They claim a filter rate of 60 kg/hr. After incineration, the ashes are transported for solidification. Experimental methods of incineration are currently being used, such as plasma flames. This plasma flame reaches a temperature of about 1600°C. The Russians claim a 60-80% waste reduction from incineration and claim that most waste is incinerated without sorting.

WASTE FORMS

Utilized waste forms are bitumen compounds, borosilicate glass, and concrete waste forms. The Soviets are also studying the feasibility of vitrification. I have observed a "synrock" type of waste form also utilized. Bitumenization is preferred for wastes with higher concentrations of salt (i.e., greater than 25 grams/liter). The bitumen wastes are poured into 200-liter tanks for shipping. They are transported to special disposal sites. Compaction is sometimes used on the bitumenized blocks for volume reduction.

Considerable Soviet research has gone into determining the leach rates of three waste forms; namely concrete, bitumen, and glass waste forms. Their findings are that glass has the lowest leach rate, followed by bitumen. These findings are to be expected, but now they are able to quantify the rates and show the government that the proper research has been done to document their waste form selections.

RADON SITE—HOSPITAL AND RESEARCH WASTES

The RADON site near Moscow is touted as the best site and serves as the model for all other LLW disposal sites. This site has been in operation since 1962 and has been taking all of Moscow's waste since then. The RADON site accepts waste from about 2,000 facilities in the Moscow region, including the nine research reactors located in Moscow.

The RADON site is located north of Moscow, just north of the city of Zagorsk. A research institute is co-located with this site and continually monitors the site. This institute is also studying qualities and characteristics of waste that have been in contact with ground water. The entrance to RADON is from the extension of the main road, which runs from Moscow to Zagorsk along a private road several miles long. Road signs caution "do not enter." Around the site itself, a 2 km (1.2 mi) defense or safety zone has been established. Locked gates are manned.

The site was selected for its favorable geologic conditions. It is a sedimentary sequence of clays and sands overlying a limestone bedrock. The uppermost unit in which the disposal site is located is a lacustrine clay 70 m (230 ft) thick. Figure 3 is a schematic cross-section of the RADON site. The water table ranges from 4 to 20 meters below land surface. The first aquifer is a sand unit located at a depth of about 70 m. It is artesian with the potentiometric surface rising to a height about 50 m below land surface.

There are about 200 monitoring wells, which are classified according to purpose and depth. The upper clay layer and the upper aquifer are the main monitoring points, but the limestone unit is used as a source of water supply and these supply wells are also monitored. Figure 4 shows their idealized monitoring scheme. The wells penetrate most of the layers and in some instances are clustered. It is interesting to note that all wells are around the perimeter rather than near the disposal trench itself.

The RADON site accepts mostly solid wastes. Most liquid wastes to be disposed of are first processed by the Kurchatov Institute in Moscow and transported to the RADON site in escorted vehicles. Incineration is used for a large portion of the waste streams, but problems with incinerating biological wastes have been encountered. They receive about 200 m^3/yr (7,060 ft^3/yr) of these biological wastes.

Once wastes have been placed in the selected waste form, they are placed in underground cement trenches that are 25 m (82 ft) long by 4 m (13 ft) wide and 6 m (20 ft) high. They hold a volume of 600 m^3 (21,190 ft^3). These wastes are then "hydro-isolated" using a type of cement grout around the waste forms, which is then covered with several layers of concrete (see Figure 5). A final cover of asphalt 1/2 m thick is then emplaced. The Soviets claim to be in compliance with IAEA limits for this type of waste, which was stated to be 200 milli-roentgens/hr, 1 cm from the surface of the primary containers.

A temporary storage building that stores three types of higher activity wastes is also located at the RADON site. These wastes are to be stored there for 10 years and eventually are to be shipped to a HLW facility. In all likelihood, the waste will probably remain in temporary storage much longer than 10 years, since the HLW siting activities have only just been initiated.

The three types of wastes stored in this temporary storage building are classified as (a) naturally occurring wastes, (i.e., radium, uranium and thorium), (b) used medical sources, and (c) scientific and laboratory wastes. Each of these types of waste has a different storage scheme. The naturally occurring wastes are placed in small containers that appeared to be about one foot square. The schematic disposal technique is shown as Figure 6. This waste is stored in a concrete trench that has 0.4 m (1.3 ft) thick walls and is about 1.8 m (6 ft) deep, including the walls. The waste forms are placed inside these trenches in the manner shown. It appears they are raised above the trench base on some sort of form. The reasons for this were not given, but possibly it is to prevent concrete degradation (maybe from temperature differences).

The used medical sources are stored much deeper. These sources were called "mid-level" wastes. They are basically stored in wells that are 6.14 m (20 ft) deep, including a 0.5-m (1.6 ft) thick concrete cap. Figure 7 illustrates this scheme. Inside the well the waste occupies a 1.6 m (5 ft) high x 0.4 m (1.3 ft) diameter cylinder. This is topped by a pipe with a 0.1 m (0.3 ft) inside diameter (presumably for monitoring purposes). The cap then is placed over this pipe. Although it was not mentioned, this structure can be assumed to be backfilled. The top of this structure was said to emit less than 500 micro-roentgens per hour at the top surface inside the building.

The third type of containment is for scientific and laboratory waste, which includes industrial resins. The selected waste form is placed in canisters made of stainless steel that are about 6 ft in length and 0.45 m (1.5 ft) in diameter. These canisters are placed, two to a well, one on top of the other. Figure 8 shows the containment design. The waste is at a total depth of 5.0 m (16 ft) including a 1.0 m (3.3 ft) thick cap. This waste configuration is used for wastes which are termed "higher than mid-level" (wastes containing in the range of from one to 20 curies per canister).

Incineration and compaction is performed at the RADON site. They have two incinerators, one an experimental plasma incinerator as discussed earlier and the other an industrial-scale liquid fuel incinerator.

The RADON site also utilizes a vitrification process. The vitrification process is a two-phase process that has a rate of 20 kg/hr. The first phase is liquid concentration. Then the concentrated liquid is mixed with the glass-making additives (borosilicate), melted in an electric furnace, and poured into canisters. Offgassing is controlled through multi-stage filtering using "absolute filters." All spent filters are compressed and placed in concrete for onsite trench disposal, since they cannot be incinerated because of the gas problems.

RADIOLOGICAL MONITORING

Radiological monitoring is carried out by a special department that answers to the Minister of Environmental Protection and the Minister of Health. This monitoring program is divided into two parts: one part monitors the production processes (worker exposures) and the other part performs environmental monitoring.

The worker exposures are monitored by several types of devices, stationary and portable, in a central control room. They monitor air and water used in the buildings, including sewage waters that are first evaporated. Spectrometry is used to determine concentrations. Gamma radiation is measured by sodium iodide

crystals. Personal computers are used to process the monitoring results. Monitoring of individuals is accomplished using TLD's and dosimeters. They claim that individual doses are 15 times less than allowable.

For environmental monitoring purposes, the area is divided into three zones. These zones were defined as: (a) Zone of Stringent Control, which includes the disposal site and processing areas, (b) Buffer Zone, which is 4-5 km (2.5-3.1 mi) in distance and was calculated according to the height of incinerator stacks. This is also termed the Fallout Zone and is not used for farming or building, and (c) Zone of People, which extends 20-30 km (12.4-18.6 mi) and can be used for any purpose including farming.

Within these zones, many parameters are measured, including radioactive concentrations in air, fallout, rain, soil, vegetation, animals, milk and small animals. Monitoring started in 1961 and shows that all areas are very near background levels.

WASTE PROBLEM SITES

Literally hundreds of contaminated sites are scattered about the former Soviet Union. The cleanup of many may not be possible. Most of us are familiar with Chernobyl and more recently Chelyabinsk (known as the most contaminated site on earth). Here highly radioactive reservoirs threaten not only the Siberian rivers, but the Arctic as well. The northern seas are also at risk from the dumping and testing conducted at Murmansk and Novaya Zemlya. Supposedly, 15 reactors from submarines have been dumped on the ocean floor near Novaya Zemlya, along with as many as 17,000 containers of radioactive waste. Some of these containers were sealed, but when they would not sink, the Soviet Navy shot holes in them (Newsweek, 1992). No one has yet figured out how to recover these containers from the ocean floor, but a number of surrounding countries are becoming nervous. The Finns are installing special alarms on the Russian nuclear reactors. The King of Sweden recently gave $1.5 million to clean up Ignalina Power Station in Lithuania and the Norwegians are allowed to measure radiation on Novaya Zemlya itself, but not in the surrounding waters. The U.S. government has recently approved $800 million in aid for building plutonium storage facilities to donating special blankets to protect missiles during transport, should they blow up. For Russia to do much about these problems, they must first stabilize their economy to come up with the money for remediation. This is liable to be a long-term endeavor, so we are unlikely to see much progress with regard to remediation without a huge influx of foreign capital.

REFERENCE

Bogert, Carroll, "Get Out the Geiger Counters," Newsweek, November 2, 1992, p. 64-65.

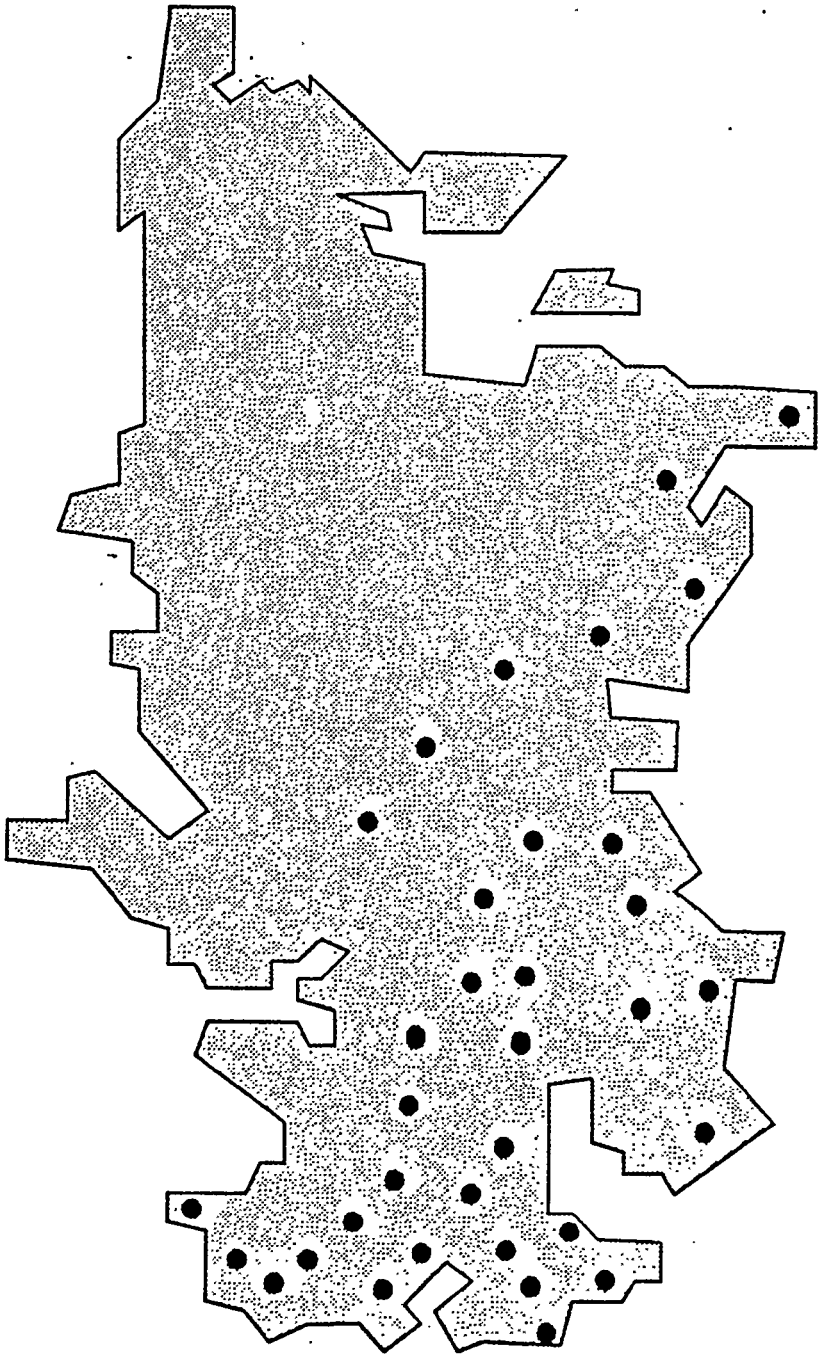


Figure 1. Low level disposal sites in U.S.S.R.

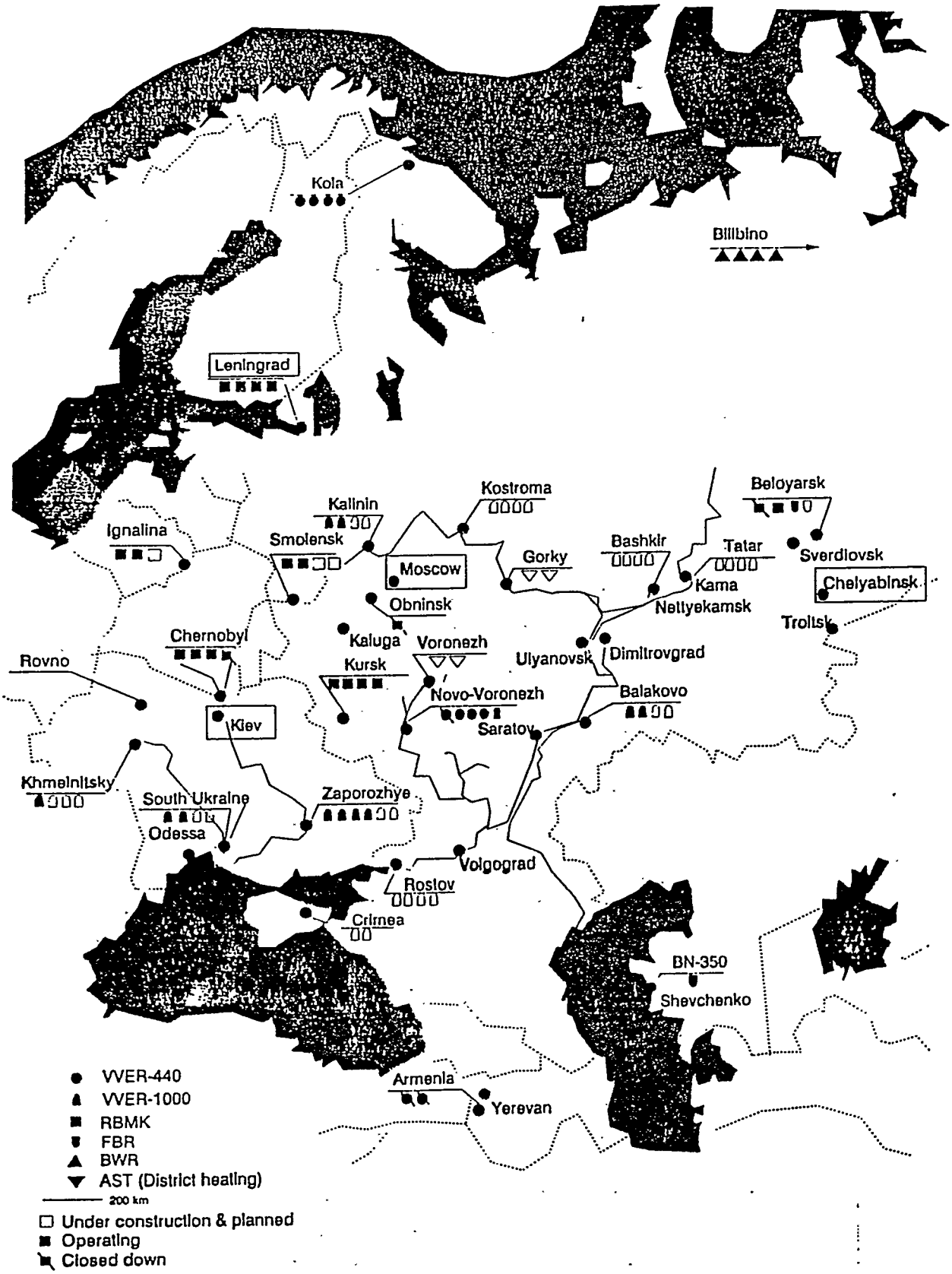


Figure 2. Location of Soviet reactors (after Dr. Walter Kato, 1989).

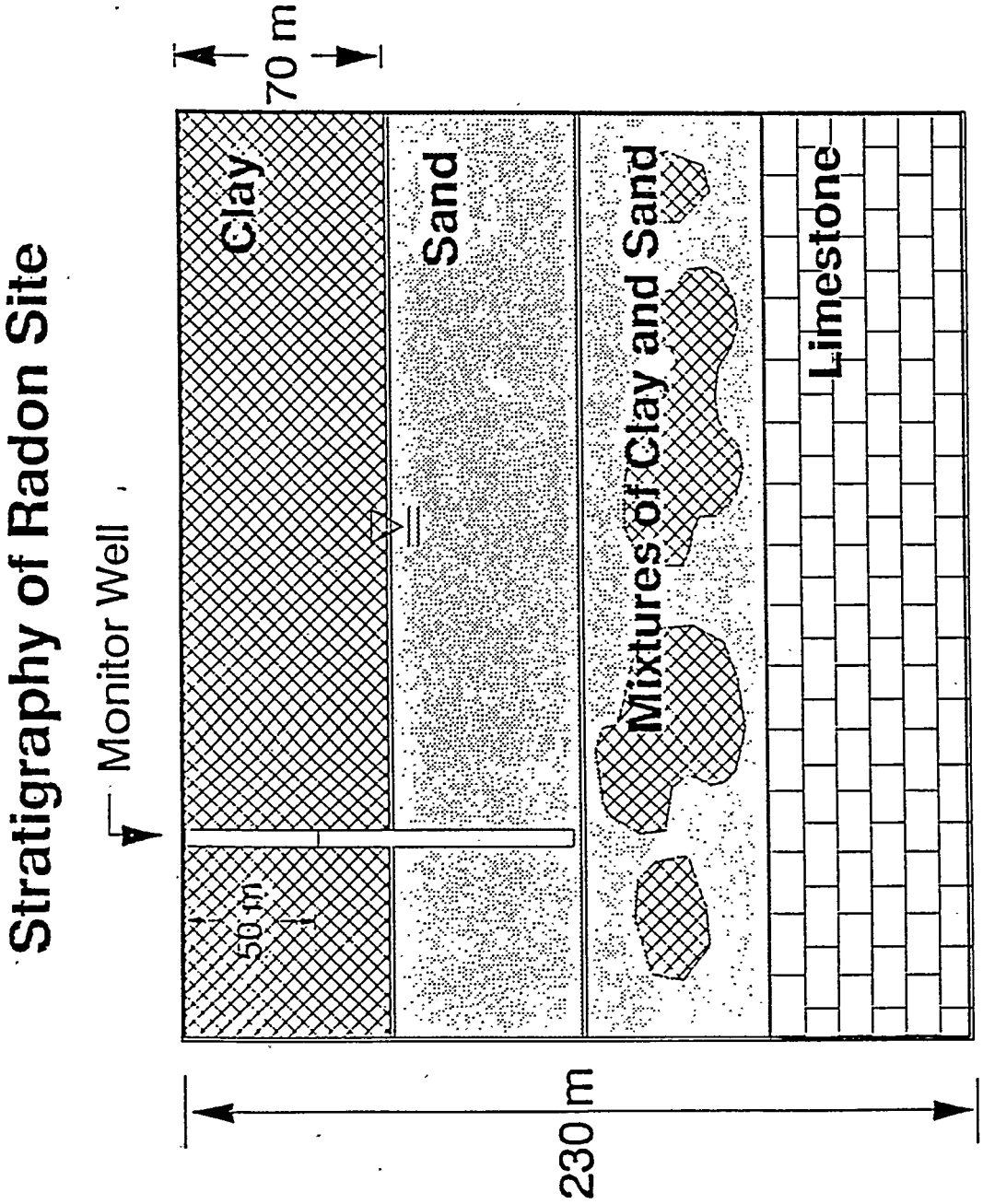


Figure 3. Stratigraphy of Radon Site.

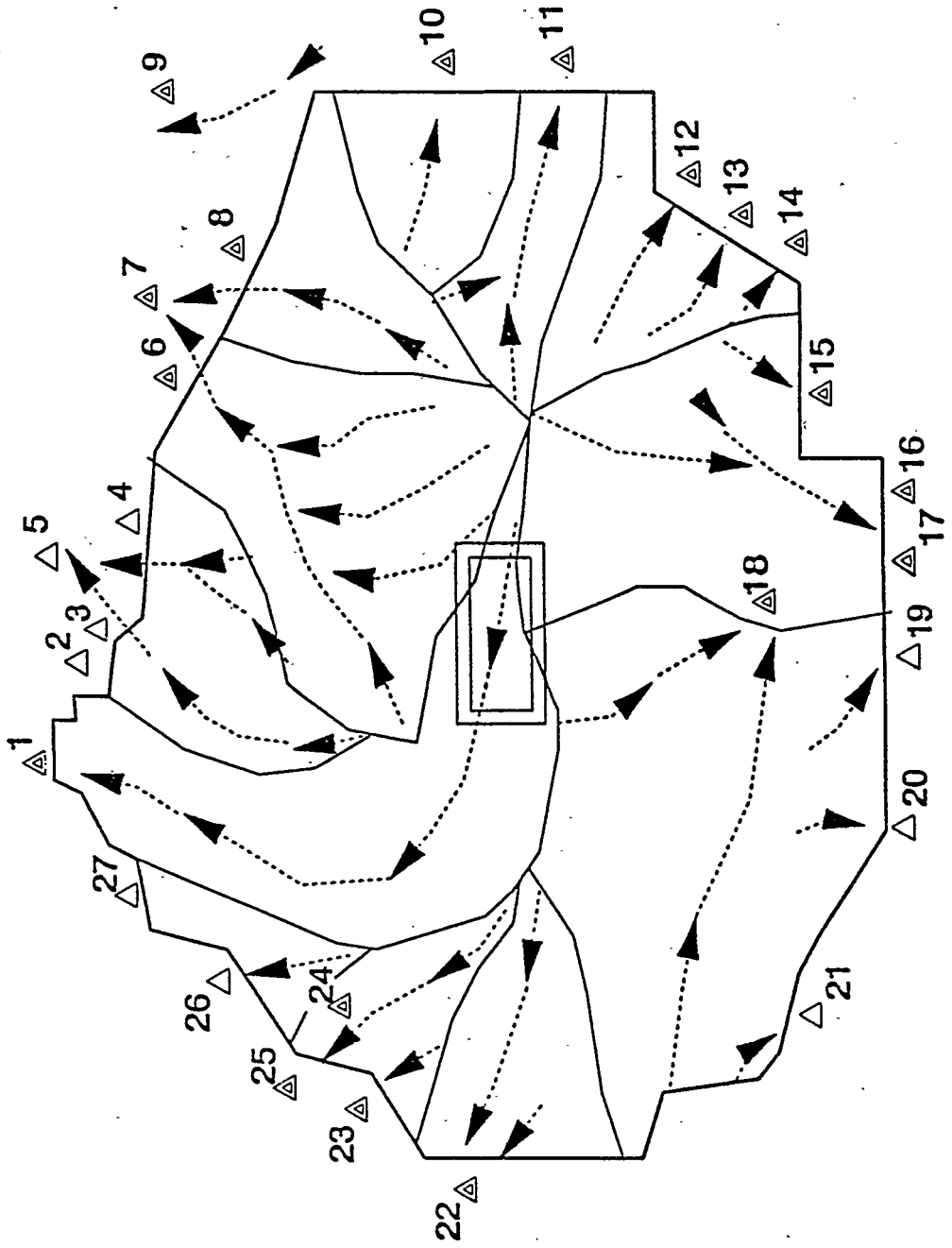


Figure 4. Optimal monitoring scheme.

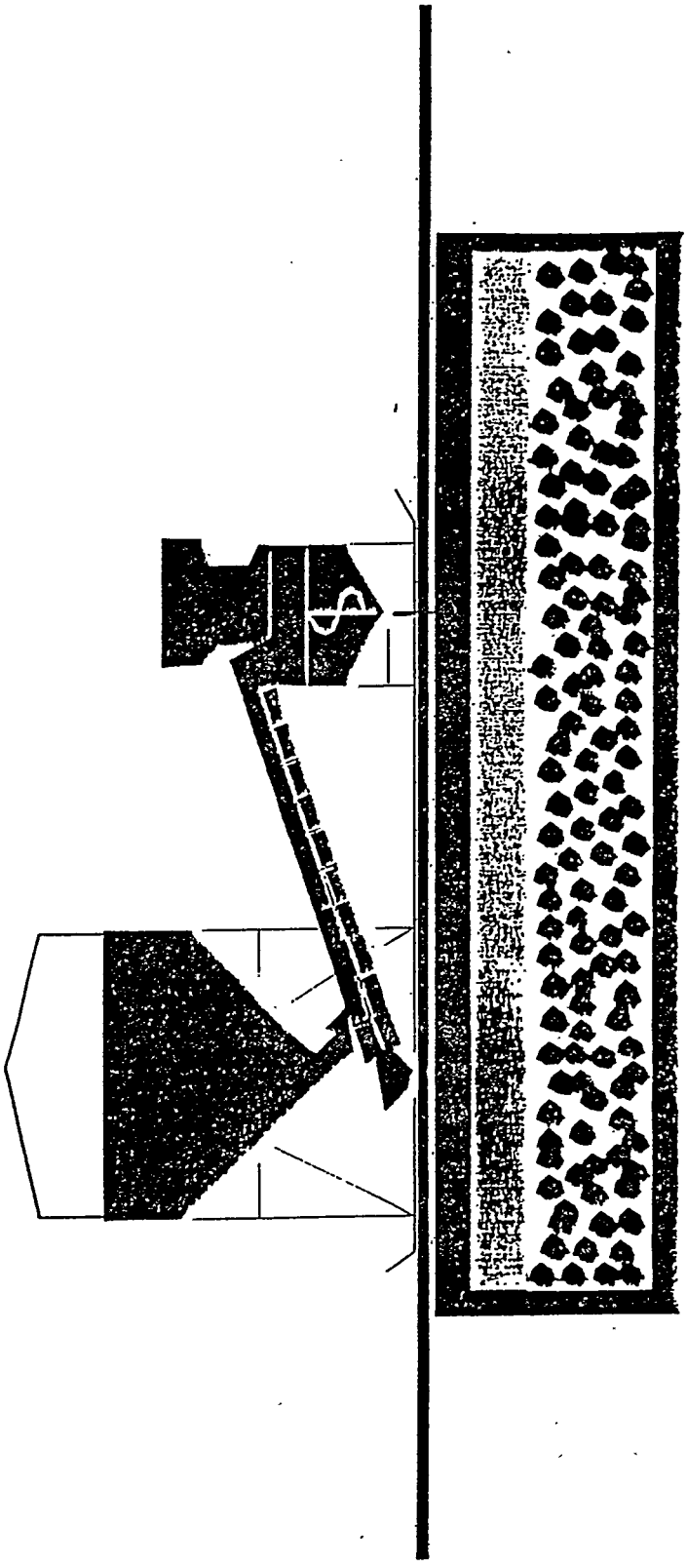


Figure 5. Trench disposal method—grouting.

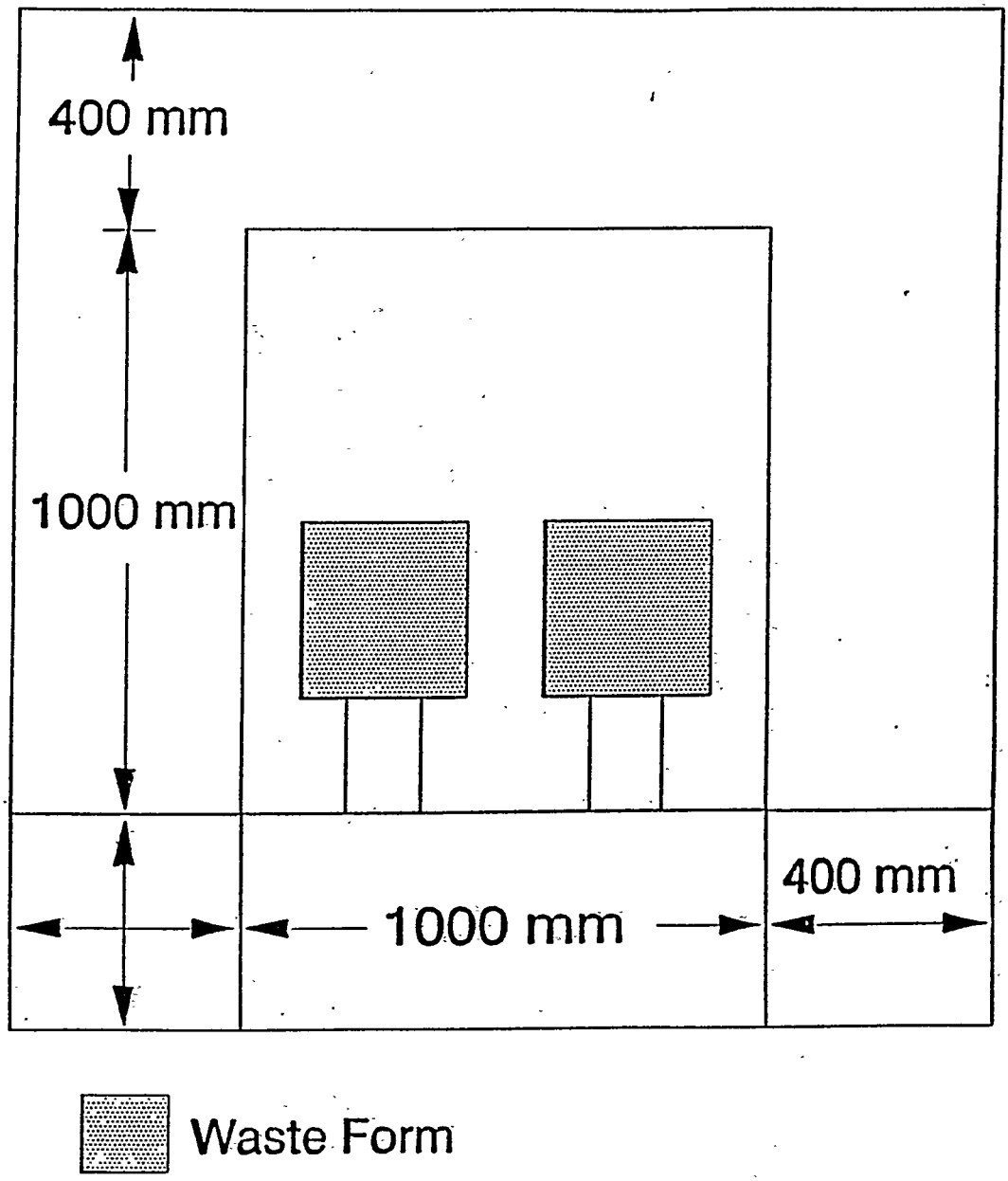


Figure 6. Storage design for naturally occurring radionuclides (Ra, U, Th).

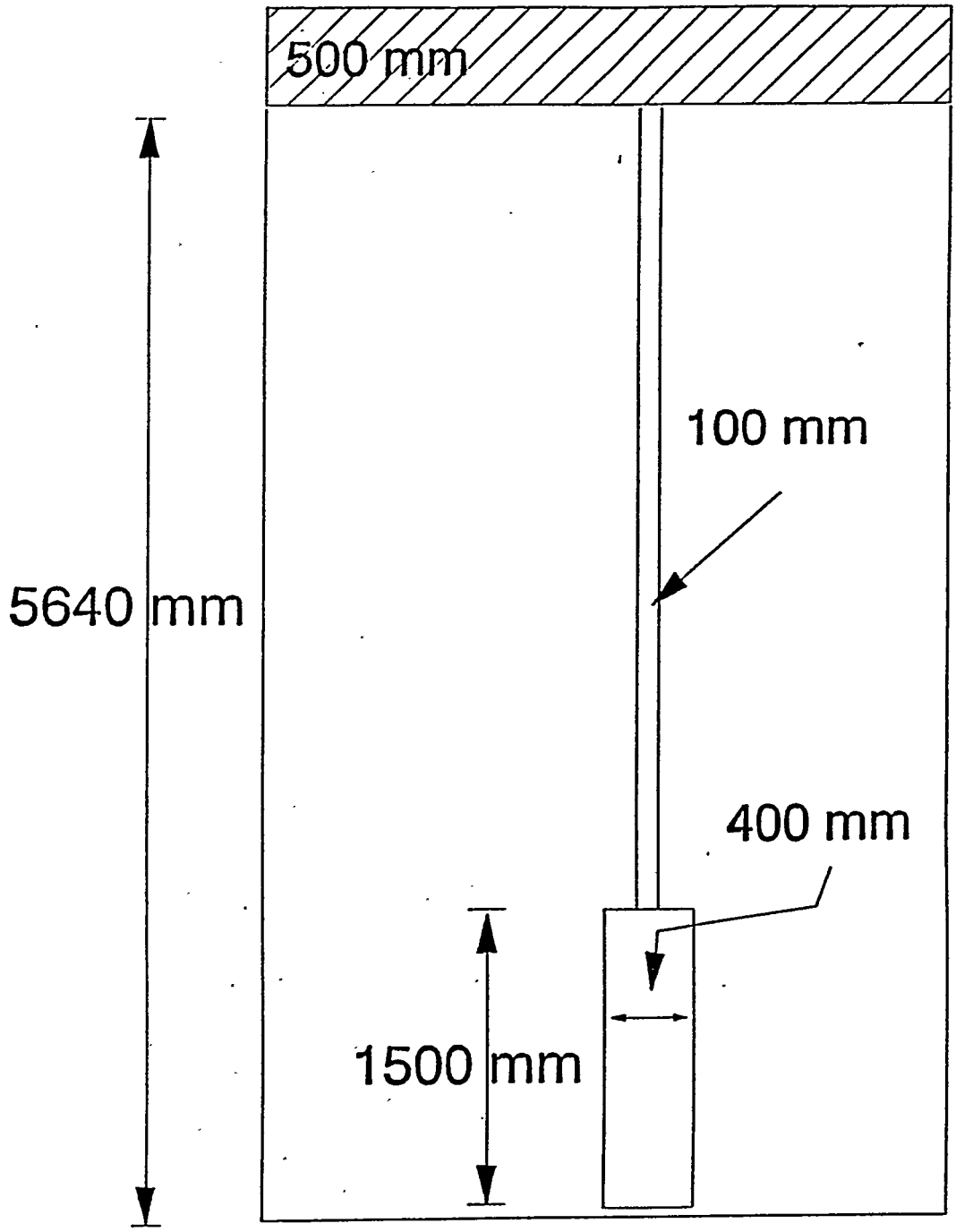


Figure 7. Used medical sources storage design.

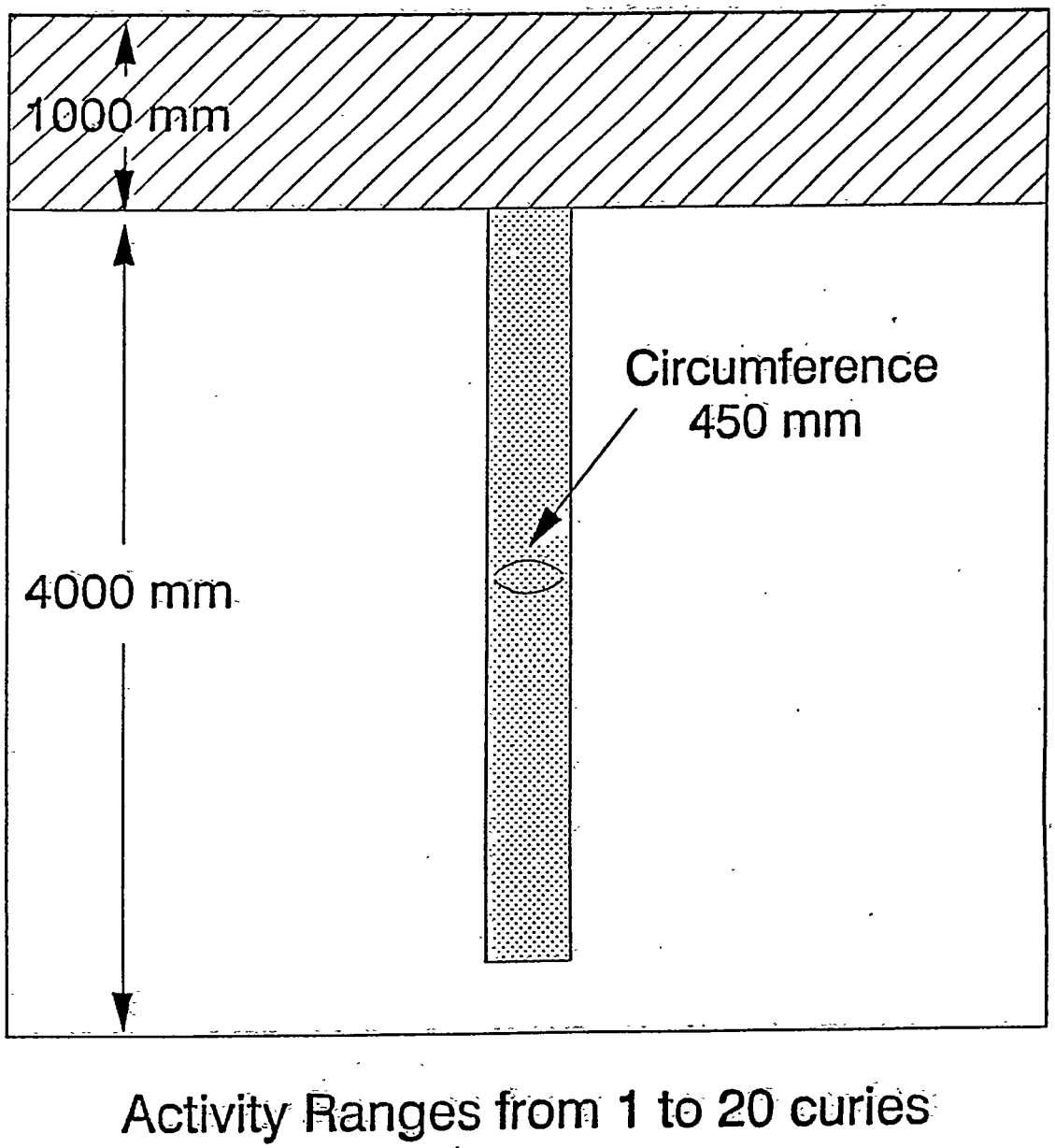


Figure 8. Disposal design of scientific and research laboratory wastes.

Status of Low-Level Radioactive Waste Management in Korea

Kun Jai Lee
Department of Nuclear Engineering
Korea Advanced Institute of Science and Technology
373-1, Kusong-dong Yusonggu, Taejon, Korea

INTRODUCTION

The Republic of Korea has accomplished dramatic economic growth over the past three decades; demand for electricity has rapidly grown more than 15% per year. Since the first nuclear power plant, Kori-1 [587 MWe, pressurized water reactor (PWR)], went into commercial operation in 1978, the nuclear power program has continuously expanded and played a key role in meeting the national electricity demand. Nowadays, Korea has nine nuclear power plants [eight PWRs and one Canadian natural uranium reactor (CANDU)] in operation with total generating capacity of 7,616 MWe. The nuclear share of total electrical capacity is about 36%; however, about 50% of actual electricity production is provided by these nine nuclear power plants. In addition, two PWRs are under construction, five units (three CANDUs and two PWRs) are under design, and three more CANDUs and eight more PWRs are planned to be completed by 2006. Table 1 shows the currently established nuclear power program. With this ambitious nuclear program, the total nuclear generating capacity will reach about 23,000 MWe and the nuclear share will be about 40% of the total generating capacity in the year 2006.

In order to expand the nuclear power program this ambitiously, enormous amounts of work still have to be done. One major area is radioactive waste management. This paper reviews the status of low-level radioactive waste management in Korea. First, the current and future generation of low-level radioactive wastes are estimated. Also included are the status and plan for the construction of a repository for low-level radioactive wastes, which is one of the hot issues in Korea. Then, the nuclear regulatory system is briefly mentioned. Finally, the research and development activities for LLW management are briefly discussed.

GENERATION AND CHARACTERISTICS OF LOW-LEVEL WASTE

Low-level radioactive wastes are generated from the operation of nuclear power plants and nuclear fuel fabrication plants of Korea Nuclear Fuel Company (KNFC), and the use of radioisotopes in hospitals, industries, and research institutions. The low-level radioactive wastes generated from the nuclear power plants, KNFC and KAERI, have been treated and stored in surface storage facilities. The cumulative low-level radioactive waste from nuclear power plants, comprising the majority of total waste generation, amounted to about 34,000 drums (200L drum) by the end of 1991 and will reach up to about 170,000 drums by year 2000. Table 2 shows the status of low-level waste storage at each site. The capacity of current storage facilities in nuclear power plants is expected to reach the maximum limit until year 2000. The volume of radioisotope wastes from hospitals, industries, and institutions is growing rapidly and will take up to 20% of the total waste generation by 2025. Figure 1 shows the expected cumulative low and intermediate-level waste generation. Under these circumstances, the necessity of a centralized repository for low-level radioactive wastes was recognized as one of the most important national tasks to be solved soon.

Table 3 illustrates the characteristics of low and intermediate-level waste from the nuclear power plants. Trash and concentrated liquid occupy most of the volume, whereas approximately 90% of activity is in the spent resin. Nuclide-specific activity measurements must be performed before disposal at the nuclear power plants to classify the waste. It is very important that the final repository should have complete data about the activity inventory. It is suggested that the waste packages be classified into two classes for the practical purposes depending on the dose rate, transportability, and long-term safety.

Waste Class A

The wastes that can be transported from nuclear power plants or other producers to the final repository without any shielding should be classified as low-level radioactive waste. The transportation is performed according to the transportation regulations of Korea and IAEA recommendations; the surface dose rate must be less than 2 mSv/h or the dose rate at 2 m distance from the transport container must be less than 0.1 mSv/h. In the repository, the containers are handled with a 25-ton forklift truck. The wastes from hospitals, research institutes, and isotope production facilities may be classified as low-level radioactive wastes in most cases.

Waste Class B

The intermediate-level wastes are transported in shielded containers to the final repository. The drums are transferred in baskets or overpacks into the shielded transport containers. All the handling is carried out in baskets or overpacks in the repository. To save space and money, the activity concentration in the packages should be kept as high as possible. The product quality (waste form) and the transport regulations should be taken into considerations.

REPOSITORY CONSTRUCTION FOR LOW-LEVEL WASTE

Past Activities

In 1988, the Korea Atomic Energy Commission (KAEC) set the main goal for low-level radioactive waste management that a repository for low-level radioactive wastes will be opened by December 1995, and until the repository is built, the Korea Electric Power Corporation (KEPCO) will store the LLW at each nuclear power plant site. In the same year, the KAEC approved the LLW management plan that the first repository for low-level radioactive wastes will be a rock cavern type with a capacity of 250,000 drums, and the subsequent expansions are also scheduled to increase the capacity up to 1 million drums. Under this LLW management policy, a regional survey for a repository site was initiated to identify suitable areas in mid-1986. The geological and socio-economical condition has been reviewed to reduce the number of candidate sites to three areas. Site investigation for those three sites in the ease coast of Korea had been carried out until it was stopped in 1989 due to the strong opposition by local residents. In 1990, a new candidate site in the west coast, Anmyon Island, was attempted and eventually cancelled due to local riots again. Currently, Korean nuclear industry is considering a new approach to find a repository site with some funds to support local residents. Depending on the geological conditions of the future candidate site, either a shallow-land or rock-cavern type repository will be built for low-level radioactive wastes.

Preliminary Concept for Design, Construction and Operation

The location of a final repository has not been decided yet. However, the repository caverns are currently assumed to be located near or under the seabed. The total number of drums to be disposed of in the final repository is 1,000,000, with a volume of about 200,000 m^3. This amount of wastes corresponds to the low and intermediate-level waste produced till 2025. The total activities in the wastes are estimated at between 1.0×10^5 and 1.0×10^7 Ci. The repository will be constructed at four stages. Each stage should be for 250,000 drums. The underground repository area is about 0.5 km^2. The geological conditions are assumed to be favorable for constructing tunnels and caverns of large size, about 20 m wide and 20 m high. Concrete structures should be designed to meet the radiological requirements during the operational phase of the repository.

The first stage of the final repository consists of the followings:

1. Four caverns for low-level wastes
2. Three caverns for concentrated liquid wastes

3. Two caverns for intermediate-level wastes
4. An office and a workshop building above ground
5. A reception and inspection building
6. A terminal building for temporary storage of waste drums
7. A ventilation building with HVAC systems and electrical systems
8. The underground service area.

Two entrance tunnels are needed for the construction and operation of the repository. The caverns for low-level waste (CLLW) serve as a final repository for the low-level radioactive wastes contained in standard freight containers. Figure 2 shows the cross section of the CLLW. The cavern dimensions are about 17.5 length, 15.1 width and 13 m height. The CLLWs have an inclination of 1% towards the cavern entrance tunnel to facilitate the drainage of water into the drain water basin.

When all caverns are filled with wastes, final closure of the repository can start. This work includes the final arrangement of the engineered barriers as required (e.g., filling the empty spaces between the rock, concrete walls and ceiling). When the back-filling material is in place, concrete should be poured to form concrete plugs at the two entrances to each cavern.

Safety Consideration of the Repository

The geologic formation under consideration is an area on the western coast of the Korean peninsula. The repository is located under the seabed with access tunnels from the island or the mainland. The maximum depth of the sea above the repository is 20 m. The bedrock consists of granitic gneiss of precambrian age and is overlain by at least 5 m of sediments consisting of 50–90% sand and 10–50% silty clay. The physical properties of the bedrock are good enough for the excavation of caverns with a cross-section of 20 m × 20 m. The area is considered almost aseismic and specific protective measures against earthquakes are not required.

The groundwater flow pattern is important in locating the repository. The idealized calculation of the groundwater flow pattern under a coastal area shows that the groundwater movement is extremely slow. The conclusion is that, in order to avoid or limit the groundwater flow over the repository, it should be located either at great depth under the land or under the seabed at a shallower depth, but at an adequate distance from the shore. It is obvious that a location at several hundred meters under the land is less favorable than at a shallower depth from the economic point of view. Other advantages of the sub-seabed location are:

1. There will be no argument about future drilling of wells for drinking water through or near the repository
2. The sediment layers on the sea bottom will constitute an extra barrier for radionuclide migration
3. If some small portions of radionuclides eventually reach the sea, they will be diluted; also, the circulation of the water will be effective due to tidal variations.

For the reasons mentioned above, it is recommended that the continued planning for the repository be directed toward a sub-seabed location. However, the sub-seabed option can only be considered when the site is secured from the western coast of the Peninsula. On the other hand, the eastern coast of the country is mountaineous and the location of repository cavern under a hilly mountain will then be the most probable choice.

NUCLEAR REGULATORY SYSTEM IN KOREA

In Korea, the ultimate responsibility for the safe management of radioactive waste rests on the waste management licensee, Korea Atomic Energy Research Institute (KAERI). The licensee always has responsibility to verify the safety of the waste management activities. The government has the responsibility for the protection of public health and safety through the regulatory control and safety examination on governmental level for the whole activities of nuclear facilities. Safety authority entrusted by government, Korea Institute of Nuclear Safety (KINS), provides technical assessments and reports the results to the government. It also conducts safety inspections for all waste management activities. Figure 3 shows the framework for nuclear safety confirmation system. Regulating and licensing of nuclear facilities in Korea are based on the provisions of the Atomic energy Act and its Enforcement Decree and Regulation. The Ministry of Science and Technology has prime responsibility for nuclear regulatory and licensing work on behalf of the Korean Government.

Principle of Regulation

In 1990, thousands of Anmyon Island residents had protested for several days a government's plan to construct nuclear waste storage facilities on their island. As the result, government had announced cancellation of the plan. From this unfortunate incident, the entire Korean nuclear community could learn very important lessons. The event taught us the necessity of public consensus to conduct some projects related to nuclear power. Corresponding with the public's strong will to assure nuclear safety and to satisfy their "right to know," Korean nuclear community has adopted the following principles: Independence, Openness, Efficiency, Clarity, and Reliability.

Radiation Protection Standards

Currently, the Korean nuclear community is considering revising the radiation protection standards, which are based on the dose limit of 50 mSv/yr for radiation workers. If the safety authority, KINS, is going to take action for revision to the new standards based on ICRP Publication 60, annual radiation exposure to individual members of the public from licensed activities will be lowered to a limit of 1 mSv per year, compared with the present limit of 5 mSv per year. In special circumstances, a higher value of effective dose can be allowed in a single year, provided that the average over any five years does not exceed 1 mSv per year.

The sum of both internal and external doses (effective dose) to workers exposed to radiation is expected to be limited to 20 mSv per year, averaged over five years, with the further provision that the effective dose should not exceed 50 mSv in any single year. The current occupational dose limits in Korea are limited to 50 mSv as the basis of "Annual Dose Equivalent." In conjunction with the anticipated revision of radiation protection standards, licensees will be required to make the substantial changes in every stage of waste disposal activities. Waste licensees will also be requested to implement programs aimed at keeping radiation doses "as low as reasonably achievable (ALARA)." However, the practical application of the ALARA principle at the stage of license still remains on works to be solved in the near future for nuclear community.

RESEARCH AND DEVELOPMENT ACTIVITIES

The Korean nuclear society has several institutions including KAERI and Korea Advanced Institute of Science and Technology (KAIST). The research and development activities related to management of low-level radioactive wastes are currently focused on the development of safety assessment technology for waste disposal and the evaluation of structural behavior, geological and hydrogeological characteristics. In connection with the performance assessment for disposal system, research related to inventory estimation, leaching of waste form, radionuclide migration through the geologic media and environmental transport are being carried out as follows:

1. Study on solidified waste form characteristics and development of waste form inspection technology
2. Evaluation of repository source term

3. Development of engineered barriers evaluation technology

4. Development of natural barriers evaluation technology

5. Development of disposal system evaluation technology.

Ongoing research and development activities related to the repository characteristics and other categories are as follows:

1. Structural behavior of rock cavern

2. Evaluation of rock material properties

3. Characterization of groundwater movement and geochemical properties.

Activities related to decontamination and remedial technology, chemistry of radioactive waste and others are being carried out as follows:

1. Development of chemical decontamination reagents

2. Study on chemical decontamination mechanisms and its kinetic behavior

3. Process development of chemical loop decontamination

4. Incineration and solidification of low-level radioactive waste

5. Chemistry of radionuclides in groundwater

6. Chemical corrosion of materials used in waste disposal.

CONCLUSIONS

Korea's long-term nuclear power program and low-level radioactive waste management program are reviewed. For the purpose of the establishment of safety for radioactive waste disposal, Korean nuclear community is currently developing the related codes, technical standards, and regulatory guides as one of the public acceptance activities. Estimation of current and future generation of low-level radioactive waste shows the necessity of centralized repository. In accordance with the requirement, two alternative concepts are being considered for the location of the repository: under an island and under the seabed. Currently, the sub-seabed option is recommended to be more safe. Considering complex public acceptance issues and the pursuit of universally accepted methods for safe waste management, close international cooperation is desirable to solve the impending challenges.

Table 1. Korean Nuclear Power Program

Status	Name of Plant	Reactor Type	Start of Operation	Capacity (MWe)	Cumulative C. (MWe)
In Operation	Kori 1	PWR	1978. 4.	587	587
	Kori 2	PWR	1983. 7.	650	1,237
	Kori 3	PWR	1985. 9.	950	2,187
	Kori 4	PWR	1986. 4.	950	3,137
	Wolsong 1	CANDU	1983. 4.	679	3,816
	Yonggwang 1	PWR	1986. 8.	950	4,766
	Yonggwang 2	PWR	1987. 9.	950	5,716
	Ulchin 1	PWR	1988. 9.	950	6,666
	Ulchin 2	PWR	1989. 9.	950	7,616
Under Construction	Yonggwang 3	PWR	1995. 3.	1,000	8,616
	Yonggwang 4	PWR	1996. 3.	1,000	9,616
	Wolsong 2	CANDU	1997. 6.	700	10,316
	Ulchin 3	PWR	1998. 6.	1,000	11,316
	Ulchin 4	PWR	1999. 6.	1,000	12,316
	Wolsong 3	CANDU	1998. 6.	700	13,016
	Wolsong 4	CANDU	1999. 6.	700	13,716
Planned	KNU #17	PWR	2000. 6.	1,000	14,716
	KNU #18	PWR	2001. 6.	1,000	15,716
	KNU #19	CANDU	2002. 6.	700	16,416
	KNU #20	PWR	2002. 6.	1,000	17,416
	KNU #21	PWR	2003. 6.	1,000	18,416
	KNU #22	CANDU	2003. 6.	700	19,116
	KNU #23	PWR	2003. 10.	1,000	20,116
	KNU #24	PWR	2004. 6.	1,000	20,529*
	KNU #25	PWR	2005. 6.	1,000	21,529
	KNU #26	PWR	2006. 6.	1,000	22,529
	KNU #27	CANDU	2006. 6.	700	23,229

* Kori-1 Out of Commission

Table 2. LLW Storage in Korea

Location	No. of Units	Storage Capacity (Unit : 200 L drum)	Inventory (1991. 12.) (in 200 L drum)	Loss of Storage Capacity
Kori	4	32,906	25,514	1992
Yonggwang	2	13,330	4,160	1995
Ulchin	2	14,400	2,763	1996
Wolsong	1	9,000	1,513	2001
			Σ = 33,950	

Table 3. Volume percent, activity and surface dose rate of LILW

LILW	Volume (%)	Activity (%) (Ci/y)	Surface dose rate (mSv/h)
Trashes	46.8	5.9 (5.5%)	0 - 5.5
Concentrate	42.1	4.1 (3.8%)	0.02 - 1.7
Spent resin	8.7	96.4 (89.4%)	0.01 - 220
Spent filter	2.4	1.4 (1.3%)	0.05 - 9.67

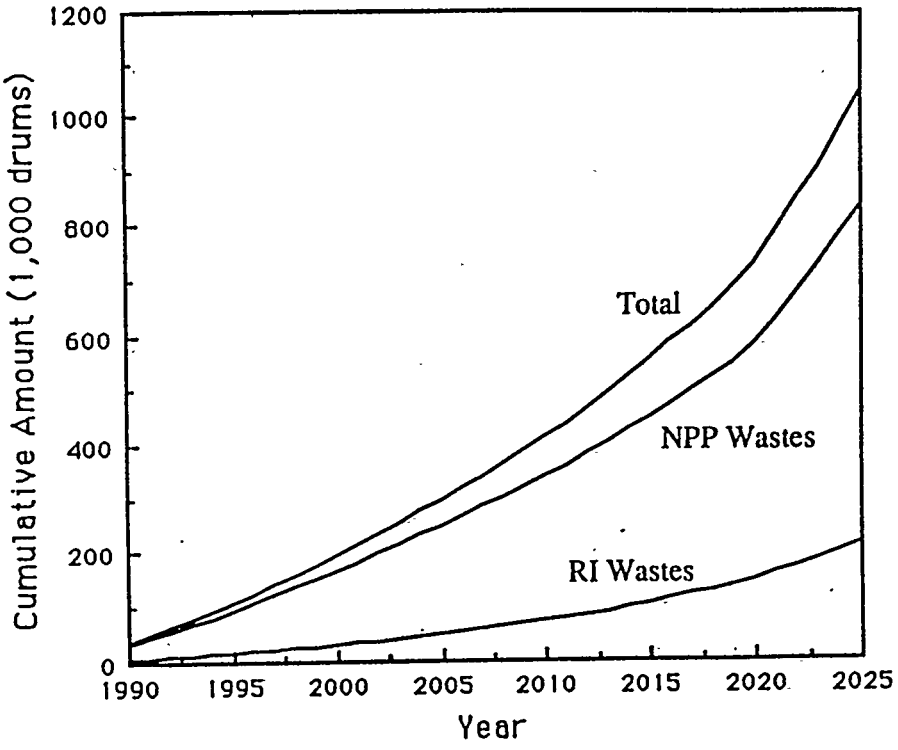
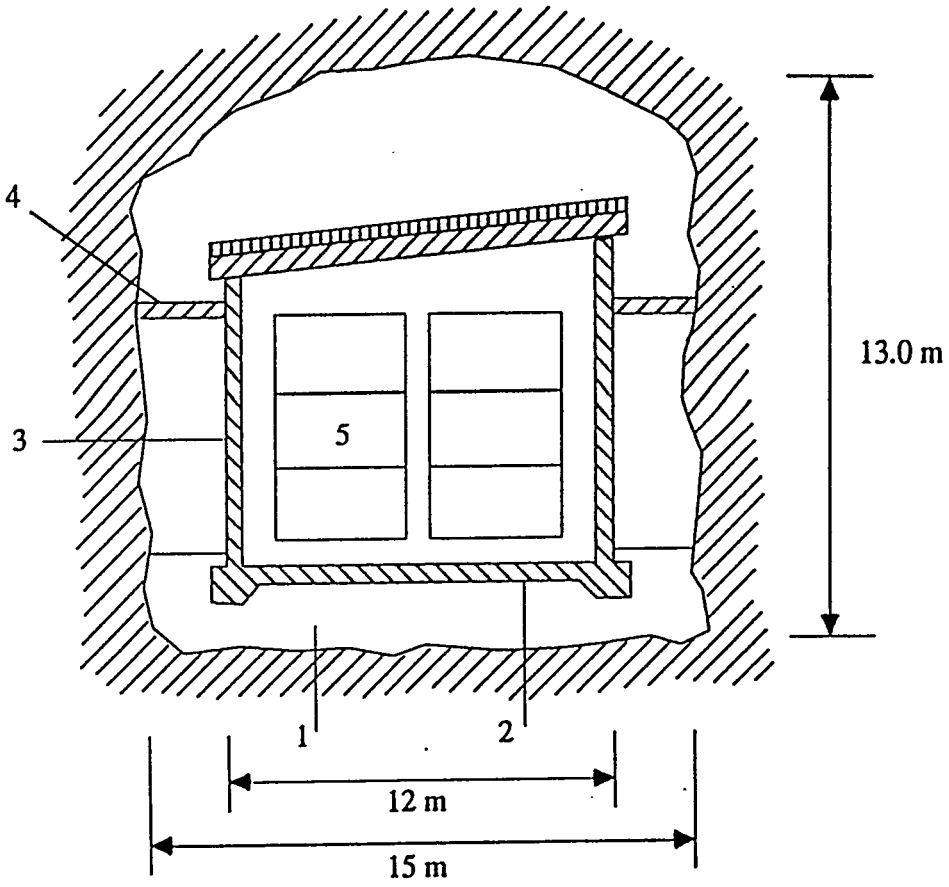


Fig. 1 LLW Arisings in Korea



1. Drainage Cource
2. Concrete Floor
3. Concrete Wall
4. Supporting Beams
5. Containers

Fig. 2 Cross-sectional schematic of the cavern for low level waste

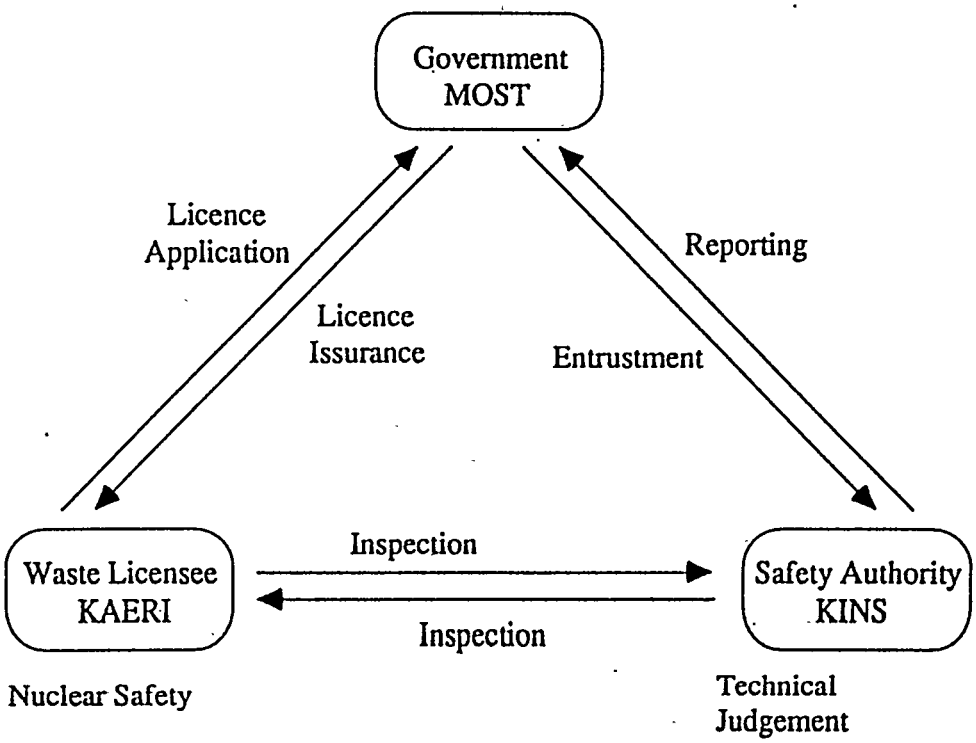


Fig. 3 Fundamental Framework for Nuclear Safety Confirmation

Technical Issues in Licensing Low-Level Radioactive Waste Facilities

Reuben Junkert, P.E.
Project Director, Low-Level Radioactive Waste
Department of Health Services
State of California

ABSTRACT

The California Department of Health Service spent two years in the review of an application for a low-level radioactive waste disposal facility in California. During this review period a variety of technical issues had to be evaluated and resolved. One of the first issues was the applicability and use of NRC guidance documents for the development of LLW disposal facilities. Other technical issues that required intensive evaluations included surface water hydrology, seismic investigation, field and numerical analysis of the unsaturated zone, including a water infiltration test.

Source term verification became an issue because of one specific isotope that comprised more than 90% of the curies projected for disposal during the operational period. The use of trench liners and the proposed monitoring of the unsaturated zone were reviewed by a highly select panel of experts to provide guidance on the need for liners and to ensure that the monitoring system was capable of monitoring sufficient representative areas for radionuclides in the soil, soil gas, and soil moisture. Finally, concerns about the quality of the preoperational environmental monitoring program, including data, sample collection procedures, laboratory analysis, data review and interpretation and duration of monitoring caused a significant delay in completing the licensing review.

INTRODUCTION

More than nine years have now passed since the California Legislature passed and the Governor signed enabling legislation for the Department of Health Services (DHS) to select a private entrepreneur as license designee to develop a facility for the disposal of LLW generated in California. Almost to the month, seven years ago, December 1985, US Ecology accepted the honor of being license designee and by their acceptance agreed to select and characterize a site, prepare an application for a license and, upon receipt of a license, operate the disposal facility for 30 years. All of this was to be paid for out of their own pocket and eventually would be recaptured over the 30-year operational period.

Good progress was made in the mid and late 1980s. A preferred site was selected in March of 1988 and the application for a license was deemed complete and ready for the review process to begin in December of 1989. The draft environmental impact report was released in June of 1990 and was followed by the final report in April 1991. The draft license was also released for public comment in June of 1991. And finally in December of 1991 the Department went on record as having all information needed to make a licensing decision.

TECHNICAL ISSUES

Before the numerous technical issues were dealt with there was another matter that had to be addressed, and that was the applicability of the numerous Nuclear Regulatory Commission guidance documents for the design of a facility to meet the performance objectives of 10 CFR 61. There really was not a great debate about this issue. The decision was quickly made that the documents were undoubtedly the best road map available and we would require the applicant to follow the guidance or explain why exceptions were being made.

Technical issues that would require intensive evaluations and resolution did not just materialize when DHS started to review the application for a license. Although, in my opinion, the restrictive nature of the site selection criteria automatically eliminated some issues, other technical issues were highlighted by the very

nature of the restrictive site selection criteria. For example, the requirement that the mean annual precipitation be less than 10 in. a year meant that the California desert would be a potential area. California deserts, however, are subject to flash flooding in addition to normal things like the effects of an earthquake. So one of the first items that found its place on the technical issues list was the matter of flash floods.

There were other considerations that carried heavy emphasis, such as the concept of a closed drainage basin or, to restate the criterion, a basin that has no outlet for surface water flows. In the desert, the lowest point in the basin is the dry lake bed. Other considerations for the watershed area were the location of the flood plain and surface features, such as slope of the site and existing evidence of erosion from surface flows. The selected site is approximately 100 ft above the nearest ephemeral stream. Surface slope is approximately 2-2.5% and the watershed area is approximately 5 square miles.

Extensive effort was put into the search for a site that would not be susceptible to major impacts from an earthquake. Earthquakes with a Richter magnitude of 3.0 or larger within a 200-mile radius were evaluated, and all known earthquakes, regardless of magnitude, within 50 miles were evaluated. These evaluations led to a final design factor of 0.3G for acceleration. This provides a very adequate factor of safety of approximately 2.5.

The site has a substantial unsaturated zone. Depth to groundwater is in the range of 650 to 700 ft. The proposed trench depth of 60 ft still leaves approximately six hundred feet of dry material between the trench bottom and groundwater. To determine the properties of the unsaturated zone, boreholes were drilled and five monitoring wells were installed. Extensive lab analyses provided information on soil properties. To provide the final confidence and a glimpse of potential performance under very abnormal conditions, a water infiltration test was conducted. Besides the data that showed a very limited movement of water, the test confirmed that the unsaturated zone had a tremendous capacity to absorb moisture.

I will share a few details of the infiltration test. A square area of approximately 27 ft was excavated to a depth of 6 ft, which in effect removed all the top soil and exposed the partially developed hardpan or impermeable layer. The sides of the excavated area were lined with plastic to allow only vertical or downward infiltration at the 15-foot square base. Water was added over a period of a few minutes to provide the equivalent of approximately 38 in. of water for infiltration. Infiltration of the water occurred over a period of 25 to 33 hours. Instrumentation extended into the zone under the pond and around the perimeter. Vertical movement was approximately 10 ft in five days. Total vertical movement during the 139-day test was approximately 16 ft. As might be expected, vertical movement amounted to only 2 ft in the last 119 days of the test. Total lateral movement was between 3.5 and 15 ft. If we were to do it over, we would have an instrument located between 3.5 and 15 ft. In summary, movement of the wetted front was within the range projected by computer modeling.

Before computer modeling and analysis of the unsaturated zone was performed, a verification and validation exercise was completed. Both the infiltration test and the modeling results show that it is highly improbable that active movement of any of the radionuclides via soil moisture or water vapor will occur through the zone because there is no available pathway.

The source term estimate took an unexpected twist because of a very high projection for tritium-bearing waste from one generator. More than 90% or about 4.8 million of the total curies projected for the disposal site were of tritium. To verify the tritium estimate, we went back to the generator for verification. The verification exercise was a series of letters between the Department and the generator wherein the generator ultimately acknowledged that the original estimate was a very optimistic business projection and the realistic source term was approximately one-fourth to one-third of the original estimate. Nevertheless, the performance assessment was not modified to reflect the lower tritium estimate. In fact, we even ran one assessment on the assumption that all the tritium would be centered at one point and would be released instantaneously. The natural question that arises is why would such a scenario be evaluated? The short answer is, to prove a point. The long answer is that because of the findings of very small amounts of tritium at the 100-foot level below ground surface, a small public group succeeded in convincing others that a great potential for tritium migration existed. The finding was 1 tritium unit or 3.2 picocuries per liter, or roughly 6000 times less than the standard for drinking water. This kind of thinking forced us to perform analyses of this and other incredible scenarios.

I might add that the concern about migration of radionuclides through the unsaturated zone also drove the design of the monitoring system for the disposal area.

Public perception also was the determining factor that resulted in the Department convening a highly select panel of 11 experts to review the proposed trench design, specifically whether plastic trench liners are necessary. The committee's collective recommendation was that liners are not necessary and could possibly prevent the disposal unit from performing to design requirements. The committee's recommendations also resulted in a major expansion of the monitoring system. The final design provides for monitoring of the trench cap, areas next to the trench covers, and the zone below the trenches. The presence and migration, if any, of radionuclides will be detected by collection of soil gas, detection of water vapor, and gamma logging. The equipment for monitoring will be designed and located in sets across the width of each trench and along the length of the trench every 200 ft so that a complete picture of conditions will be available at each location. This spacing corresponds to the planned incremental excavation to meet the yearly need for space for disposal of waste. Each set or instrument island will have access tubes to different depths to allow readings. Boreholes for soil sampling, detecting water vapor and gamma logging are proposed to go 100 ft below the bottom of the trench. Soil gas sampling is proposed to go to the 60 foot level. In addition, slant bore holes will be located a midpoint between stations along the longitudinal axis. These boreholes will also allow retrieval of soil samples from the areas below the trenches.

Monitoring of the unsaturated zone will provide data to plot gradients and by having a minimum of two action levels, will allow early warnings of the need for some type of corrective action.

ENVIRONMENTAL MONITORING

Environmental monitoring of a proposed site is not a task that just happens. In California, items like quality of data, sample collection procedures, laboratory analysis, data review and interpretation and duration of monitoring all contributed to a significant delay in completing the licensing review. Some of the down-to-earth items that must be dealt with are the literal mountains of data, analysis of the data, much of which is at the lower limits of instrument detection, long time delays in getting the data analyzed and resolution of anomalies. Speaking from experience, a successful monitoring program must have an early decision regarding a realistic and practical lower limit of detection. It is not always better to analyze the smallest or at the lowest unit possible. We experienced delays, questionable quality, considerable frustration, and large costs because, in my opinion, we were looking for uniformity of data at the lower limits of equipment capability and not at all what was required to determine normal background and regulatory standards.

Quality control and audits of collection procedures and laboratory analysis are imperative and become increasingly important as you search for and analyze data at the lower limits of detection. Remember, a few minutes ago I was telling you about finding one tritium unit at 100 ft? Well, that was also the lowest limit of detection for the instrument and had an associated error of approximately plus or minus half a tritium unit. Therefore, the result was not very meaningful. Nevertheless, this became a big issue with other regulatory agencies and the public as well.

CONCLUSIONS

In summary, in my opinion, the technical questions regarding the site selection, design of the facility, environmental monitoring, use of trench liners, monitoring of the unsaturated zone, and quality control have been recognized, addressed, and resolved in California. Documentation of the final outcome is contained in the three-volume final environmental impact report/statement (EIR/S), which also contains responses to the more than 200 individuals who had concerns and questions during the open comment period on the draft EIR/S.

The question that I cannot answer is: Will we have new technical questions to answer if the court decision is to hold additional public hearings on the project. At this time it is hard to conjecture what the questions might be.

Issues in the Review of a License Application for an Above Grade Low-Level Radioactive Waste Disposal Facility

Jay D. Ringenberg
LLRW Program Manager
Nebraska Department of Environmental Quality

INTRODUCTION

In December 1987, Nebraska was selected by the Central Interstate Compact (CIC) Commission as the host state for the construction of a low-level radioactive waste disposal facility. After spending a year in the site screening process, the Compact's developer, US Ecology, selected three sites for detailed site characterization. These sites were located in Nemaha, Nuckolls and Boyd Counties. One year later the Boyd County site was selected as the preferred site and additional site characterization studies were undertaken. On July 29, 1990, US Ecology submitted a license application to the Nebraska Department of Environmental Control (now Department of Environmental Quality-NDEQ). This paper will present issues that the NDEQ has dealt with since Nebraska's selection as the host state for the CIC facility.

The Central Interstate Compact, formed in 1983, consists of Louisiana, Arkansas, Oklahoma, Kansas and Nebraska. Nebraska's statute dealing with low-level radioactive was passed by the Nebraska legislature in 1986 and subsequently regulations were promulgated. The Nebraska regulations parallel to a large extent the regulations found at 10 CFR 61, however, the Nebraska statute specifies that any low-level radioactive waste disposal facility constructed in Nebraska be constructed above grade. Thus, Nebraska Administrative Code Title 194—Rules and Regulations pertaining to the Management of Low-Level Radioactive Waste deal with the construction of an above grade facility in addition to the other requirements. Nebraska statute also vested low-level radioactive waste management authority in the Department of Environmental Control. As an "agreement state," radiation protection issues related to radioactive materials licenses have been traditionally handled by the Nebraska Department of Health (NDOH) through its Division of Radiological Health. Thus, in order to coordinate the license application review effort between the two agencies, it was necessary to develop a Memorandum of Understanding (MOU). The MOU details the responsibilities of each agency in the review process. Generally, the NDEQ has authority for disposal activities as generally outlined in 10 CFR 61 and NDOH has authority for the general public and worker safety related to radioactive materials.

In January 1988, the Low-Level Radioactive Waste Division was formed in the Department of Environmental Control to manage activities related to the expected receipt of a license application. The decision to hire a small permanent staff and utilize consultants to assist in the technical review was made. Thus, the current permanent staff consists of a Division Manager, an environmental engineer, an environmental program specialist, a public liaison specialist, a quality assurance and records management specialist and a secretary. In mid 1989, the NDEC went through a rigorous selection process to select a team of consultants to assist the agency in project activities.

The initial consultant team activities were focused on development of a Licensing Program Plan and a Quality Assurance Plan to guide the project's activities. The Licensing Plan includes procedures for numerous issues ranging from selection and credentialing of technical reviewers to preparation of the required project documents. The Quality Assurance Plan includes Quality Assurance Procedures and provides for compliance inspection audits and surveillances of the license applicant and its subcontractors as well as the State agencies and their consultants.

MAJOR ISSUES

Several issues have emerged through the first four years of project activity through a combination of sources including the general public, the NDEQ, the NDOH and others involved in the process. These include:

- Regulatory Guidance Documents
- State Auditor Report
- Quality Assurance
- Performance Assessment
- Environmental Monitoring.

REGULATORY GUIDANCE DOCUMENTS

The applicability of Nuclear Regulatory Commission (NRC) documents in general, and specifically to the issue of above grade disposal of waste since most of their guidance documents are focused on near surface disposal has been an issue to be dealt with in the review of the license application. Many NRC documents have been utilized by both the applicant and the state program during the process. These include:

- NUREG 0902—Site Suitability, Selection and Characterization
- NUREG 1274—Review Process for Low-Level Radioactive Waste Disposal License Application Under Low-Level Radioactive Waste Policy Amendments Act
- REGULATORY GUIDE 4.18—Standard Format and Content of Environmental Reports for Near-Surface Disposal of Radioactive Waste
- NUREG 1199—Standard Format and Content of a License Application for a Low-Level Radioactive Waste Disposal Facility
- NUREG 1200—STANDARD REVIEW PLAN for the Review of a License Application for a Low-Level Radioactive Waste Disposal Facility
- NUREG 1300—ENVIRONMENTAL STANDARD REVIEW PLAN for the Review of a License Application for a Low-Level Radioactive Waste Disposal Facility
- NUREG 1293—Quality Assurance Guidance for Low-Level Radioactive Waste Disposal Facility.

These documents have proven to be extremely useful in the process, however, it has been necessary for the State program to interpret the guidance documents and determine their applicability to the specific project under review.

STATE AUDITOR REPORT

In late 1991, the Director of Department of Environmental Control requested that the Nebraska State Auditor conduct a fiscal and performance audit of the LLRW Program Division. The objective was to provide the Director with information regarding the LLRW Program Division's effectiveness in controlling the license application review process. The audit began in December 1991 and concluded with the submission of a formal report in July 1992. Twenty-eight specific recommendations were made in the report. In addition, ten areas were identified for improvement as follows:

- Controls over License Review
- Controls over Consultant Team
- Develop Estimate of License Review Schedule

- Licensing Program Procedures Compliance
- Technical Review of ER and SAR
- Quality Assurance Program
- Key Decision Documentation
- Completeness Review Documentation
- Documentation of Billings
- Host State Selection Related Expenditures.

The LLRW Program Division is currently developing response actions to 23 of the recommendations. The Director did not agree with all of the recommendations made by the State Auditor report including some related to the establishment of a firm schedule for the license application review process. Since the review process entails iterative rounds of development of questions for the applicant and its corresponding response, the development of a schedule is beyond the control of the agency.

QUALITY ASSURANCE

One of the significant outcomes of the State Auditor's report was an increased emphasis on the quality assurance (QA) program for the project. Although significant QA work was being accomplished prior to the report, it was recommended that an increased emphasis be placed on QA. As a result, several steps have been taken to strengthen the existing QA program. One of these is the development of a QA guidance methodology. Key aspects of the methodology are as follows:

- Audits Address 6-8 NQA-1 Criteria
- Surveillances Address 2-3 NQA-1 Criteria
- Minimum two Audits Annually for License Applicant
- Audits/Surveillances Address Corrective Action of Outstanding Nonconformance Reports
- Audits/Surveillances Headed by Certified Lead Auditor in Accordance with NQA-1
- Focus on Intense Work Areas
- Focus on Areas with Trend Toward Increasing Nonconformance
- Focus on Volume or Critical Nature of Work Being Done.

This methodology, combined with the training of new auditors and an increased pace of audits and surveillances, has been instrumental in a successfully expanded quality assurance program. The table below highlights the increasing number of both audits and surveillances conducted on both the applicant and the state program.

	Audits	Surveillances
Applicant		
1990	1	1
1991	4	1
1992	5	6
Subcontractors		
1990	1	3
1991	2	2
1992	5	5
State Agencies		
1990	0	0
1991	1	0
1992	7	6
Contractors		
1990	0	0
1991	4	1
1992	9	17

PERFORMANCE ASSESSMENT

Issues related to performance assessment have proven to be significant in the license review process. At this stage, no definitive conclusions have been reached since the performance assessment (PA) process is incomplete. The review effort has been approached from two distinct directions. The first is review of the license application utilizing the Standard Review Plan found in NUREG 1200. This effort is focused on a formal review of the data submitted by the applicant in the Safety Analysis Report. Early in the review process, the decision was made to also conduct an independent performance assessment program.

This independent effort has involved considerable preparatory work by the review team. Computer codes have been selected and evaluated for applicability for various transport mechanisms. Various release scenarios, not necessarily corresponding to those selected by the applicant, have been developed. Considerable time has been devoted to training of review team members in the specifics of code utilization. A formal Performance Assessment Program Instruction (PAPI) document, which outlined a nine step PA process, was developed to formalize the process for all participants. At this time, the independent PA process has progressed through the sixth step of the process, the development of screening calculations. The technical, fiscal and computer resources to implement an independent PA program as well as conduct review of material submitted by a license applicant are considerable.

ENVIRONMENTAL MONITORING

Environmental monitoring has also been an issue that has required considerable time and resources to implement. The applicant provided, either in the original SAR or in response to subsequent comments, one year of pre-operational environmental monitoring data. Additionally, the applicant has continued to gather data from selected media during the license review process. The license review effort has been approached from two distinct directions. The first is review of the license application utilizing the Standard Review Plan found in NUREG 1200 and the Environmental Standard Review Plan found in NUREG 1300. Concurrently, the State of Nebraska has undertaken the development and implementation of an independent environmental monitoring program. Full time staff have been added to the State agency and consultant personnel have been utilized to assist in sample collection, laboratory analysis of samples and data interpretation. The State continues to gather baseline environmental monitoring data on a regular basis. Currently, a Health Physics Assessment Facility (HPAF) is being established in Butte, Nebraska, the closest community to the proposed facility, for the purpose of collecting and analyzing environmental monitoring data during the license review process. The staff, equipment, monetary and other resources necessary to address environmental monitoring issues have proven to be considerable.

SUMMARY—LICENSE REVIEW STATUS

The license application submitted to the NDEQ consisted of two documents.

- Environmental Report (ER)—2 Volumes
- Safety Analysis Report (SAR)—11 Volumes.

The combined documents contain approximately 4,000 pages. Additional material submitted in response to completeness and technical review has resulted in a total of 12,000 pages to review. Completeness review was the first activity after receipt of the application. Completeness review identified 42 deficiencies related to material not submitted that was required to conduct the overall review. The applicant submitted additional material in response to the completeness review and on December 24, 1991, approximately 17 months after receipt, the NDEC declared the application complete.

Technical review of the license application began immediately after the completeness review on those portions of the application that were complete. The first round of technical review was completed in April 1991. Separate documents addressing questions related to the ER and SAR were directed to the applicant. The review was conducted by approximately 100 technical personnel representing numerous engineering, scientific, legal and financial disciplines. The review issues were divided into eight functional areas and a Review Manager was selected for each area as follows:

- Site Characteristics
- Design and Construction
- Facility Operations
- Performance Assessment
- Environmental Issues
- Quality Assurance
- Financial Assurance
- General Information.

The technical reviewers were all assigned to one or more of the Review Managers. The License Plan specified procedures for the reviewers to direct questions and comments to the Review Manager. The questions were then evaluated by the Review Manager and forwarded with or without comment to the Overview Committee. This group consists of the following individuals:

- Representative of the NDEQ—Environmental Engineer
- Representative of the NDOH—Health Physicist
- Representative of the NDEQ—Environmental Specialist
- Consultant Team Member—Principal Author of Safety Evaluation Report
- Consultant Team Member—Principal Author of Environmental Report.

The Overview Committee reviewed and synthesized all questions and comments received from the Review Managers. Their principal function is to combine duplicate comments prior to submittal to the

applicant. This has resulted in the deletion of duplicate comments and the combining of similar comments. In some cases, the Overview Committee has generated original questions that have arisen as a result of the synthesis process. This effort has eliminated the possibility of sending duplicate questions to the license applicant and has proven to be extremely valuable in the overall review process. The first round of technical review resulted in 249 comments on the Environmental Report and 473 comments on the Safety Analysis Report. The same process was followed for the second round of technical review which began in October 1991 after the applicant responded to the first round of comments and also furnished material in response to the Completeness Review. In April 1992 the second round of comments was forwarded to the applicant. The second round resulted in some comments being "closed out" due to receipt of a satisfactory response by the applicant. However, 113 comments were generated related to the Environmental Report and 419 comments were generated related to the Safety Analysis Report. The applicant responded to the second round comments in October 1992 and the third round of technical review began in November 1992.

Low-Level Waste Management Alternatives and Analysis in DOE's Programmatic Environmental Impact Statement

Jerome S. Gerstein
Office of Environmental Restoration and Waste Management
U.S. Department of Energy
Washington, DC 20585

INTRODUCTION

The Department of Energy is preparing a Programmatic Environmental Impact Statement (PEIS) for the Environmental Restoration and Waste Management Program. The PEIS has been divided into an Environmental Restoration section and a Waste Management section. Each section has a unique set of alternatives. This paper will focus on the waste management alternatives and analysis. The set of alternatives for waste management has been divided into waste categories. These categories are: high-level waste, transuranic waste, low-level waste, low-level mixed waste, greater-than-class C and low-level waste from commercial sources, hazardous waste, and spent nuclear fuel. This paper will discuss the alternatives and analytical approach that will be used to evaluate these alternatives for the low-level waste section. Although the same alternatives will be considered for all waste types, the analysis will be performed separately for each waste type. In the sections that follow, information will be provided on waste management configurations, the analysis of waste management alternatives, waste types and locations, facility and transportation activities, the facility and transportation impacts assessment, and the compilation of impacts.

WASTE MANAGEMENT ALTERNATIVES

In formulating the PEIS alternatives, DOE has two primary questions to consider, "How many waste management facilities are required to accomplish waste management activities?" and "Where are the best places around the country to locate those facilities?" The waste management alternatives to be considered in the PEIS are basically siting alternatives. It is expected that the Record of Decision will identify sites that will host low-level waste treatment, storage, and disposal facilities. Throughout this discussion, "site" will mean the geographic location where DOE activities are presently, or formerly were, conducted. "Facility" refers to the physical entity required to execute a specific waste management activity, and "location" refers to the actual spot on a particular site where a facility resides.

The PEIS is the first part of a two stage National Environmental Policy Act (NEPA) process that will be used to analyze alternatives for DOE waste management. The PEIS will consider where waste management facilities should be sited. A project-specific EIS will be needed to address issues that are not covered in the PEIS. For example, alternatives to specific treatment and disposal technologies and location on a DOE site would be examined in a project-specific EIS.

There are three alternatives being considered in the waste management section for each waste type. These are the no action, minimum consolidation, and maximum consolidation alternatives. Currently, there are six sites disposing of low-level waste. The "No Action" alternative is not a true no action but more a continuation of the current program. This alternative consists of generator sites continuing to package waste for transportation and doing whatever treatment is necessary to meet transportation requirements. Further treatment may be performed at the disposal locations or a limited number of commercial treatment facilities capable of accepting radioactive waste. Disposal of low-level waste currently takes place at six DOE sites. DOE has also disposed of some waste from environmental restoration activities at commercial disposal facilities. The first alternative, the minimum consolidation alternative, considers consolidating waste management functions at three to five DOE sites. The second alternative, the maximum consolidation option, considers further consolidation of waste management functions for low-level waste at two sites.

Currently specific sites that will be considered in the consolidation alternatives have not been identified. This is because DOE does not yet have sufficient information to make that judgment. Analysis of the current

program and the risks and impacts associated with waste management facilities at a given site will provide a comparative ranking of the sites. Selecting reasonable combinations of DOE sites will be a part of the PEIS analysis. Figure 1 identifies the analytical logic behind the assessment process. As indicated in the diagram, each of the DOE sites affected by the waste type alternatives is evaluated under the proposed waste loadings associated with that alternative. Since each waste type has its own unique characteristics and regulatory requirements, each is evaluated independently of all others. The assessment process is composed of the four major components shaded on Figure 1: the identification of waste types and locations, the identification of facility and transportation activities, the identification of the transportation and facility impacts, and the compilation of impacts according to the waste type alternatives and total DOE installation impacts. Each of these major components is briefly discussed in the following sections.

WASTE CHARACTERISTICS AND LOCATIONS

The first step in the waste management analysis is to identify the waste that needs to be managed by DOE. DOE generates low-level waste at over 30 sites around the country. This waste is a primarily the result of the weapons production facilities, which includes reactors and chemical separations facilities. DOE also manages low-level waste from its five test and research reactors. In the future an increasing amount of waste is expected to be produced by the environmental restoration program. In order to evaluate the risks and impacts of the waste management program, the amount and characteristics of the waste for each must be defined. This includes waste that is generated yearly in addition to any waste currently in storage. Characteristics include the mass, volume, physical form, chemical constituents, radionuclide distribution, and likely or currently acceptable treatment of the waste produced by each installation.

Currently there are six sites that are disposing of low-level waste: Savannah River Site, Oak Ridge Reservation, Los Alamos National Laboratory, Nevada Test Site, Hanford Site, and Idaho National Engineering Laboratory. The analysis of each waste type will be initiated by compiling available information on the sources, characteristics, and locations of each waste type. Projections of future quantities and characteristics of each waste type will then be made, or reviewed where presently available, taking into consideration:

- Changes in projected generation rates as a result of recent presidential decisions concerning the nuclear weapons stockpile and production of special nuclear materials
- Quantities and characteristics of waste that may result from environmental restoration activities
- Ongoing and future efforts to reduce waste generation as a result of new technologies, substitution of nonhazardous materials for hazardous materials, and continued waste minimization efforts.

For each waste type, a range, or upper bound as appropriate, of the quantities of that waste type by relevant characteristic and installation will be identified. The PEIS will identify and discuss this information. In addition, the PEIS will discuss any major assumptions associated with projected waste type quantities or characteristics.

There are significant uncertainties regarding the quantities of low-level waste that DOE will need to further manage as a result of its environmental restoration program. Estimates of this waste will be developed from the analysis of the Environmental Restoration program alternatives. Further treatments, if any, will also need to be defined to model the type of facilities required to manage this waste.

FACILITY DEFINITION

The facility definition is the basis for the PEIS analysis. For each waste type, generic facilities for treatment, storage, and disposal need to be developed. For low-level waste, a generic comprehensive treatment facility will include sorting, incineration, metals recovery, compaction, stabilization, and final packaging. Storage facilities required would be barrel storage areas. Disposal facilities will include shallow-land disposal and engineered disposal facilities. For each facility developed, any effluent, emission, or waste product that

is produced by the facility must be characterized to determine its effect on workers, the public, or the environment. A conceptual design for each waste management facility will need to be developed. In many cases, existing or designed facilities will be able to provide this design basis. Examples of this are the Waste Experimental Reduction Facility in Idaho or the Saltstone Disposal Facility at Savannah River. A description of the facility is needed not only to provide an estimate of the capital and operating costs for that facility but also to estimate the number and locations of workers involved in facility operation and maintenance. This information is needed to develop estimates of worker exposure and health risks.

The generic facilities will be based on an assumed technology for that operation. An assumed technology may be the in use technology, best available technology or a predicted technology depending on what is appropriate for the waste. The sensitivity of the risks and impacts due to the chosen technology will be discussed in the PEIS. For example, a rotary kiln incinerator may be the assumed technology for combustible waste. A possible future technology would be molten salt oxidation. This technology would still produce a waste product requiring stabilization, an offgas to be filtered, and would still have workers exposed to radiation and the accompanying risks. Therefore this technology is not expected to produce environmental consequences that will affect the siting decisions.

In order to assess environmental impacts the PEIS will consider both normal and upset conditions. Because many facilities have not been designed, it will not be possible to do a probabalistic risk assessment complete with fault trees and event trees to help in defining severe accidents for the facilities. Therefore, accidents will not be based on a mechanism for failure. Instead an accident will be developed for each facility that does not consider initiators will be developed. For example, a fire in a storage facility is postulated. Exposure due to the unfiltered release of the combustion products will be evaluated. This will indicate if there are any inherent benefits from one installation due to remoteness, meteorology, etc., and whether this risk is significant.

FACILITY IMPACTS ASSESSMENT

By using generic facilities located at each DOE site considered in an alternative, a comparative analysis can be developed. This comparison can be applied to different sites considered as part of an alternative, for example to risk sites in the no action alternative. In addition a qualitative and quantitative comparison of the no action alternative can be made with each of the consolidation cases.

Environmental impacts will be evaluated as changes to the baseline condition. This involves a three step process that can be consistently applied across various categories of environmental impacts at DOE sites or along transportation corridors. The first step is to develop a description of the baseline or affected environment for the relevant locations. Next, the variables that were identified in the baseline affected environment are reevaluated under the hypothesis of the new set of circumstances that attend each programmatic alternative. The final step in the analysis consists of the comparison of the baseline with the projected consequences of implementing a given programmatic alternative. Regulatory requirements applicable to the baseline will be identified.

The focus of environmental impact assessment for the waste management alternatives includes risks to human health and ecology, compliance with environmental quality standards (air and water), and broader socioeconomic effects. The following list contains some protocols to be used in the assessment of detailed waste management facility and transportation parameters.

- The baseline environmental conditions for any affected DOE site will include current background conditions plus those resulting from actions that could foreseeably occur during the construction and operational life of the proposed facility. Baseline conditions will also include currently programmed actions that will occur regardless of the PEIS decisions. Facility construction and operation periods will vary with each waste type.

- Impacts and risks will be identified for radiological and non-radiological events/releases.

- Where appropriate, the assessment process will identify impacts and risks under each alternative both on and off the site.

- Cumulative impacts and risks will be assessed.

Uncertainties in technology are to be addressed by using best available information.

Risk assessments will be based on generic site locations at each affected site to accommodate the quantitative nature of the models.

TRANSPORTATION RISK ASSESSMENT

The PEIS evaluates tradeoffs between the current program of waste management facilities at six or more regionally dispersed sites as opposed to consolidating facilities at fewer sites. The resulting transport of waste to implement consolidation potentially results in impacts. Radiological and non-radiological risks will be identified for truck and rail transport of these wastes. The assessment will be performed for normal and upset conditions.

Using the waste characteristics information, transportation routing maps will be developed for each alternative. The number of shipments can be estimated from the quantity of waste generated at a given site.

The assessment team will utilize the RADTRAN IV model to assess transport related radiological risks to human health. RADTRAN codes (variables) will be adjusted for each transportation route according to the waste type and source of the wastes. A methodology will be developed to assess ecological risks from transport of radiological wastes, using procedures comparable to those developed to assess ecological risk at sites.

Methodologies to assess impacts from non-radiological wastes under upset conditions are in development. Impacts to the ecology as well as to human health will be assessed.

HUMAN HEALTH RISK ASSESSMENT

A human health risk methodology (based on EPA's Risk Assessment Guidance for Superfund methodology and other applicable risk methodologies) is being developed to assess the human health and worker risks both on and off the site. Sources of risk include both construction and operation of waste management facilities that treat, store, and/or dispose of waste. The methodology will be based on readily available environmental transport and exposure assessment models.

Criteria for model selection include ready availability of environmental and chemical data sets for model execution, ability to model a variety of waste type scenarios, and recognized acceptance of models and their capabilities. The models chosen will be comparable to and compatible with those being developed for the environmental restoration portion of the PEIS.

A baseline risk estimate will first be computed for existing and currently planned waste management activities. Both population and individual carcinogenic and noncarcinogenic risk/hazards, as well as physical hazards associated with construction, operation, and maintenance activities will be computed for current and projected exposures.

ECOLOGICAL RISK ASSESSMENT

An ecological risk methodology for assessing risks to the ecology from the construction and operation of waste management facilities is also under development. First, the affected environments at the major DOE sites will be characterized, including the climatic regime and ecosystem types. Data requirements will be identified and will include:

- Climatology, meteorology, and air quality
- Surface and ground water resources
- Surface and subsurface geology
- Terrestrial and aquatic ecological resources
- Protected resources.

For each of the contaminants included in the defined cases, information will be provided on hazards such as acute toxicity, chronic toxicity and bioaccumulation of contaminants. Appropriate endpoints will be selected and defined (e.g., reduction in recreational opportunities or wildlife abundance, adverse impacts on threatened or endangered species, etc.). Risks will be categorized to facilitate comparisons of impacts across sites and alternatives. To the extent possible, environmental transport models will be used to quantify contaminant exposures.

AIR AND WATER QUALITY IMPACTS ASSESSMENT

Facilities will be required to meet air and water quality standards, such as those promulgated in the Clean Air, Clean Water, and Safe Drinking Water Acts. Verification of compliance and/or assessment of impacts will be based on review and analysis of technology designs, with backup use of transport or dispersion models when required.

Sources of air quality impacts at affected DOE sites will be stack and fugitive emissions from waste management facilities. Significance of the impacts will be determined from standards established in the Clean Air Act. Technology designs will be reviewed against Prevention of Significant Deterioration or New Source Review procedures and for compliance with State regulations and State Implementation Plans. Dispersion models will be utilized to determine air pollutant concentrations as required.

The sources of impacts to water media from proposed waste management facilities include water consumption and the releases from these facilities. Water intake and discharges from proposed facility designs will be assessed against standards established by federal and state laws, such as those regulated by the National Pollution Discharge Elimination System and by state appropriation and use permits. Generally, the existing condition and use of water resources will be assessed as the baseline for estimated potential impacts. Water resource assessments will include both surface and groundwater resources at each of the affected sites.

SOCIOECONOMIC IMPACTS ASSESSMENT

Changes in employment and income will be analyzed as a function of the construction and operation of waste management facilities and of waste transportation requirements. The analysis of these changes will employ a socioeconomic model that uses employment data as its primary information source. The outputs are production, income, and employment numbers, after accounting for multiplier effects. Other socioeconomic variables (e.g., stress) are tied to model output thresholds.

The composition of employment will also be analyzed to determine the type and availability of labor required by each considered waste management complex in the alternatives. The size and composition of the labor force in a reconfigured complex will be estimated to identify impacts such as overall employment and regional impacts.

Risks to human health and the environment will be assessed for their impacts on regional economic welfare. Changes in morbidity and moribundity will be examined for implications for the health care system, foregone earnings, and the quality of life. Risks to ecosystems may also impose burdens on the social structure, and will be analyzed.

Effects on housing in the region of influence will be assessed. Housing will be examined to describe total units, rental versus owner occupied housing, and vacancy rates. Impacts will be analyzed in terms of any anticipated changes in these characteristics resulting from the construction and operation of the proposed facilities and the availability of existing housing or capacity to construct new housing to meet any increased demand.

Population will be described in terms of a demographic profile of existing regional patterns, historic growth trends, and estimates of projected future growth. Population changes impact infrastructure. The infrastructure of communities surrounding each of the waste management sites will be characterized in terms of the extent and availability of public services (police, fire, medical, education), public safety and the capability to respond to emergency situations. Local and regional transportation access will be described, and any potential impacts assessed. Impacts to cultural and historic resources will also be identified on a regional basis.

Land use impacts will include direct impacts from the use of land within DOE sites, as well as legal constraints on the use of DOE lands. Land use assessments will include the benefits of alternative uses, costs of alternative land uses, land use compatibility, and regulatory constraints on the land. Conflicts between objectives of Federal, State, Local, and Tribal governments land use plans will also be assessed.

COMPILATION OF IMPACTS

The analysis proceeds for each of the alternatives for a waste type, and each set of results is compiled so that the waste type configuration alternatives can be compared. The comparison will include the quantitative risk to workers and the public from transportation and operation of waste management facilities. A qualitative comparison can be made of impacts such as air and water quality and some of the ecological impacts. Each waste type is subjected to a similar analysis of its unique alternatives. It is expected that a preferred alternative will emerge for each waste type. The impacts of these preferred waste type alternatives will then be compiled to determine what the cumulative impacts on individual DOE sites would be from consolidating facilities to manage various waste types there.

CONCLUSIONS AND NEXT STEPS

The PEIS will analyze the alternatives to siting of DOE waste management facilities. This analysis will provide the basis for the Record of Decision to identify the DOE sites that will treat, store and dispose of low-level waste. This decision expected at the end of 1994 is the first step in the construction of a national strategy for DOE low-level waste management. An EIS will be needed for each project that will need to consider alternatives for locations on a DOE site, technologies that may be used and capacity of the facility.

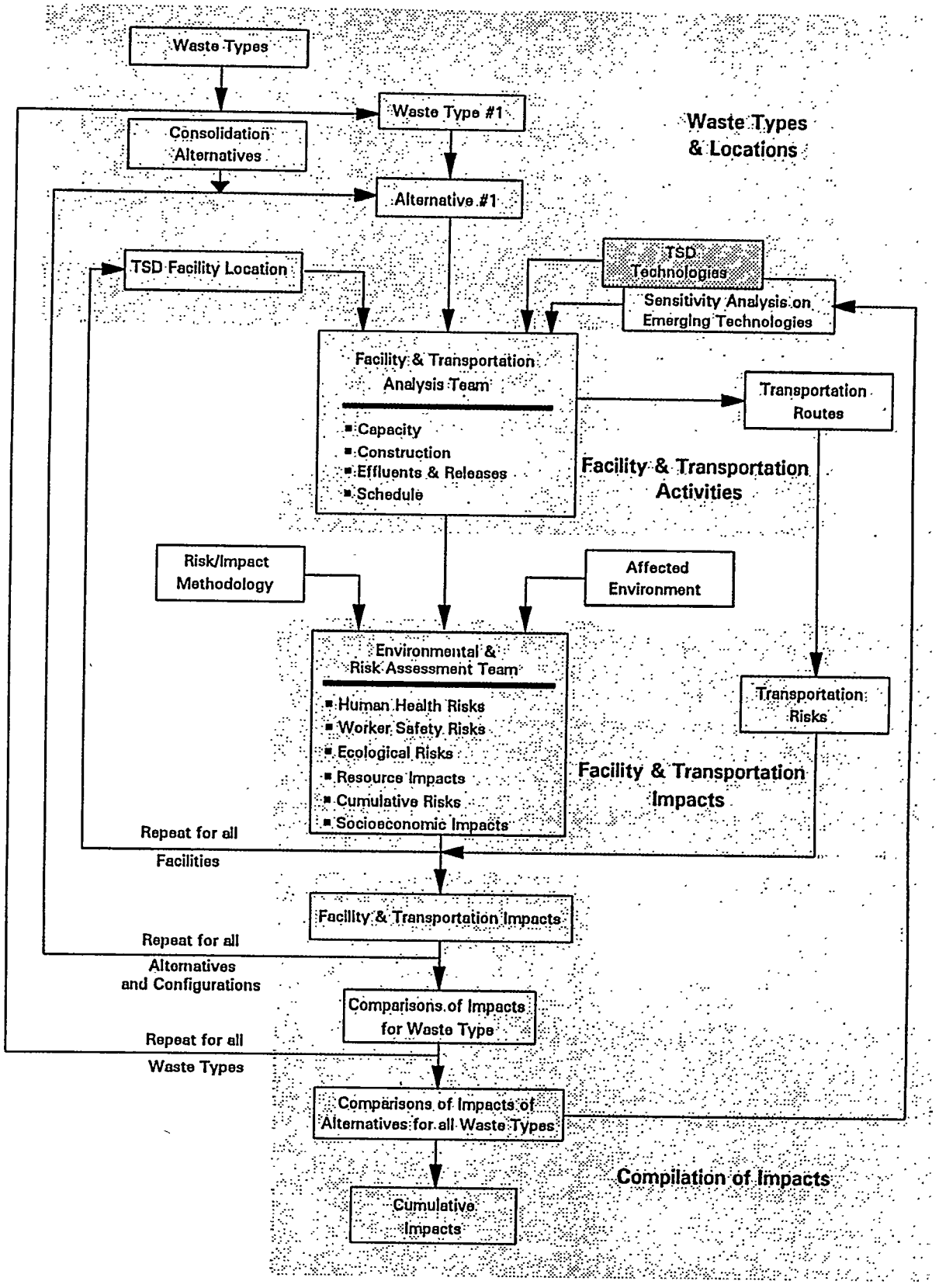


Figure 1. Process for analysis of WM Programmatic Alternatives.

DOE'S Integrated Low-Level Waste Management Program and Strategic Planning

Gregory Duggan
Office of Environmental Restoration and Waste Management
U.S. Department of Energy, Washington, D.C. 20585

Jou Hwang, Ph.D
Science Applications International Corporation
Germantown, Maryland 20874

INTRODUCTION

At the advent of the nuclear age in the 1940s, little attention was given to the management of waste resulting from research and production activities. America was at war and the secret Manhattan Project's objectives were clearly defined; nuclear waste management was not a priority. Since World War II, nuclear energy programs (both commercial and defense) have continued, and the U.S. Department of Energy and its predecessor agencies have played a major role. But the focus until recent years remained "production." Definitions of types of radioactive waste and associated management methods (including those for low-level waste) were developed, but they were based primarily on operational requirements for safe handling by generators, not on permanent safe disposal.

For many years, waste generated in DOE installations was managed using a site-by-site approach, with minimum coordination and integration between sites. Today, with the focus on environmental responsibility, waste management operations have a new mission and face a wide variety of managerial and technical challenges. DOE is now subject to many new interagency agreements and regulations and is working to comply with complex, and at times conflicting, requirements. Even now, many DOE field offices and sites are developing site-specific strategies to manage LLW that do not maximize the value of DOE resources. Regulatory compliance issues, coupled with budget and manpower constraints, are leading DOE to a more centralized management approach. An integrated waste management program is essential as a result of DOE's changing mission. Resource limitations, increasing waste volume from environmental restoration (ER) and decontamination and decommissioning (D&D) activities, risk reduction requirements, and public concern and opposition to new waste management facilities are issues that DOE must address.

To meet the DOE's commitment to operate its facilities in a safe, economic, and environmentally sound manner, and to comply with all applicable federal, state, and local rules, regulations, and agreements, DOE created the Office of Environmental Restoration and Waste Management (EM) in 1989 to focus efforts on controlling waste management and cleaning up contaminated sites. In the first few years of its existence, the Office of Waste Management (EM-30) has concentrated on operational and corrective activities at the sites. In 1992, the Office of Waste Management began to apply an integrated approach to managing its various waste types. Consequently, DOE established the Low-Level Waste Management Program (LLWMP) to properly manage its complex-wide LLW in a consistent manner.

The objective of the LLWMP is to build and operate an integrated, safe, and cost-effective program to meet the needs of waste generators. The program will be based on acceptable risk and sound planning, resulting in public confidence and support. Strategic planning of the program is under way and is expected to take two to three years before implementation of the integrated waste management approach.

LOW LEVEL WASTE MANAGEMENT PROGRAM (LLWMP)

The LLWMP was established within the Division of Technical Support as part of the Office of Waste Management's specific waste-type management initiative to develop and implement a system-wide, coordinated approach for managing LLW from receipt of waste from generators to its disposal. The LLWMP is managed by an EM program manager with support provided by the DOE Headquarters (DOE-HQ) Waste Management

contractor and by other support contractors for specific work groups. The organizational structure for the LLWMP is provided in Figure 1.

The primary goal of the LLWMP is to establish an integrated DOE complex-wide plan for managing LLW, which avoids generating LLW as much as possible and disposes of it safely and cost effectively with little or no use for interim storage.

The LLWMP is currently developing an integrated management plan that will use the most technically effective and cost-efficient means possible to safely and acceptably prevent/minimize, handle, characterize, treat, store, transport, and dispose of DOE LLW. Through development and implementation of this integrated, documented plan, which will incorporate waste generators' experience and public participation during the planning process, DOE expects to improve its credibility and its decision-making effectiveness. The objectives of the LLWMP are to:

- Assist generators in minimizing waste generation through sound planning, recycling, process alteration, and technology development
- Bring operating facilities into compliance with applicable and acceptable requirements
- Reduce risks to the environment, workers, and the public for all LLW operations
- Ensure that the infrastructure for LLW management is available on time, and is efficiently operated
- Ensure cost-effective and efficient use of resources.

The LLWMP also will provide assistance in assessing technology needs for waste management equipment and systems, and participate in cooperative demonstration projects with the Office of Environmental Restoration, the Office of Technology Development, and the Office of Facility Transitions, as appropriate. The LLWMP will participate in DOE system-wide cooperative planning projects with the Office of Programmatic Guidance and Compliance, the Office of Planning and Resource Management, and the Office of Facility Transitions, as appropriate. The LLWMP will provide other technical assistance for activities affecting the management of DOE radioactive waste to include supporting DOE meetings and conferences, supporting international technology exchange programs, and supporting technical working groups having system-wide concerns.

Steering Committee for Low-Level Haste Planning

An LLWMP Steering Committee, comprised of senior DOE/EM personnel, DOE Office of Environment, Safety, and Health (EH), and DOE Field Office management or contractors, has been established. Committee meetings will be held as necessary to provide guidance, review information, and approve deliverables prepared by the Program. A Work Group will also be established to provide technical support to the Steering Committee. The Steering Committee will provide guidance and recommendations in support of the DOE LLWMP, with the goal of developing and implementing an integrated and comprehensive LLW management system. The Steering Committee presently consists of a Chairperson, from the Office of Waste Management, the Division of Technical Support, and 16 members with representatives from DOE-HO and from each of the major DOE field offices. The DOE-HQ organizations represented include Environment, Safety, and Health (EH-232), Waste Management (EM-30), Site Operations (EM-32), Projects (EM-34), Environmental Restoration (EM-40), and Technology Development (EM-SO). A listing of all members and their alternates is provide in Figure 2. Additional members from DOE-HQ, public agencies, and stakeholders will be added as appropriate.

Field office participants are key to the program to propose ideas, review progress, and provide field perspective to the LLWMP. The success of the Program is dependent upon the proactive participation of the

committee. The Steering Committee is the LLW Program Manager's tool for decision making and implementation of the LLWMP.

Two Steering Committee meetings were held in 1992, and four are planned for 1993. The first Steering Committee meeting was held June 15-17, 1992, in Las Vegas, Nevada. The first meeting consisted of a series of facilitated exercises that aided in developing a preliminary conceptual strategic plan (Future State Document) for the management of LLW. Based on the vision and mission developed for the LLWMP, the Steering Committee will provide appropriate recommendations and guidance to the EM-30 management for the overall direction of the LLWMP. A charter for the Steering Committee was developed during the first meeting.

The second committee meeting was held September 15-16, 1992, in Denver, Colorado. During the meeting, the Steering Committee finalized the Future State Document (mission, vision, goals, and objectives) and approved the Steering Committee charter. They discussed and finalized review comments on the LLW Current State (Background) Document and identified additional information needs and information sources for revision of the LLW Current State Document. The Steering Committee also identified key LLW issues in regulatory, institutional/ management, technical, risk, public and general areas for further detailed analysis; developed a preliminary strategy with options to address each key issue identified; and reviewed and discussed LLW management alternatives proposed in the Programmatic Environmental Impact Statement (PEIS).

STRATEGIC PLANNING APPROACH

The fundamental approach to the strategic planning process is to: (a) develop and implement a complex-wide LLWMP jointly with field offices to meet waste generator's needs and incorporate operational experience from DOE installations, commercial facilities, and international practice, (b) establish a proactive and flexible program based on anticipated forthcoming regulatory requirements, new technology development, and coordination among field offices, and (c) document the strategic planning process. The strategic planning process includes the following major stages and is shown in Figure 3.

Low-Level Waste Background Report

A Background Report is being prepared to provide a comprehensive description of the present waste management system, and attempt to provide a baseline for measurement of progress. The Background Report includes information on:

- Physical treatment, storage, and disposal (TSD) plant capabilities, conditions, and constraints
- Regulatory requirements (laws, regulations, compliance agreements, etc.)
- Waste inventories and their characterization
- Production and programmatic commitments.

The first draft of the Background Report was completed in September 1992 and reviewed by the Steering Committee. A major revision effort is ongoing to provide a broader spectrum of complex-wide waste management activities and to compile the most up-to-date information. A proposed outline for the revision can be found in Figure 4. The Steering Committee will review the proposed outline and make a recommendation to proceed with the revision.

Future State Document

A Future State Document to define the desired future state of the LLWMP is currently being prepared. The Future State Document will include mission, vision, goals, objectives, definitions, and assumptions of an integrated LLWMP. The first draft of the Future State Document (Conceptual Strategic Plan) is scheduled to be completed in early 1993. A draft vision statement has been developed as:

DOE Operating a Nationally Integrated, Cost-Effective, Low-Level Waste Management Program Based on Acceptable Risk and Sound Planning, and Incorporating Structured and Defined DOE Regulatory and Oversight Programs, Resulting in Public Confidence and Support.

and a draft mission statement as:

Develop and Implement a Nationally Integrated Program for DOE Low- Level Waste Management Using a Combination of Federal and Private Facilities to Meet the Needs of Waste Generators, While Fully Protecting Workers, the Public, and the Environment, and Establish and Implement a Comprehensive DOE LLW Regulatory and Oversight Program to Fulfill the Department's Responsibilities to Ensure that the Management of DOE LLW is Protective of the Public and Environment and Consistent with the Protection Provided in the Commercial Sector.

Comprehensive Strategic Plan

Based on the vision of how DOE will manage LLW in the future and the current state of DOE's management of LLW, the LLWMP will identify the differences and develop strategic options for achieving the projected vision during the strategic planning process. The first phase of the strategic planning process is to identify issues and develop strategic options, and the second phase is to evaluate options and select a preferred strategy using a system analysis methodology. The two-phased planning process will be documented in a Comprehensive Strategic Plan. The tasks for the first phase include:

- Identification of the differences between the current and the desired future state of the LLWMP
- Identification of program issues (including barriers and constraints)
- Identification of missing technology links/elements
- Establishment of system requirements and configuration
- Development of strategic options for accomplishing the desired future state.

Once the strategic options are identified, systems analysis will be performed to determine how to modify the current approach, and to evaluate various options developed to accomplish the objectives of the future state. In the second phase, the System Analysis Work Group will identify and collect required data, and analyze strategic options including their related planning assumptions, program uncertainties, and contingency plans. They will perform risk analyses (technical, cost, regulatory, etc.) for each candidate strategic option and evaluate and rank each one.

The LLWMP Systems Analysis Work Group will systematically assess the technical validity and accuracy of current information on critical issues, such as waste inventories, waste characterization, waste treatment, waste storage, waste disposal, and best life-cycle waste management alternatives. A detailed description of subtasks to be performed in the second phase include:

- Identification of critical issues and data needs. The Systems Analysis Work Group will assess the issues identified and associated data needs as well as collect data. Reference cases and TSD options will be identified.
- Development of a comprehensive pathway analysis model. The Work Group will develop and refine appropriate model(s) and use LLW physical and chemical characteristics to evaluate the reference cases and TSD options. Additional TSD options will be evaluated as they are identified.
- Evaluation of the cost and schedule information for LLW management options. Based on historical cost and schedule information, the Work Group will apply appropriate cost estimation methodology to determine the cost/schedule estimates for LLW options.

- Identification of the impact of regulatory compliance issues. The Work Group will identify current and impending LLW regulations and evaluate their impact on LLW management options.

- A system-wide, health-based risk assessment. The Work Group will refine the pathway analysis methodology, develop scenarios, collect data, and evaluate risks associated with various LLW management options.

- Integration of various methodology components. The Work Group will evaluate various alternatives for LLW management options, based on the risk, regulatory compliance, and cost to evaluate and document the recommended management alternatives.

The system analysis will be supported by a credible quality management program and ensure the participation from both HQ and field offices. A Comprehensive Strategic Plan will be prepared to recommend the final LLW management approach.

Long Range Integrated Management Plan

The LLWMP's Long Range Integrated Management Plan (LRIMP) will be developed to implement the DOE preferred strategy. Component activities include:

- Developing a task-oriented LLWMP Work Breakdown Structure (WBS)

- Describing the Scope of Work

- Defining the schedule, milestones, estimated costs, owners, etc., for each WBS element, covering LLWMP's lifetime

- Defining a breakdown of budget information by task and site.

In the third year, the Strategic Plan will be implemented through the LRIMP. The LRIMP will be reviewed and updated annually. Implementation of the plan and annual program review activities include:

- Providing SP/LRIMP planning process quality improvement and control

- Reviewing plans, roadmaps, technical reports, and other comparable documents

- Developing draft program guidance

- Reviewing budget and scheduling requests

- Establishing and facilitating workshop groups to interface between EM and other DOE and outside organizations

- Reviewing program progress and developing corrective actions to improve progress; and interacting and communicating with stakeholders.

Document Hierarchy

A document hierarchy has been developed to properly document the strategic planning process (Figure 5). Documentation of LLW strategic planning will include developing and updating, as appropriate, the Current State (Background) Report, the Future State Report, the System Analysis Workplan, the Program Plan, the Comprehensive Strategic Plan, and the LRIMP.

A status report will be prepared on the results of the annual review of the DOE/LLWMP. This report will contain a summary of the accomplishments and recommendations for the planned activities. Review and

recommendations will include the areas of technical program, program management, integration with other DOE programs, and communications and outreach programs.

Communication, Coordination, and Public Participation

It is important to coordinate LLW strategic planning efforts with other planning efforts, including the Five-Year Plan, Roadmaps, PEIS, the Waste Management Operations Committee (WMOC), and other waste type planning activities. Liaison with internal and external stakeholder organizations will allow the LLWMP to establish and maintain a mechanism for integrating and coordinating all activities and for enhancing and sustaining public involvement and communication.

SCHEDULE

A schedule for completion of this integrated strategic planning effort is presented in Figure 6. The primary activities include the following:

- Low-Level Waste Management Program (LLWMP)
- Steering Committee and Meetings
- Program Plan
- Future State of LLW Management
- Current State of LLW Management
- Strategic Plan (I)—Issue Identification/Option Analysis
- Strategic Plan (II)—System Analysis
- Long-Range Integrated Management Plan (LRIMP).

CONCLUSION

The development of an efficient and effective management system for DOE LLW is perceived as an arduous task, but one that is worthwhile and necessary. DOE can no longer afford to take a parochial approach to management of waste at its sites. Instead, it must look to life-cycle waste management incorporating quality practices into an equitable, safe, cost-effective, and complex-wide system. The approach will require dedication, communication, and commitment from all those involved in its formulation, and courage by DOE decision makers to implement the necessary changes.

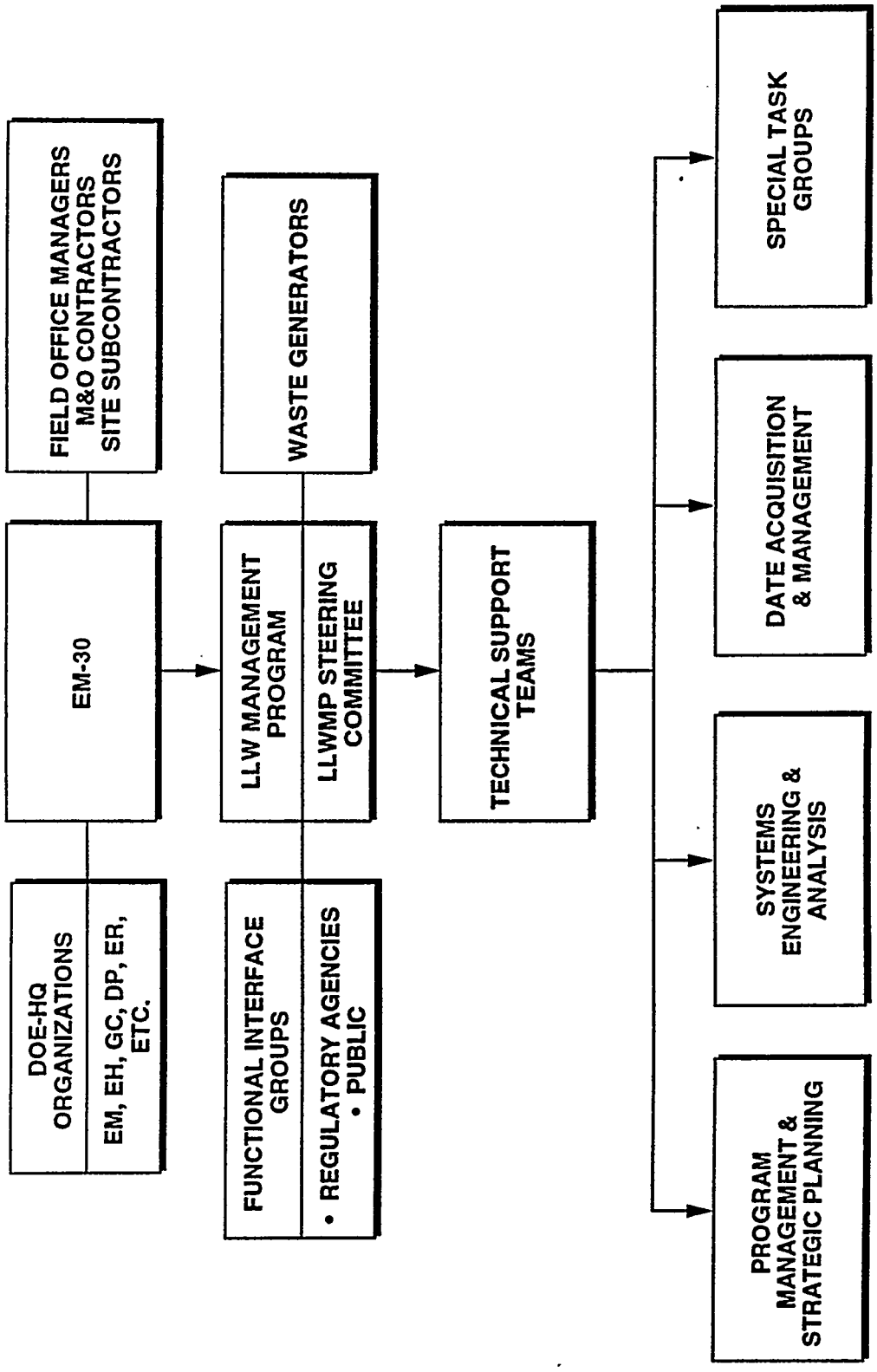
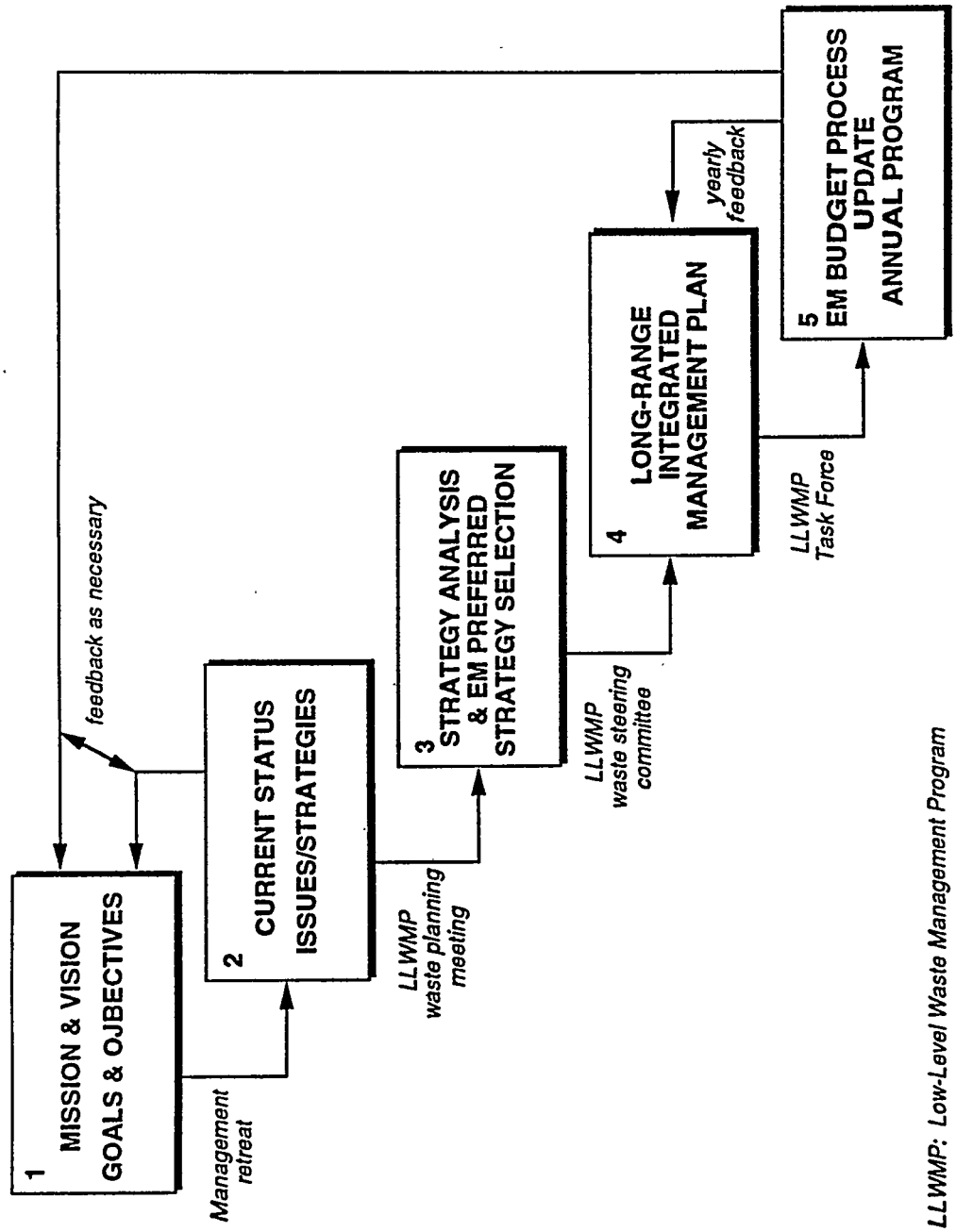


Figure 1. Organization Structure of DOE Low-Level Waste Management Program

Organization	Designated Committee Member Name	Designated Committee Member Phone	Designated Committee Member Fax
EM-35	Greg Duggan	301-903-7451	903-7234
EM-36	TBD		
EM-34	TBD		
EM-33	Lee Stevens	301-903-7133	
EM-32	Bryan Westich	301-903-7110	903-7168
EM-30	Dave Huizenga	202-586-0368	586-0449
EM-42	Cynthia Anderson	301-903-7612	903-8156
EM-43	Dianne Isbell	301-903-8109	903-8550
EM-50	George Coyle	301-903-7659	903-7457
EH-23	Gary W. Roles	202-586-0289	586-3915
Albuquerque Field Office	Jim Orban	505-845-4421	845-4664
Chicago Field Office	Ray Lang	708-252-2230	252-1654
Fernald Field Office	David Rast	513-738-6322	738-6650
Idaho Field Office	Joel Case	208-526-6795	526-1405
Nevada Field Office	Stacey A. Sorg	702-295-1694	295-1810
Oak Ridge Field Office	Bill Gilbert	615-576-1817	576-5333
Richland Field Office	Rudy Guercia	509-376-5494	372-1926
Rocky Flats Field Office	Maria Vargus	303-966-5922	966-2256
San Francisco Field Office	Roy Keams	510-422-7541	422-0832
Savannah River Field Office	Howard Pope	803-725-5544	725-3616

Figure 2. DOE Low-Level Waste Management Program Steering Committee



LLWMP: Low-Level Waste Management Program

Figure 3. Strategic Planning Process

PROPOSED OUTLINE/CONTENT:

I. SITE DESCRIPTION
- Land-Use Restrictions and Planning
- Site Geographic, Physical and Infrastructure Characteristics
- Human Resource and Economic Characteristics
- Site-Specific Political Environment

II. FACILITY AND WASTE DESCRIPTION
- Site/Facility Past/Current/Future Missions
- Site/Facility Past/Current/Planned Activities
- Waste Characteristics and Volume
  - Waste Inventory
  - Waste Characteristics
  - Generation Rates
- Waste Profile
- Waste Minimization Forecast

III. CURRENT AND PAST WASTE MANAGEMENT PRACTICES
- Waste Management and Organizational Structure
- Responsibilities and Accountabilities of Each Organization
- Current Site Waste Management Activities and Procedures
- Waste Information Management Electronic Systems and Databases
- Past Site LLW Management Performance and Incidents

IV. REGULATORY COMPLIANCE
- Federal Compliance Requirements
- DOE Orders Compliance Requirements
- State/Local Requirements

V. CURRENT FIELD/SITE PLANNING ACTIVITIES
- PEIS
- Roadmaps
- Roadmaps - Resource Requirements
- Five-Year Plan
- Activity Data Sheet
- Site-Specific Plan/Waste Management Plan

VI. T/S/D CAPACITIES and CAPABILITIES
- Treatment Capabilities (Current & Expandable)
- Storage Capabilities (Current & Expandable)
- Disposal Capabilities (Current & Expandable)
- Current Site Facilities and SAR's
- Current Planned Facilities and Activities

VII. MAJOR WASTE GENERATION ACTIVITIES
- Decontamination and Decommissioning
- Environmental Restoration

VIII. WASTE MANAGEMENT ISSUES
- Regulatory
- Management
- Technical
- Public

Figure 4. Contents of the Revised Background Report

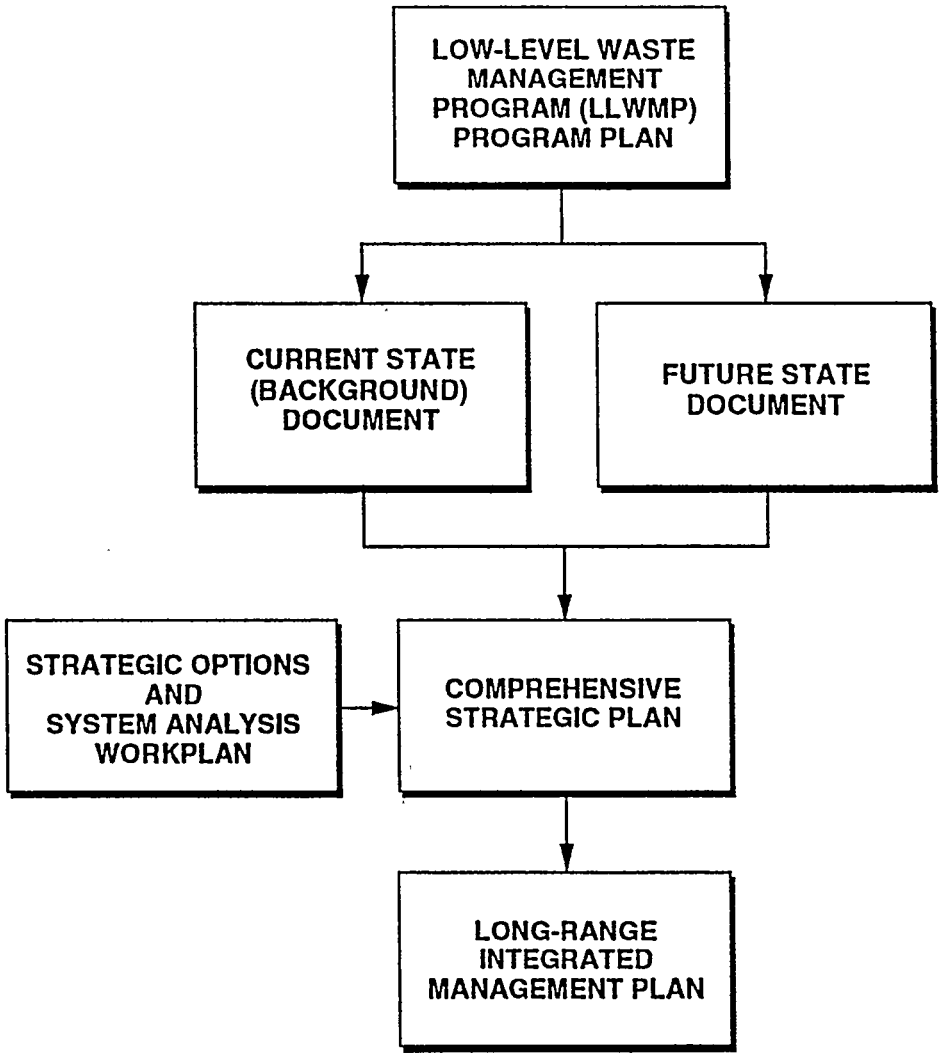


Figure 5. Document Hierarchy for Low-Level Waste Management Program

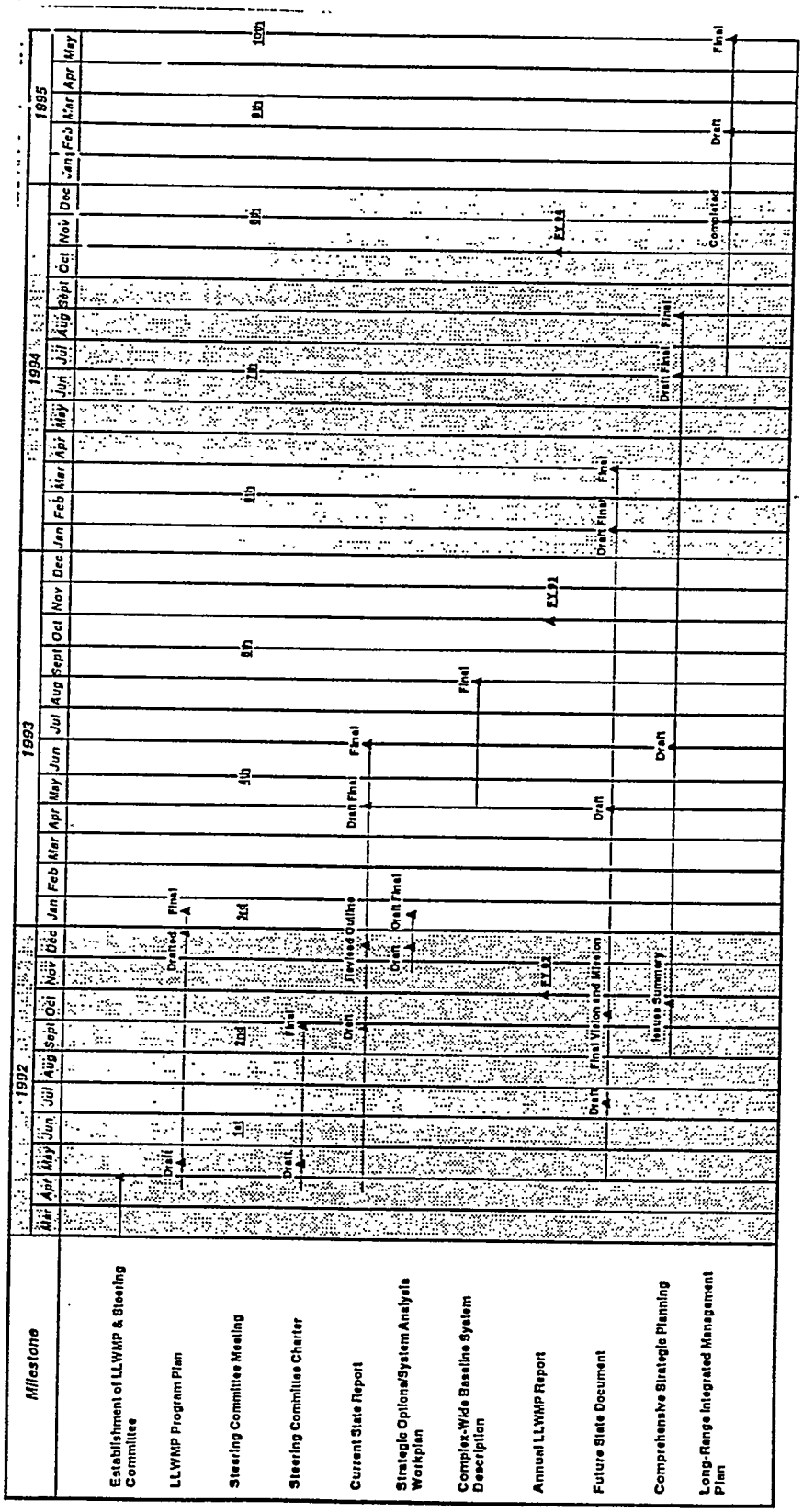


Figure 6. Schedule for Low-Level Waste Management Program

Treatment of DOE and Commercial Mixed Waste by the Private Sector

Thomas W. Garrison, M. Lynn Apel, and Colleen M. Owens
Idaho National Engineering Laboratory[a]
EG&G Idaho, Inc.
Idaho Falls, ID 83415

ABSTRACT

This paper presents a conceptual approach for private sector treatment of mixed low-level radioactive waste generated by the U.S. Department of Energy and commercial industries. This approach focuses on MLLW treatment technologies and capacities available through the private sector in the near term. Wastestream characterization data for 108 MLLW streams at the Idaho National Engineering Laboratory (INEL) were collected and combined with similar data for MLLWs generated through commercial practices. These data were then provided to private treatment facilities and vendors to determine if, and to what extent, they could successfully treat these wastes.

Data obtained from this project have provided an initial assessment of private sector capability and capacity to treat a variety of MLLW streams. This information will help formulate plans for future treatment of these and similar wastestreams at DOE facilities. This paper presents details of the MLLW data-gathering efforts used in this research, private sector assessment methods employed, and results of this assessment. Advantages of private sector treatment, as well as barriers to its present use, are also addressed.

INTRODUCTION

Defense and weapons production practices undertaken by the United States throughout this century have resulted in a stockpile of radioactive, hazardous, and mixed wastes at many Department of Defense and DOE facilities. To a lesser degree, similar wastes have been produced by utilities generating electricity from nuclear fuel, medical research and testing facilities, scientific laboratories, and other components of commercial industry. Treatment and ultimate disposal of these wastes in a manner that is safe, economically feasible, and environmentally acceptable are major issues facing the United States today.

A significant quantity of these wastes are MLLWs. For the purposes of this research, a MLLW is a hazardous waste containing less than 100 nCi/g transuranic radionuclides and having a surface dose rate less than 200 mrem/hr (as defined in Section 1004(5) of the Resource Conservation and Recovery Act). Successful treatment of many of these wastes might be accomplished at facilities owned and operated by the private sector.

MLLW CHARACTERIZATION

To assess the feasibility of private sector treatment of MLLWs, characterization and treatment data for these wastestreams at the INEL were compiled. These data included wastestream quantity (volume and mass); annual generation rate; physical form; storage method; chemical and radiological characterization; identification of reclassified transuranic wastestreams; applicable Environmental Protection Agency waste codes; description of hazardous characteristics as defined in Subpart C of 40 CFR 261[1]; identification of hazardous wastes listed Subpart D of 40 CFR 261; and applicable generator and treatment comments.

To maintain consistency with previously collected wastestream data at the INEL, and also minimize duplication of data collection efforts underway through other federally supported activities,[2,3] much of the

---

a. Work supported by the U.S. Department of Energy, Office of Environmental Restoration and Waste Management, under DOE Contract No. DE-AC07-76ID01570.

information used in this project was obtained from the Waste Management Information System (WMIS) database. The WMIS database is presently maintained by HAZWRAP in Oak Ridge, Tennessee. This database was first developed and reported in the "National Report on Prohibited Waste and Treatment Options for Rocky Flats Federal Facility Compliance Agreement"[4]. The WMIS database also served as a main source of information for the "Land Disposal Restriction Case-By-Case Extension Application for Radioactive Mixed Wastes"[5] submitted by DOE to EPA in October 1991, as well as for DOE's Integrated Data Base[6]. Figure 1 shows an example of the information provided in the WMIS database. Additional sources of information at the INEL were also used to augment data in the WMIS.

After completion of wastestream identification and characterization efforts, treatment scenarios for each wastestream were determined. When appropriate, the Best Demonstrated Available Technology (BDAT) for each wastestream was identified. Treatment trains, incorporating waste minimization technologies, such as recovery of metals, lead, and other materials, and innovative treatments such as vitrification were also proposed for each wastestream.

The MLLW streams were categorized into 15 treatment groups, and are identified in Table 1. Figure 2 shows a distribution of the quantity of waste presently in storage at the INEL for each treatment group. Analysis of these data shows that 90% (by weight) of the INEL MLLW is lead contaminated, and approximately 83% (by weight) is contaminated with mercury. Figure 3 illustrates the relative distribution of INEL waste to the other DOE contributors. The DOE complex currently stores approximately 179,200 m^3 of MLLW. By comparison, it is reported in the "National Profile on Commercially Generated Low-Level Radioactive Mixed Waste"[7] that the commercial sector has generated approximately 4,000 m^3 of MLLW, and had slightly more than 1000 m^3 in storage for 1990. Figure 4 illustrates the distribution of waste types and generators. The bulk of the commercial waste is made up of Liquid Scintillation Fluids (LSF), which have several available commercial treatment options.

PRIVATE SECTOR TREATMENT OF MLLW

After collection and evaluation of the wastestream data, private sector assessment efforts were initiated. These efforts included (a) review of previous activities at the INEL and other DOE facilities to identify private sector treatment participants; (b) publishing, in the Commerce Business Daily (CBD), a request for expression of interest for facilities capable of treating the identified INEL MLLW streams; (c) review and analysis of information from respondents; and (d) follow-up communication with respondents to obtain clarification of data received and additional information about select treatment technologies and their application to the wastestreams identified. Data from these activities were then analyzed to determine if, and to what degree, private sector treatment facilities could assist in successfully eliminating these MLLWs.

Data from this investigation suggested that specific mixed wastestreams need to be analyzed to determine if private sector treatment is applicable. Without specific waste characterization being performed on the mixed wastestreams, it is difficult to say what capacity and compatibility is available.

At the time of investigation, five companies hold both the Nuclear Regulatory Commission's licenses and EPA permits necessary to handle MLLW. These companies are Diversified Scientific Services, Inc. (DSSI), ENVIROCARE of Utah, Inc., NSSI/Source & Services, Inc., RAMP Industries Incorporated and Quadrex Recycle Center. Scientific Ecology Group, Inc. (SEG), has filed an application with the EPA to treat MLLW.

DSSI, of Kingston, Tennessee, is licensed and permitted to store and incinerate flammable liquid mixed wastes. Their permits allow acceptance of D002, F001-F005, plus many D-, U- and P-listed materials. DSSI is licensed to receive about 2000 isotopes, including some special nuclear and source material. Under typical operating conditions, waste is burned onsite in a co-generation mixed waste fueled boiler at a rate of approximately 1.1 million gallons per year. Wastes are usually processed within one month, avoiding long-term storage liabilities. DSSI's overall storage capacity is about 1750 fifty-five gallon drums (95,000 gallons) at any

one time in the bermed, covered, and fire-protected storage area. Bulk fluid storage is available up to 30,000 gallons at any one time.[a]

ENVIROCARE of Utah, Inc., of Salt Lake City, is licensed and permitted to dispose of radioactive mixed wastes. Their Waste Acceptance Criteria (WAC) includes characteristic waste codes D001-D043, listed wastes F001-F012, F019, F024, F028, F039, K011, K013, K050-K052, K061, K069, and many P-listed and U-listed wastes. ENVIROCARE may accept solid-phase hazardous wastes that are radioactive. Such wastes include contaminated soils and debris from government cleanup projects, process solids, sludges, and other wastes.[b]

NSSI/Sources & Services, Inc., of Houston, Texas, is licensed and permitted for treatment and storage of a wide range of radioactive, hazardous, and MLLW. A full list of currently acceptable waste is available from NSSI upon request. Treatment capabilities of NSSI include fuel blending, consolidation of waste containers into lab packs, reconsolidation of lab packs for disposal or processing, chemical treatment, neutralization, oxidation, reduction, recycling of solvents, cleaning of particulate solids, empty drums, and equipment, centrifugation, filtration and ion exchange, solidification, shredding, separation (chemical or mechanical), absorption, solids drying, and recovery of waste chemicals for reuse or resale.[c]

Quadrex Recycle Center, of Gainesville, Florida, is licensed and permitted to treat liquid scintillation fluids and vials for fuel reclamation. They also decontaminate and recycle lead shielding and bricks (not categorized as waste). The NRC license is limited to 5 μC/g.[d] Contact Quadrex for more information.

RAMP Industries Inc., of Denver, Colorado, is licensed and permitted to treat absorbed liquids, compacted trash, contaminated plant hardware, contaminated bulk, dewatered filter media, demineralizers, dry activated waste, gaseous sources, incinerator ash, institutional lab and biological waste, liquids (solidified), liquids (aqueous and organic), liquid scintillation fluids and vials, radioactive devices of gauges, sealed sources, solidified uranium waste and sludges, transuranic material (<100 nCi/gm), non-uranium mineral extraction waste sludges, depleted uranium metals and oxides, source material, and special nuclear materials in quantities not sufficient to form a critical mass. Their treatment capabilities include volume reduction by compaction and shredding, separation, reclamation of liquid scintillation fluids, decontamination, and solidification.[e]

SEG is currently licensed for the processing of low-level radioactive waste. Their treatments include ULTRA compaction, incineration, decontamination, and metal melting. Acceptable wastes include dry activated waste, lead, metals, soils and oils. A current WAC can be requested from SEG. SEG has applied for an EPA Part B permit for the treatment of MLLW (excluding incineration, which will be applied for in the near future under a separate permit).[f]

INCENTIVES AND BARRIERS TO PRIVATIZATION

There are many incentives for the DOE to utilize the private sector for waste management. These include timing, money, opportunity for recycling/reuse, reduced storage inventories, regulatory compliance, and the "spirit" of cooperative research and development agreements (CRADAs). Some facilities operating today

---

a. Brochure and personal correspondence with Larry Hembree dated October 15, 1992.

b. Brochure and personal correspondence with Susan P. Rice dated August 11, 1992.

c. Brochure and personal correspondence with Robert E. Gallagher dated August 13, 1992.

d. Brochure and personal correspondence with Val Loiselle dated August 5, 1992.

e. Brochure and personal correspondence with John E. Lucas dated November 13, 1992.

f. Brochure and personal correspondence with William H. Carder dated July 31, 1992.

can treat some fraction of the MLLW currently stored. These capabilities could be expanded to represent a solution for a larger fraction of the wastestreams that is more timely and cost-effective than siting, building, licensing/permitting, and operating new facilities. Other, more problematic wastes present an opportunity for CRADAs. The end result could be recycling/reuse, volume reduction, alleviated storage problems, and regulatory compliance.

Barriers to privatization include complicated regulatory framework, liability, and environmental, safety, and health risks. The complicated nature of the regulations creates an environment of uncertainty as to what is the correct action. One example is in DOE Order 5820.2A, Radioactive Waste Management," which states that all radioactive DOE waste shall be disposed of in a DOE disposal facility. This does not exclude private sector treatment of the waste; however, it does bring up real questions such as: does DOE require complete decontamination efforts before and after treatment to ensure the return of all DOE waste? These issues must be resolved on a case-by-case basis, taking into account the facility's capability and potential for cross contamination. Liability creates another barrier that must be addressed. Dealing with private sector companies that are properly licensed, permitted, and operated reduce the liability to the DOE. Environment, safety, and health issues are not unique to the private sector. Risk reduction measures taken within the DOE complex should be observed in commercial MLLW treatment operations.

CONCLUSION

Based on the information gathered in this investigation, it is apparent that the private sector currently possesses the capacity to treat a large fraction of the U.S. commercial MLLW, and some fraction of the DOE-generated MLLW. Through cooperative efforts, the private sector could increase its capacity. In addition, since several companies are currently licensed and permitted, DOE has the potential to realize competitive bidding on projects solicited for the treatment of specific wastestreams. As the DOE utilizes the private sector, commercial capacity is likely to increase.

ACKNOWLEDGMENTS

The authors wish to acknowledge the technical assistance of Mr. Jeffery D. Mousseau and direction of Mr. William J. Quapp. This work was supported by the Department of Energy, Office of Environmental Restoration and Waste Management, under DOE Idaho Field Office, Contract DE-AC07-761D01570.

REFERENCES

1. Code of Federal Regulations, 40 CFR 260–299, "Protection of the Environment," Office of the Federal Register National Archives and Records Administration, July 1, 1991.

2. W. A. Ross et al., "Locations, Volumes, and Characteristics of DOE's Mixed Low-Level Wastes," *Waste Management '92 Conference*, Tucson, AZ, March 1-5, 1992.

3. L. H. Harmon et al., "Technology Needs for Treatment of DOE's Low-Level Mixed Wastes," *Waste Management '92 Conference*, Tucson, AZ, March 1-5, 1992.

4. U.S. Department of Energy, *National Report on Prohibited Waste and Treatment Options - As Required by Rocky Flats Plant Federal Facility Compliance Agreement*, September 1989.

5. U.S. Department of Energy, *Land Disposal Restriction Case-By-Case Extension Application for Radioactive Mixed Wastes*, as submitted to the U.S. Environmental Protection Agency, October 1991.

6. U.S. Department of Energy, *Integrated Data Base for 1991: U.S. Spent Fuel and Radioactive Waste Inventory, Projections, and Characteristics*, DOE/RW-0006, Rev 7.

7. Oak Ridge National Laboratory, *National Profile on Commercially Generated Low-Level Radioactive Mixed Waste*, Technical Letter Report for Task Seven, Oak Ridge, Tennessee, FIN L-1647-0, August 14, 1992.

Table 1. Treatment group classification.

Treatment Group No.	Treatment Group Name
1.	MLLW Lead Contaminated Solids (No Mercury), Transuranic Radionuclide Content Less than 10 nCi/g
2.	MLLW Lead Contaminated Solids (No Mercury), Transuranic Radionuclide Content Greater than 10 nCi/g
3.	MLLW Mercury Contaminated Solids (No Lead), Transuranic Radionuclide Content Less than 10 nCi/g
4.	MLLW Mercury Contaminated Solids (No Lead), Transuranic Radionuclide Content Greater than 10 nCi/g
5.	MLLW Mercury and Lead Contaminated Solids, Transuranic Radionuclide Content Less Than 10 nCi/g
6.	MLLW Mercury and Lead Contaminated Solids, Transuranic Radionuclide Content Greater Than 10 nCi/g
7.	MLLW Mercury Contaminated Liquids from HTRE-3, Transuranic Radionuclide Content Less Than 10 nCi/g
8.	MLLW Noncombustible TC Solid Debris, Transuranic Radionuclide Content Greater Than 10 nCi/g
9.	MLLW Noncombustible TC Solid Debris, Transuranic Radionuclide Content Less Than 10 nCi/g
10.	MLLW TC Metal and Other Combustible Solids, Transuranic Radionuclide Content Less Than 10 nCi/g
11.	MLLW TC Metal and Other Noncombustible Liquids, Transuranic Radionuclide Content Less Than 10 nCi/g
12.	MLLW TC Metal and Other Combustible Liquids, Transuranic Radionuclide Content Less Than 10 nCi/g
13.	MLLW Ignitable Reactive Liquids, Transuranic Radionuclide Content Less Than 10 nCi/g
14.	MLLW Water Reactives, Transuranic Radionuclide Content Less Than 10 nCi/g
15.	MLLW PCB Contaminated Oil, Transuranic Radionuclide Content Less Than 10 nCi/g

WASTE MANAGEMENT INFORMATION SYSTEM
WASTE PROFILE REPORT

DOE FIELD OFFICE, IDAHO
IDAHO NATIONAL ENGINEERING LABORATORY

Waste Name: ALUMINUM SLUDGE MIXED W/VERMICULITE

Description: This sludge is generated during the routine cleanout and maintenance of a wet air scrubber. This sludge was mixed with vermiculite to absorb the liquids out of the sludge.

LDR Category : 3RD THIRDS
Waste Still Generated: NO

Generation Rate Assumptions:

Treatment Required Before Disposal: YES
Waste Regulated By : FEDERAL/STATE

Characterization

RCRA Characterization
RCRA Category : IGNITABLE REACTIVE
Ignitable Type : REACTIVE
Reactive Type : WATER REACTIVE

EPA Code(s): D001 D003
Confidence Level: LOW

RCRA Comments: Comprehensive analytical analysis of this waste stream has not been accomplished at this time. Case-by-case data: key chemicals - aluminum chips.

Radioactive Characterization
Radioactive Category : LLW
Radiation Level Indicator : CONTACT-HANDLED

Chemical Characterization
PCBs? : NO

Physical Characterization
Physical Form : SOLID
Type : ABSORBENT MATERIALS

Combustible Category: MIXED

Waste Stream Management

Destination: STORAGE Initial destination: YES
Unit Name: SOLID STORAGE AREA Bldg. No: TAN 628
Quantity : 4.4000 m3 5358.1000 kg

Destination: TREATMENT Initial destination: NO
Unit Name: CHEMICAL/THERMAL OXIDATION Bldg. No: TAN 629
Unit Status: EXISTING Installation: IDAHO NATIONAL ENGINEERING LABORATORY
Unit Approved for this waste: YES

Comments: There are no general comments
Delisting Candidate: NO

Figure 1. Waste stream information provided by WMIS.

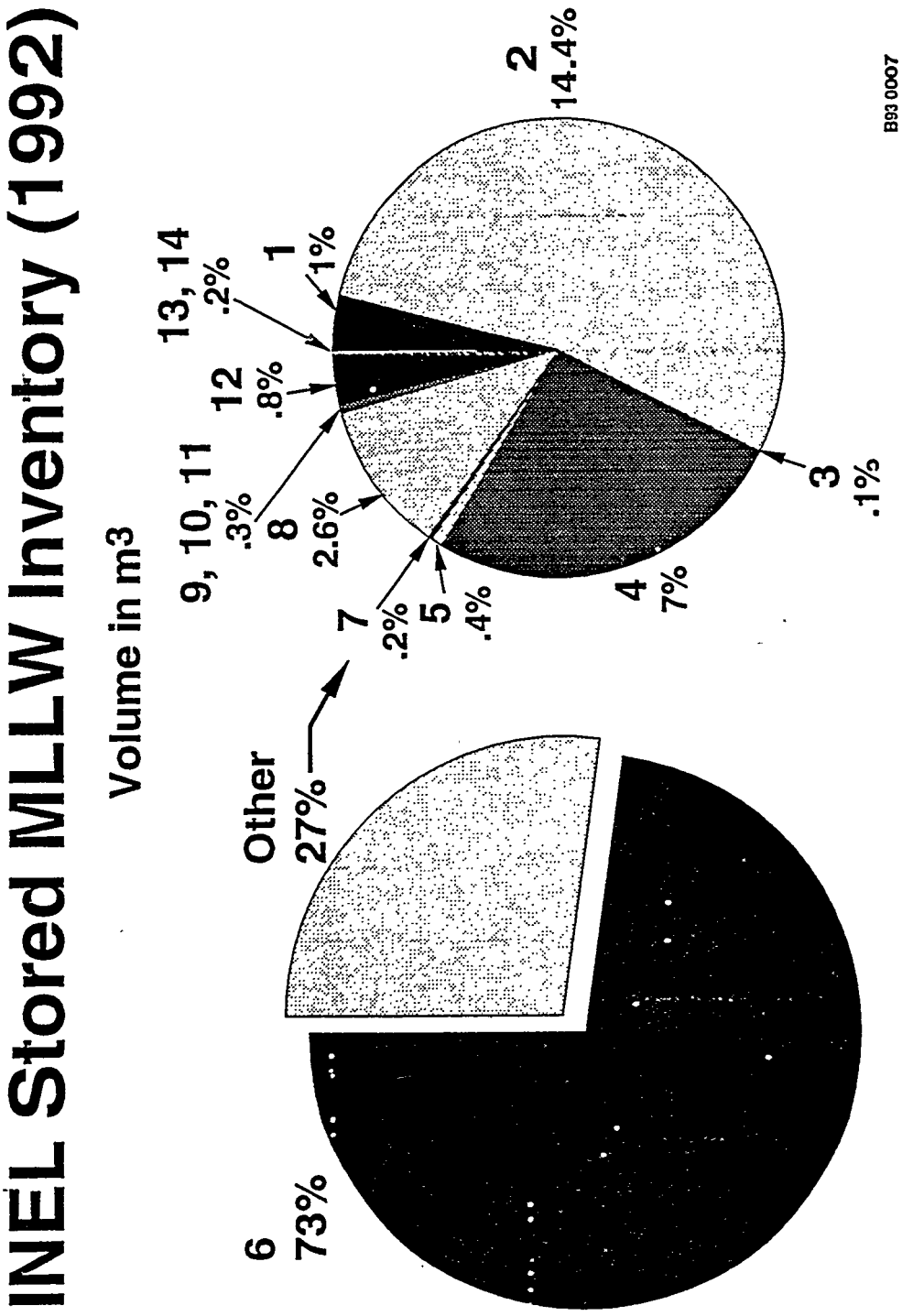


Figure 2. INEL Distribution of waste (see Table 1 for number identities).

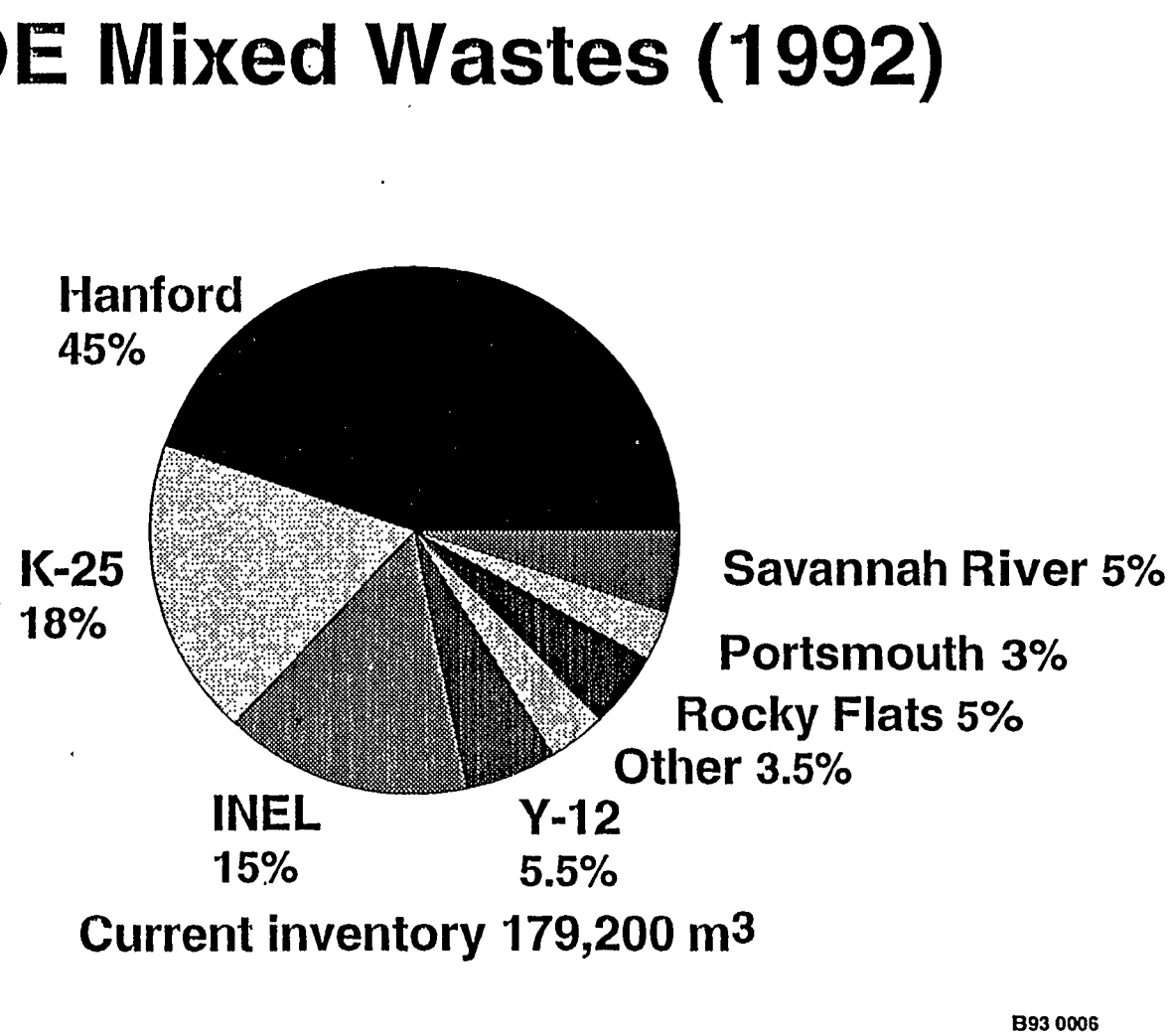


Figure 3. DOE stored mixed low-level waste distribution.

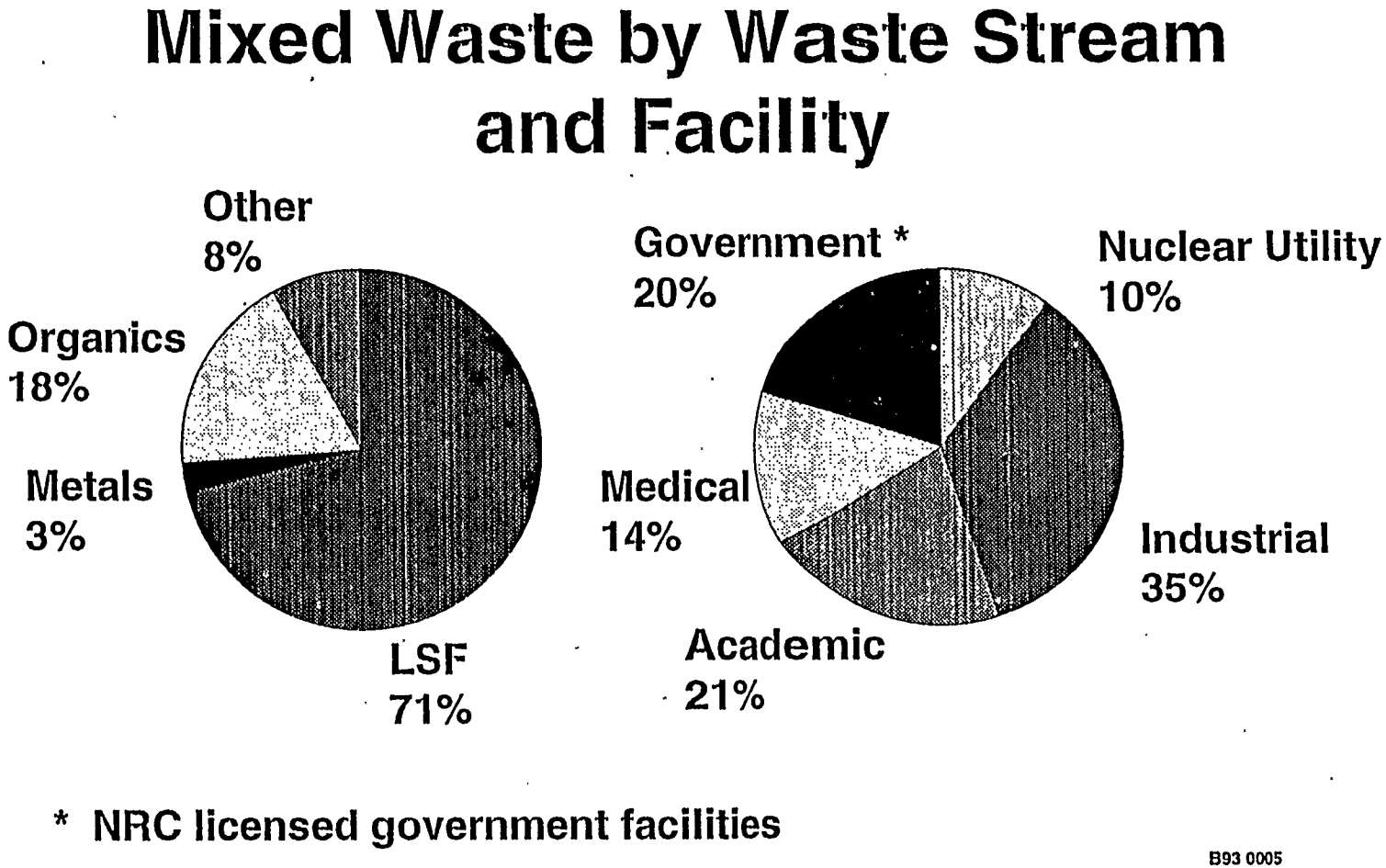


Figure 4. Commercial mixed low-level waste distribution.

Interim Onsite Storage of Low-Level Waste at Nuclear Power Plants

Carol Hornibrook, Manager
Electric Power Research Institute

Michael D. Naughton
TARAwest Technologies
San Jose, CA

BACKGROUND

For many nuclear utilities, January 1, 1993, looms as a date of considerable significance. From then on, state compacts with operating low-level waste disposal sites can exclude access to waste generated outside their regions. The commercial burial site at Beatty, Nevada, has stated its intention to close as of January 1, 1993. The Hanford site plans to limit the waste acceptance to that generated within the Northwest Compact. South Carolina has agreed to continue operations at Barnwell until June 30, 1994. On June 19, 1992, the Supreme Court overruled a key provision on the Low-Level Radioactive Waste Policy Amendments Act of 1985. The Court struck down the "take title" provision that mandates that states that have not developed low-level waste disposal facilities by January 1, 1996, accept title and possession of liability for privately generated waste. The entire situation is further compounded by the lack of progress in developing new disposal facilities. As a result, a majority of nuclear plants could be left with no available radioactive disposal options in 1993.

Whether utilities will actually be excluded from the disposal of radioactive waste is a matter of conjecture. However in this situation, utilities are taking the prudent approach of seriously considering interim onsite storage for their LLW. Regulatory and technical issues make this seemingly simple task decidedly more complex. Moreover, the uncertainties surrounding the duration of storage, the projected storage volume, and the final disposal requirements of the future sites further complicates the planning process.

Each utility must evaluate these issues for its unique situation. No single solution adequately addresses the range of variables facing the nuclear power industry. As a result, considerable variation can be seen in the approaches being selected by utilities planning interim onsite storage facilities.

EPRI'S INTERIM ONSITE STORAGE OF LOW LEVEL WASTE PROJECT

The Electric Power Research Institute (EPRI) responded to the disposal uncertainties by initiating research project RP 3800, "Interim On-Site Storage of Low Level Waste." The purpose of this project was to develop a comprehensive set of technical and regulatory considerations that must be addressed by a utility in planning for the addition of interim onsite storage capability. The information presented under this project is presented in a format that is clear and useful in guiding individual utilities to key considerations and decisions involved in interim storage facilities. Since the approach is not prescriptive in nature, each utility is allowed to use the information as appropriate to their unique situation and needs.

Project Objective

- Develop the information necessary to effectively plan for interim onsite storage of low-level waste
- Develop a methodology that takes a utility, step-by-step, through the process of defining and selecting facility design options that meet its site specific needs.

The project is organized to focus on five distinct aspects associated with extended onsite storage. Each subject will be published as separate report. They are:

- Licensing and Regulatory Issues
- Facility Design Options
- Waste Volume Projections and Data Management
- Waste Containers for Extended Storage
- Waste Forms for Extended Storage.

REGULATORY CONSIDERATIONS

In considering onsite storage, each utility must provide reasonable assurance that public health and safety are adequately protected. In addressing these requirements, utilities need to consider whether the proposed storage will:

- Result in changes to the plant's license or technical specifications
- Create any unreviewed safety question
- Exceed the NRC's guideline related to duration.

Normally, a safety analysis of these issues is performed under 10 CFR 50.59 ("Changes, Tests, and Experiments") This analysis involves assessing the environmental dose associated with normal and accident conditions. NRC storage guidelines require utilities to limit their storage facility's design volumes to a historically justified value. This requires careful consideration of the plant's waste generation rate and near-term plans for major waste generating projects. Additionally, plant licenses often limit the curies allowed to be possessed for such items as LLW. Again, the utility must review its operating license to determine if the additional LLW activity will require a license amendment.

EXISTING ONSITE STORAGE FACILITIES

As part of this project, EPRI surveyed nuclear utilities concerning existing LLW storage facilities and their plans for such facilities. A majority of nuclear stations responded. The resulting data needs to be carefully analyzed. For example, for those responding to the survey, approximately 80% reported having existing onsite storage facilities. However, it is unlikely that this percentage holds for all nuclear plants, since many utilities without such storage facilities did not respond to the survey

Table 1 summarizes existing facilities and their cost as reported. In reviewing the data considerable variation is seen in these cost figures. This is principally tied to specific plant requirements (e.g., inclusion of processing equipment or additional shielding required by the location). The preferred storage facility design involved reinforced concrete structures (60%). This was followed by steel frame structures (40%) and storage pads (10%).

TODAY'S FACILITY DESIGN OPTIONS

Many of the existing facilities were constructed in the mid 1980s. At that time the design of choice was reinforced-concrete buildings. In most cases these facilities were quite large, included many features, and represented a considerable capital investment. The buildings typically consisted of a reinforced-concrete structure with shielded walls and roof. A shielded truck bay and remotely operated bridge crane was integrated into the design. Often other enhancements were included, such as a ventilation system, drains and sumps, decontamination facilities, and container inspection and contamination testing facilities.

Table 1. Typical onsite storage cost.[a]

Facility type	Cost range ($/ft^3)
Reinforced-concrete building	30–400
Steel-frame building	
Unshielded facility	20–50
Storage module shielding	150
Internal precast shielding panels	10
Total cost $/ft^3	**20–210**
Outdoor Pad with Storage Modules	
Gravel pad	5
Storage modules	150
Total cost $/ft^3	**155**

a. Based on 1991 dollars.

Today, the favored approach is either an **outside storage pad with modules, steel frame and metal siding building** or a combination of the two. Each of these three options can represent an optimum solution for a utility in meeting their unique LLW storage requirements. The following section is a summary of the key features seen in today's modern storage facility designs.

Reinforced-Concrete Building

Until recently, reinforced-concrete buildings were the dominant choice for a LLW facility. Today's reinforced concrete building designs minimize building enhancements and focus on effective storage of LLW. In a number of areas the designs draw heavily on the experience gained from the earlier facilities. For example, the design criteria often include a 15- to 20-foot-wide truck bay, preferably drive through, long enough (70 feet) to allow the doors to be closed during loading and unloading operations. Additionally, the floor designs now give added emphasis to the weight of future temporary or permanent shielding. During extended storage, the container inspection program must be given added attention. Provisions for such inspections must be provided in the container arrangement.

Container handling: Experience has shown the need for careful consideration of the bridge crane design. Sufficient clearance needs to be provided for loading of the largest containers into the tallest cask. Normally the 14-foot clearance used for highway bridges is used as a minimum required lift value. Additionally, the crane capacity is normally based on lifting a loaded shipping cask of approximately 35 tons with a floor to hook clearance of approximately 35 feet. Finally, the location of the crane rails and hook travel limits are used in establishing the container arrangement.

Design approach: The general approach to today's reinforced-concrete building design is to arrange the containers to limit the bridge crane span to less than 60 feet. Containers are then arranged in areas of low and high activity. A bridge crane for the higher activity waste is then factored into the arrangement. The lower activity waste is then arranged next to the high activity area. A forklift is used to move these lower activity containers. Outside wall thickness is reduced by incorporating into the facility a heavily shielded cell

for high activity waste material, such as reactor cleanup resins. As would be expected, the shielding requirements for the remainder of the building are greatly reduced.

In summary, the following are the key advantages and disadvantages with influence the selection of this design:

Advantages

- Onsite and offsite radiation dose can be effectively controlled in the design
- Wide range of post-storage period reuses are available
- Waste can be handled using remote-controlled equipment
- Container handling and surveillance is easier in this controlled environment.

Key Disadvantages

- High initial capital investment
- Total capital investment required prior to commencing storage
- Expansion of the facility is a major project.

Steel-Frame and Metal Siding Building

The basic steel-frame and metal siding building for onsite LLW storage is a weathertight, possibly insulated, preengineered structure on a concrete slab. In many ways the design parallels that used for reinforced concrete facilities. For example, the truck bay is of similar dimensions. The building height is established to provide adequate clearance for the required lifting operations. Where a mobile crane is used, aisle width is set by the needed clearance required for its maneuvering and lifting operations.

Shielding: Alone, the building can be used to store dry active waste (DAW) with little or no shielding. With the addition of shielding, the building can provide a cost-effective option for storing all LLW materials. Shielding can be provided by means of poured walls, precast concrete panels, or in some cases, onsite storage modules. It should be pointed out that the EPRI study showed a clear economic advantage to the use of poured or precast panels over the general use of the more expensive storage modules in such structures. Where the intent is to store lower activity waste, tilt-up slabs or grouted block walls can provide the needed shielding. In some cases, the shield walls themselves can be used as part of the building's exterior walls.

Container handling: In these structures the handling of the heavier liners and high integrity containers (HICs) is accomplished by means of gantry cranes. If a bridge crane is selected its support can be integrated into the steel-frame metal siding design. Like the reinforced-concrete structure, the lower activity DAW is moved by means of a forklift.

Design approach: The general approach to design of a steel-frame and metal siding building is to begin by establishing the building footprint. Much like the reinforced-concrete building, the waste containers are arranged in rows. The shielded containers are placed in the central portion of the building and the unshielded containers next to the exterior walls. Next, access passages required for container movement and inspection are incorporated into the design.

The building size is normally fixed by standard size increments used in preengineered structures, clear-span, or with columns where a wide building design is desired. As mentioned earlier the building height is determined by the stacking height and the clearance requirements of the crane.

In summary, the following are the key advantages and disadvantages with influence the selection of this design:

Advantages

- Initial capital costs considerably below reinforced-concrete
- Post-storage reuse options are easily accommodated
- Expansion of the facility is less difficult and expensive
- Changes in container size are more easily accommodated
- Operating cost can be much lower than storage pad and module design.

Disadvantages

- Total capital investment is made prior to commencing storage
- Storage and handling of high-activity containers are more difficult.

Outside Storage Modules and Pad

The outside storage module and pad option consists of an engineered pad that is enclosed by a fence and designated as a radioactive waste storage area. The modules are normally purchased on an as-needed basis. Typically the modules are arranged in one or more rows with road access on all sides. The modules are stacked back-to-back in sections with 3- to 4-foot-wide passages for inspection. Normally, a separation of approximately 2 inches between the storage modules is needed to allow for differential settling and periodic inspections. An access of 20 to 25 feet width around the pad is normally provided for the mobile crane and shipping vehicles.

Storage pad: Design of the storage pad must support expected loads without shifting or settling of the storage modules. The pad material can be either of concrete or gravel. To minimize settling under the weight of loaded storage modules, 4 to 6 tons/ft^2 is used as reasonable design specification. Ground water leakage or poor subsurface conditions are the primary reasons for selecting concrete for the pad material. Additionally, the pad design needs to minimize water collection and prevent its accumulation under the storage modules.

Storage modules: Current module designs and features vary over a wide range. These include such items as shape, wall thickness, internal cavity dimensions, sealing arrangements, and inspection and sampling provisions. They are designed to provide adequate shielding for all the plant's waste containers. Due to the weight associated with the modules, they are generally shipped in sections and assembled at the plant site. Normally, they are designed for two-tier stacking. It is important to remember that the storage modules are highly engineered structures and are not simple concrete containers.

An important aspect of the use of storage modules relates to cost accounting. Storage modules are considered an operating expense and not a capital item. This means the modules' costs are not included in the plant's capital budget and are expensed as an operating cost, a fact of considerable significance to some utilities.

Shielding: The storage module and pad system uses exterior modular walls and upper shield panels to reduce the radiation fields beyond the storage area. Several design approaches have been developed for exterior walls, varying from interlocking concrete members to poured concrete walls backed by earth for additional shielding. The dimensions of these shields vary to meet the requirements of a specific site, and are generally restricted by shipping regulations and the capacity of the handling equipment at the point of use.

The location of the storage pad is a key parameter in establishing an efficient and cost-effective system. Where possible, the pads are located within the protected area but away from the plant boundary. The topography of the area can provide additional natural shielding. These factors play a significant role in minimizing the site boundary dose during loading and unloading operations where the liner or HIC is directly exposed to the environment.

Container handling: Usually containers are moved by a mobile crane from the perimeter of the pad. However, several current designs call for a gantry crane over the entire pad for better coverage and ease of container movement.

Design approach: Designing an outside storage pad begins by establishing the dimensions of the storage modules required for LLW containers. The modules are then arranged in rows with the lower activity waste near the exterior walls and the higher activity waste near the center of the pad. Passages are then provided for module inspections. The pad dimension is then extended to provide support of the exterior shield walls. Generally it is more cost-effective to use rectangular storage modules of thinner walls and provide additional shield walls as required to limit the offsite radiation field. It should be pointed out that the design capacity and reach of mobile cranes can affect the final pad configuration.

In summary, the following are the key advantages and disadvantages that influence the selection of this design:

Advantages

- Initial capital costs are the lowest of any storage option
- Module cost can be treated as an operating expense item
- Expansion of the storage pad is relatively easy
- Storage modules can be purchased as needed
- Changes in container dimensions are easily accommodated.

Disadvantages

- Cost for this option become high if volumes increase
- Offsite radiation dose needs to be carefully considered
- Waste container handling and inspection is more difficult
- Storage modules have little reuse value.

ECONOMIC ANALYSIS OF ALTERNATIVE ONSITE STORAGE FACILITIES

Most utilities have a standard engineering economic analysis methodology for assessing facility options. To aid utilities in their storage evaluations, EPRI developed the cost for a "typical" storage facility for each of the three principal storage options, i.e., reinforced-concrete building, steel frame and metal siding building, and the storage module and pad arrangement. First, the parameters associated with the waste to be stored were defined in Table 2.

The LLW was based on the expected waste generation over a five-year period from a moderate waste-generating dual pressurized water reactor or a low waste-generating boiling water reactor. The selected waste streams and associated characteristics were chosen to represent the range of waste materials expected to be stored in a LLW facility.

Table 2. Design-basis radwaste volumes—five year storage period.

Waste stream	Container (ft^3)	Radiation (R/hr)	Volume (ft^3)
NSSS resin	120	2,500	1,200
Radwaste resin	190	5	9,500
Other resin	215	0.005	5,375
High Active DAW	96	0.05	4,800
Low Active DAW	96	0.001	19,200
Total Volume			**40,075**

Next, a conceptual design was prepared for each of the storage options. Although conceptual in nature, considerable detail was included to derive for meaningful cost estimates.

Finally, a detailed cost estimate was prepared for each conceptual design. Capital costs were developed for the materials and labor identified in the estimating "take-off." The labor cost was based on midwest labor rates with construction occurring outside the protected area. It must be stressed that the designs and costs are generic in nature. Actual designs and costs can differ significantly from the EPRI work depending on the unique requirements of a specific site or utility.

Reinforced-Concrete Design

An estimate was developed for **The Base Facility.** Additionally, incremental costs were developed for: (a) the addition of a high-activity waste storage vault, (b) inclusion of a decontamination and inspection facility and (c) an option for future expansion of the facility by 25 feet.

The facility features of note are:

Design capacity	40,000 ft^3
Total footprint	11,606 ft^2
Crane-handled storage area	56 ft × 78 ft × 45 ft
Forklift-handled storage area	50 ft × 78 ft × 29 ft
Base slab	3 ft thick
Exterior walls	3 ft thick below crane rails, 18 inches above 18 inches thick around the forklift storage area
Roof over shielded storage area	24 inches
Truck bay	70 ft. X 20 ft. with overhead doors at each end
Estimated total base facility cost	$3,400,000
High activity storage vault option cost	$ 55,000
Decontamination/inspection option cost	$ 36,000
25 foot expansion option	$ 430,000

Steel-Frame and Metal Siding Design

Cost estimates were developed for IWO design variations of the steel-frame and metal siding facility. The base design provides the required shielding by means of prefabricated panels. The second design accomplishes the shielding by mean of storage modules. These cases provided some insight into the cost

differential between modules and prefabricated panels. Again costs were developed for the gantry crane handling and future expansion of the building.
The facility features of note are:

Design capacity	40,000 ft^3
Total footprint area	12.000 ft^2
Total outside dimensions	80 ft × 150 ft with 45 ft peaked roof*
Unshielded waste storage area	25 ft × 125 ft on each side of the building
Shielded waste storage area	30 ft × 125 ft
Base slab	18 inches thick
Shielding panels	120 panels, 5 ft × 15 ft × 24 inches
Liners stacked two high	
Gantry crane	35 tons
Estimated base facility cost	$2,680,000
25 foot future expansion option	$210,000
Replacement of panels with storage modules	$1,400,000

* Note, with the storage modules the building length was increased by 50 feet

Outside Storage Modules and Pad Design

Cost estimates were developed for the outside storage module and pad design. The present value cost of the modules is based on yearly purchase of these components. Once again, cost estimates were prepared for the addition of a gantry crane and expansion of the storage pad. The key features of the design are:

Design Capacity	40,000 ft^3
Pad dimensions	120 ft × 220 ft
Slab-concrete	12 inches thick
Waste storage area	70 ft × 150 ft
Shielding panels	130 inverted tee, 5 ft × 22 ft × 24 inches thick 60 Sky shine panels, 25 ft × 5 ft × 12 inches thick
Modules	10 cylindrical, 24 inch wall (Note: 5 year supply of modules) 25 rectangular, 6 inch wall
Gantry crane	50 tons
Estimated base facility cost	$3,080,000
Future expansion by 25 foot option	$270,000

CORRELATIONS IN FACILITY COSTS

Working from these estimates, a cost/waste volume correlation was developed for each facility type, projecting the total cost from the waste-storage volume. The analysis is quite sensitive to the mixture of waste containers and activity of the waste material. It does, however, provide insight into the relative costs of the three generic facility designs, and projects total facility direct costs over a range of waste-storage volumes (Figure 4). Note than the outside pad/module design is cost effective for smaller waste volumes, but the cost approaches that of a reinforced concrete building for higher volumes. Clearly, in choosing the preferred approach, each utility must carefully evaluate the estimated storage time involved and the resulting waste storage volume.

REFERENCES

1. Electric Power Research Institute, EPRI TR-100298 *Interim On-Site Storage of Low-Level Waste, Volume 1: Licensing and Regulatory Issues.*

2. Electric Power Research Institute, EPRI TR-100298 *Interim On-Site Storage of Low-Level Waste, Volume 2, Part 1: Facility Design Options.*

3. Electric Power Research Institute, EPRI TR-100298 *Interim On-Site Storage of Low-Level Waste, Volume 2, Part 2: Survey of Existing On-Site LLW Storage Facilities.*

4. Electric Power Research Institute, EPRI TR-100298 *Interim On-Site Storage of Low-Level Waste, Volume 4, Part 1: Waste containers for Extended Storage.*

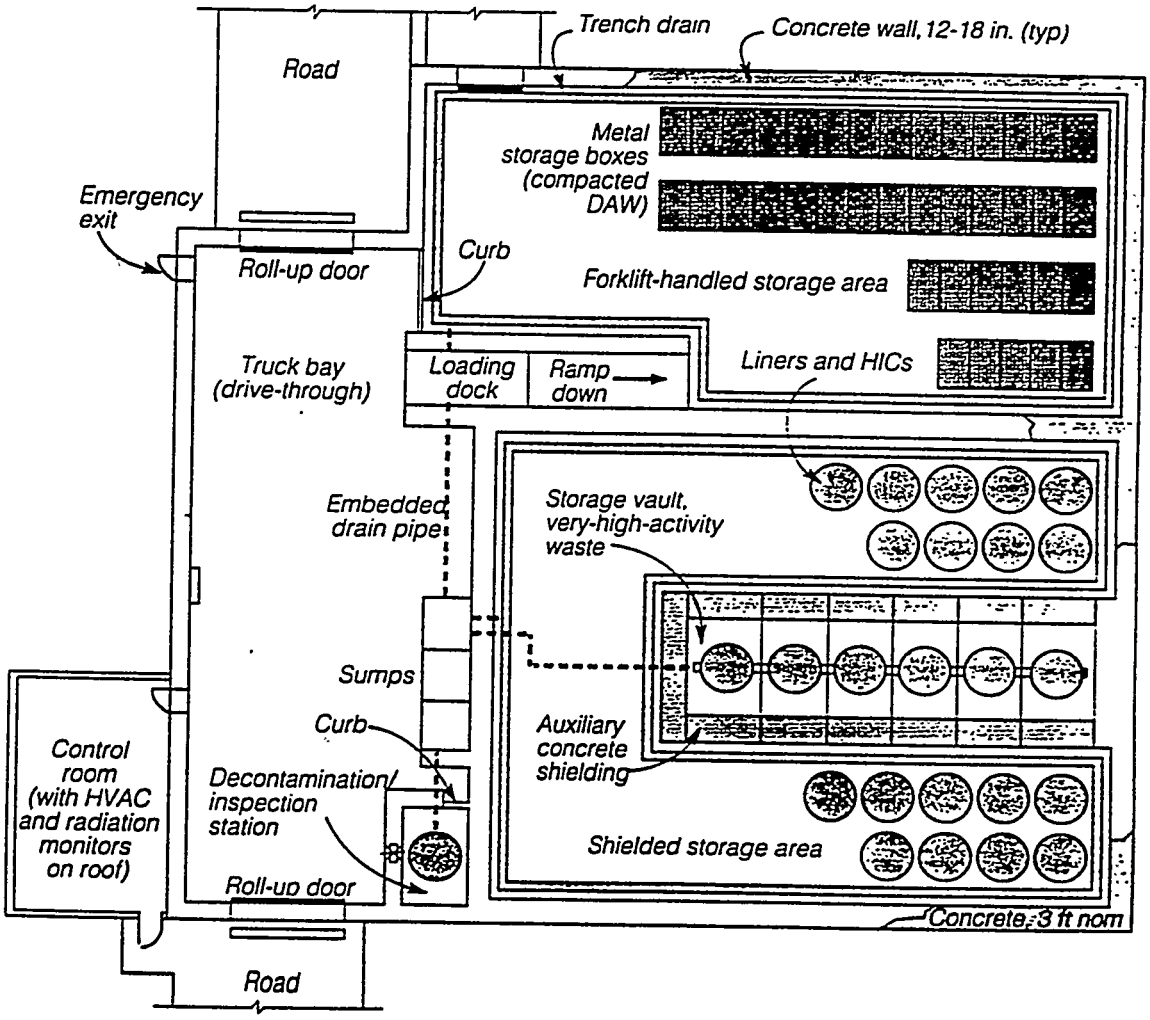


Figure 1. Reinforced concrete LLW storage.

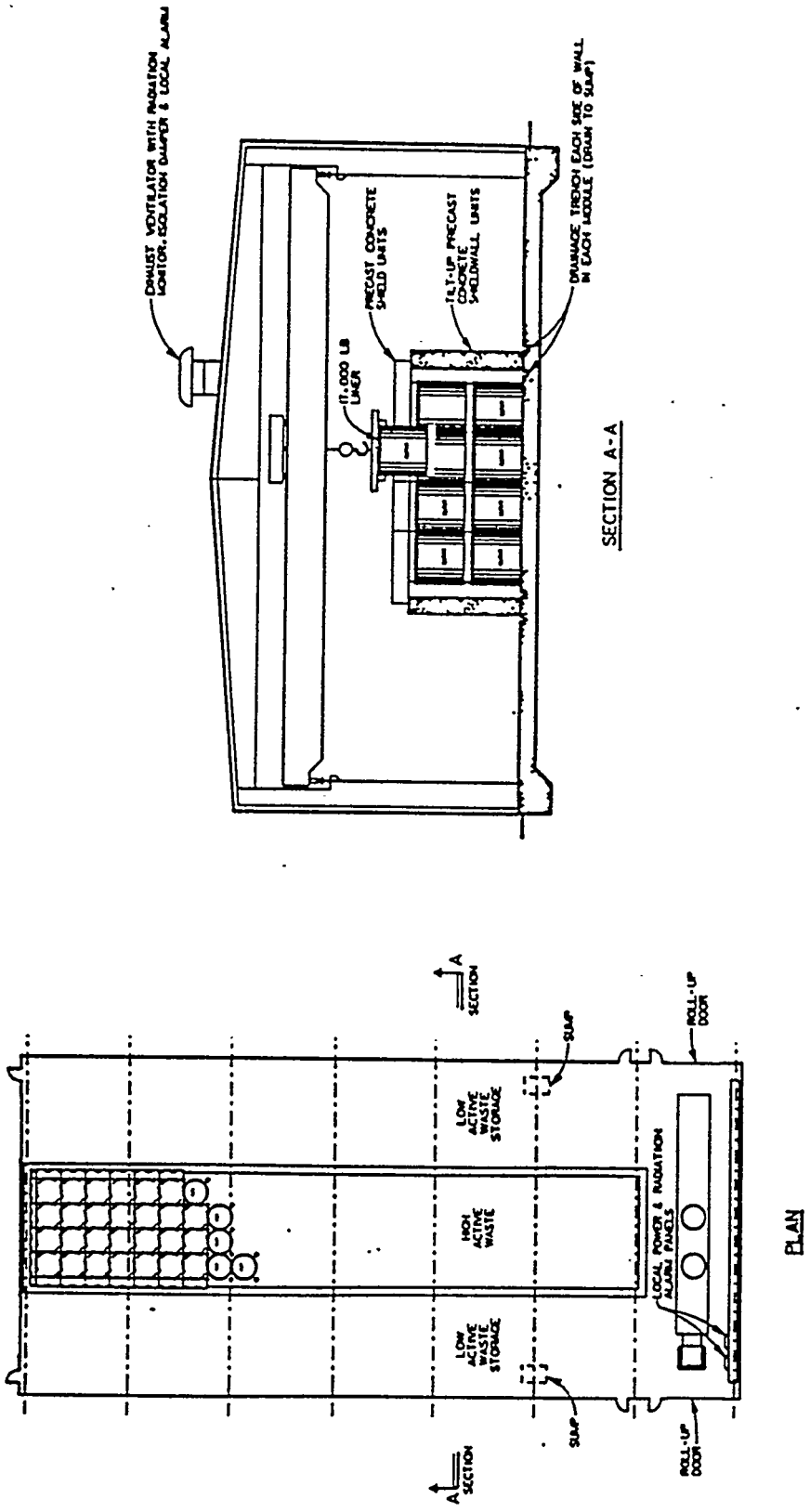


Figure 2. Steel frame shielded LLW storage.

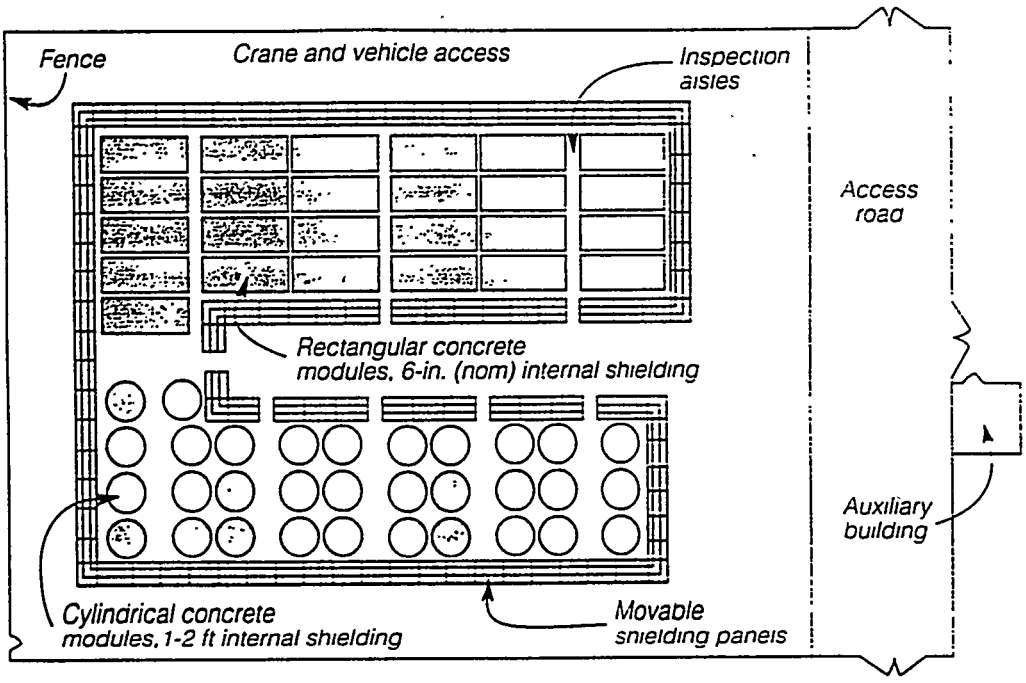


Figure 3. Pad and storage module LLW facility.

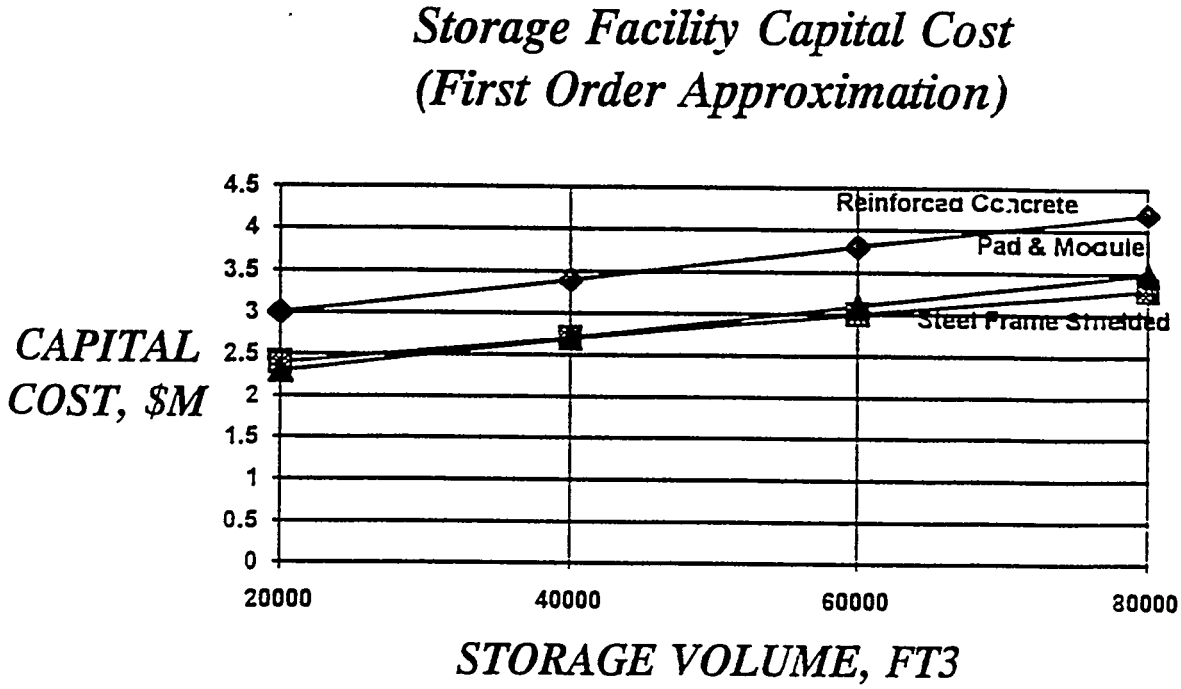


Figure 4. Design cost estimates.

An Update of a National Database of Low-Level Radioactive Waste in Canada

Pabitra L. De
Robert C. Barker
Low-Level Radioactive Waste Management Office
Atomic Energy Canada Ltd. Research
Ottawa, Ontario K1A 0S4

ABSTRACT

This paper gives an overview and update of a national database of low-level radioactive waste in Canada. To provide a relevant perspective, Canadian data are compared with U.S. data on annual waste arisings and with disposal initiatives of the U.S. compacts and states. Presented also is an assessment of the data and its implications for disposal solutions in Canada.

INTRODUCTION

Low-level radioactive waste has been produced in Canada since the refining of radium started in the 1930s at Port Hope, Ontario. Uranium processing was initiated at Port Hope in the 1940s at about the same time research and development on the applications of nuclear energy for electricity production and radioisotopes began at the Chalk River Laboratories of Atomic Energy of Canada Limited (AECL). AECL is Canada's national nuclear organization, established to develop peaceful applications of nuclear energy. To carry out this mandate, AECL not only conducts research and development for nuclear-related products and services, but also designs and markets CANDU (CANada Deuterium Uranium) nuclear power plants. In addition to AECL activities, there are 20 CANDU nuclear power plants in operation with supporting fuel cycle facilities, 10 research reactors, and about 4000 radioisotope licenses, all contributing to the generation of low-level radioactive waste. In order to offer a broad perspective of Canadian nuclear activities and the attendant waste generation, it should be mentioned that, at present, 14,000 MWe is generated from CANDU power plants as compared to 100,000 MWe in the U.S.

The volume and characteristics of the wastes affect the methods and facilities used in their management, including handling, transportation, storage and disposal. In the evolving regulatory, technical and socioeconomic environment, it is necessary to keep abreast of the inventory and characteristics of these wastes to plan and assess current and future needs. With this in view, a computerized database system was initiated by the Low-Level Radioactive Waste Management Office (LLRWMO) to provide information on low-level waste generation, accumulation, and related management issues in Canada.

The LLRWMO was established in 1982 by the government of Canada to carry out its relevant responsibilities for the long-term management of low-level radioactive waste. It must be mentioned, however, that the primary responsibility for the management and disposal of wastes, including financial responsibility, will continue to rest with the producers of the wastes. Authority to establish, and consequently, funding for, the LLRWMO is held by Energy, Mines and Resources Canada (EMR)—the department responsible for national policy for low-level radioactive waste management. The LLRWMO was established as a distinct unit within Atomic Energy of Canada Limited to take advantage of the technical expertise and support available there while remaining independent of AECL's other roles.

The primary purpose of the national database is thus to provide a basis for the federal government in the formulation of policy and for the LLRWMO in its program decisions. The database information is also expected to aid in the development of sites and the selection of appropriate disposal technology in Canada.

MAJOR WASTE CATEGORIES

Low-level radioactive waste is defined as all forms of radioactive waste except irradiated or spent nuclear fuel (referred to as high-level waste) and waste from uranium mining, milling, and mill tailings.

Low-level waste has been compiled and entered into the database in three major waste source categories: Generators, Historical Activities, and Decommissioning. The rationale for grouping waste sources into these three categories is as follows:

a) **Generators:** These are waste producers who are currently active in business and who are thus responsible for the management of the wastes they generate, including those already in storage, (i.e., **current sources**).

b) **Historical Activities:** This category represents sources of wastes that are not being managed in a manner considered acceptable, but where the original generators no longer exist or otherwise the generators cannot reasonably be held responsible for the management of the waste they generated (i.e., **past sources**).

c) **Decommissioning:** This category represents, by and large, wastes to be generated in the future, although a small inventory of such wastes already exists. It includes waste from decommissioning of all facilities involved in nuclear fuel-cycle and radioisotope applications (i.e., **future sources**).

CURRENT WASTE INVENTORY AND GENERATION RATE

Waste currently in storage[1] amounts to 1.3×10^6 m^3, which is about the same quantity disposed of in the U.S. from commercial generators[2]. As illustrated in Figure 1, about 62% of the inventory is due to historical activities related to processing of uranium and radium ores and the use of radium before the 1960's—resulting in process residues, wastes, and contaminated lands and buildings.

The contribution from decommissioning to the waste inventory is relatively small, although several decommissioning projects have been undertaken, albeit some to a limited degree. Complete dismantling of large facilities is yet to come.

Current generators account for the remaining waste inventory—over 90% of which is from nuclear R&D carried out at the Chalk River Laboratories (CRL) of Atomic Energy of Canada Limited. At CRL, about 0.3×10^6 m^3 of waste is due to contamination of soil by wastes produced during the early years of research activities. It should also be noted that CRL has historically received and continues to receive waste on a fee-for-service basis from numerous isotope users across the country.

Figure 2 shows a breakdown of the relative contribution of major sources to current waste generation rate. It is apparent that the nuclear fuel cycle and isotope users account for about 90% of the total.

Decommissioning work, while becoming more and more predominant, still contributes less than 10% of the total annual volume. At present, this originates primarily from research facilities decommissioning and environmental remediation. Dismantling of commercial facilities, which will add an average of about 5000 m^3/year, is expected to begin around 2010.

Figure 3 provides a comparison of waste generation rates in Canada with the U.S. compacts and states. In Canada, waste is currently generated at a rate of 9,100 m^3 per year. This is about 1/4th the volume from commercial generators in the U.S.[3] and is slightly more than what the U.S. Southeast Compact generated in 1991 (8,100 m^3).

The two major generators of LLW in Canada are AECL and Ontario Hydro. AECL is the national nuclear R&D organization. Ontario Hydro is one of the largest utilities in the world and currently operates

18 CANDU nuclear power plants. Their generation rates are 1500 and 4600 m^3 per year respectively. On a comparative basis, these rates are similar to Texas and to the Northwest Compact respectively.

There are no other individual generators in Canada who produced more than 500 m^3 per year.

WASTE DISPOSAL CONSIDERATIONS

Presently, all low-level radioactive waste in Canada is in storage. The federal government has assumed responsibility for disposal of wastes from historical activities. An independent federal Siting Task Force has been appointed by the Minister of EMR to find a site, using a voluntary siting approach with extensive public consultation within communities which have indicated potential interest. Progress to date has been encouraging and a successful conclusion to this process will result in a permanent facility for management of historic wastes now located mainly in the Port Hope area of Ontario. It should be noted that the characteristics of these wastes, which originated from the early years of the radium and uranium industry, are substantially different from the characteristics of most of the LLW being produced today.

The historic wastes contain low concentrations of natural uranium series radionuclides. Various heavy metals present in the original ores are also present in the wastes, with arsenic being the major concern based on its abundance, transport behaviour in the environment and chemical toxicity. As well, there has been extensive contamination of native soil, at many of the old sites. This has occurred both by physical dispersion of the original wastes and natural contaminant transport due to wind and water erosion and contaminant leaching into groundwaters. In contrast, most of the LLW currently being produced contains radionuclides arising from nuclear fission and activation processes. Although the specific activities are much higher than those of the historic wastes, the radionuclides have much shorter half-lives. In fact, the time periods over which most of the LLW currently being produced will remain hazardous are such that disposal facilities using manmade materials, such as concrete, for containment will be suitable. This is not the case for the historic wastes, where natural materials and geologic media are necessary for long term containment without periodic maintenance to, or replacement of, the disposal facility.

AECL has taken the initial steps towards development of disposal facilities for LLW for which it is responsible (both those generated by its own activities, and those received on a commercial basis from small volume generators). A subsurface demonstration disposal facility called IRUS (Intrusion Resistant Underground Structure) has been designed, and the design and safety assessment are currently under regulatory agency review.

In developing disposal facilities in Canada for waste produced on an ongoing basis, (e.g., nonhistoric waste), there are certain striking differences with the U.S.. As mentioned earlier and as shown in Figure 4, the waste generation scenario in Canada is dominated by two major organizations—AECL and Ontario Hydro, both of which generate waste of similar nature and type. They are also both located in the same province (i.e., Ontario). Thus, almost all of the existing inventory and currently generated waste in Canada is located in one province. The concept of having several compacts or regional disposal facilities, therefore, is not viable.

In principle, in order to take advantage of the economies of scale, a disposal facility developed by either one of the two major generators mentioned above could accommodate waste from the other, as well as the wastes from others in the nuclear fuel cycle and the numerous small volume generators involved in the application and use of radioisotopes. The total volume of low-level waste from these small volume generators is such that a disposal facility serving only these generators would have high costs per unit volume of waste. Either or both of the major generators (i.e., AECL and Ontario Hydro) would also have to be customers of such a facility to reduce the unit costs. Thus, from technical and economic viewpoints, the concept of multiple disposal facilities does not appear too attractive in Canada.

For waste produced on an ongoing basis, it should be noted that disposal facilities in Canada will be similar in scale to those now being planned by various U.S. compacts. If there were only one such facility, the annual input would be similar to that of the largest U.S. compact (i.e., the Southeast Compact). If facilities

are developed independently by the two major generators, the annual inputs will still fall within the ranges of those for facilities planned by a number of U.S. compacts and individual states.

SUMMARY

The national database on low-level radioactive waste was set up by the federal Low-Level Radioactive Waste Management Office, primarily to provide a basis for federal policy formulation in this field, and for LLRWMO program plarming and decisions.

Existing waste inventory stored in Canada is 1.3×10^6 m^3, which is about the same quantity disposed through 1991 in the U.S. from commercial generators. In contrast, the rate of generation is 9.1×10^3 m^3 which is about 1/4 of that of the U.S. commercial generators or slightly more than the generation rate of the U.S. Southeast Compact.

There are only two major waste generators in Canada—AECL and Ontario Hydro, both of which are located in the same province. Based on technical and economical considerations alone, one disposal facility could satisfy the needs of all current generators in Canada. Such a facility would have an annual waste input similar to that of the largest U.S. compact (i.e., the Southeast Compact).

REFERENCES

1. "Inventory of Low-Level Radioactive Waste in Canada, Annual Report 1991", prepared by the Low-Level Radioactive Waste Management Office, Ottawa, Canada, 1992 (in publication).

2. "Integrated DataBase for 1991: US Spent Fuel and Radioactive Waste Inventories, Projections and Characteristics," Prepared by ORNL for US DOE, DOE/RW-0006, Rev. 8, 1992 (in publication).

3. "The Radioactive Exchange," Exchange Publications, Washington, DC, January 31, 1992.

Figure 1, LLRW Inventory by Major Source Category
Total: 1,294,406 m3

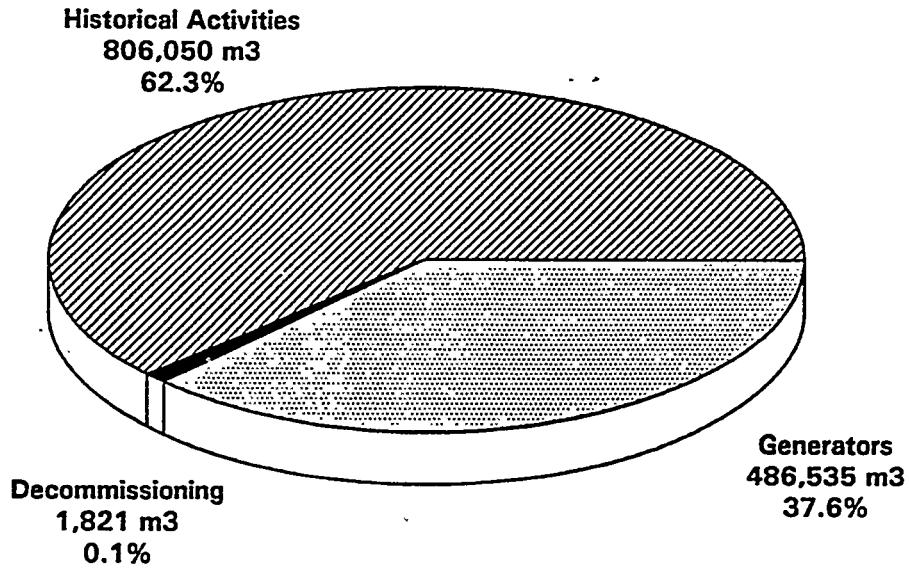


Figure 2, LLRW Accumulation Rates by Source Category
Total: 9,086 m3/a

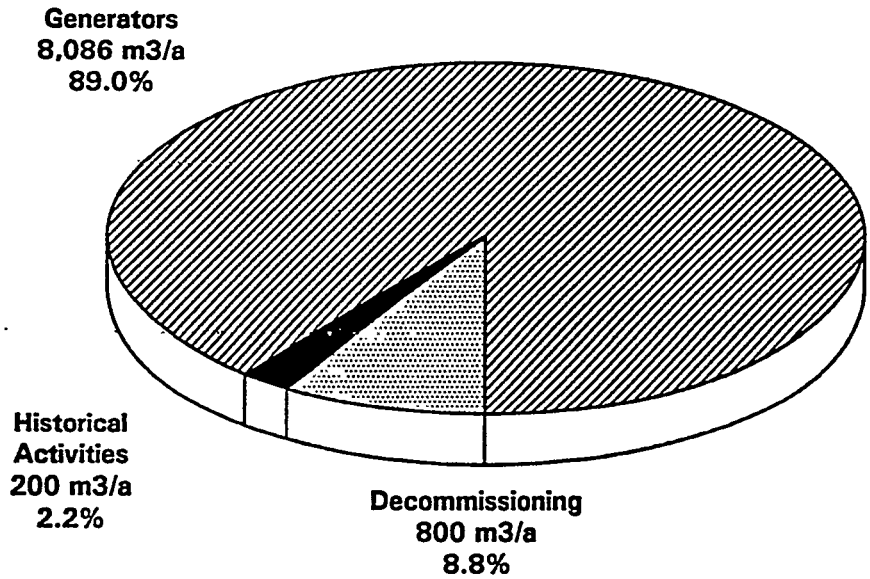
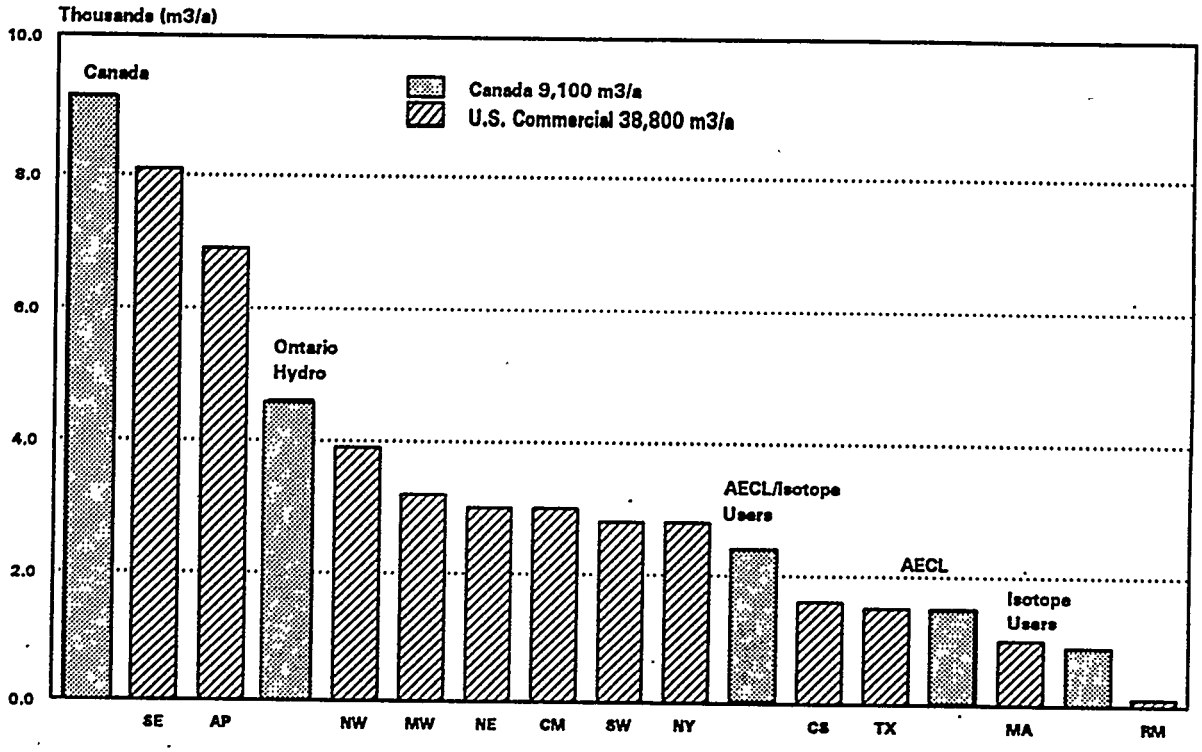


Figure 3, Comparison of Waste Generation Rates in Canada with U.S. Compacts and States (1991)

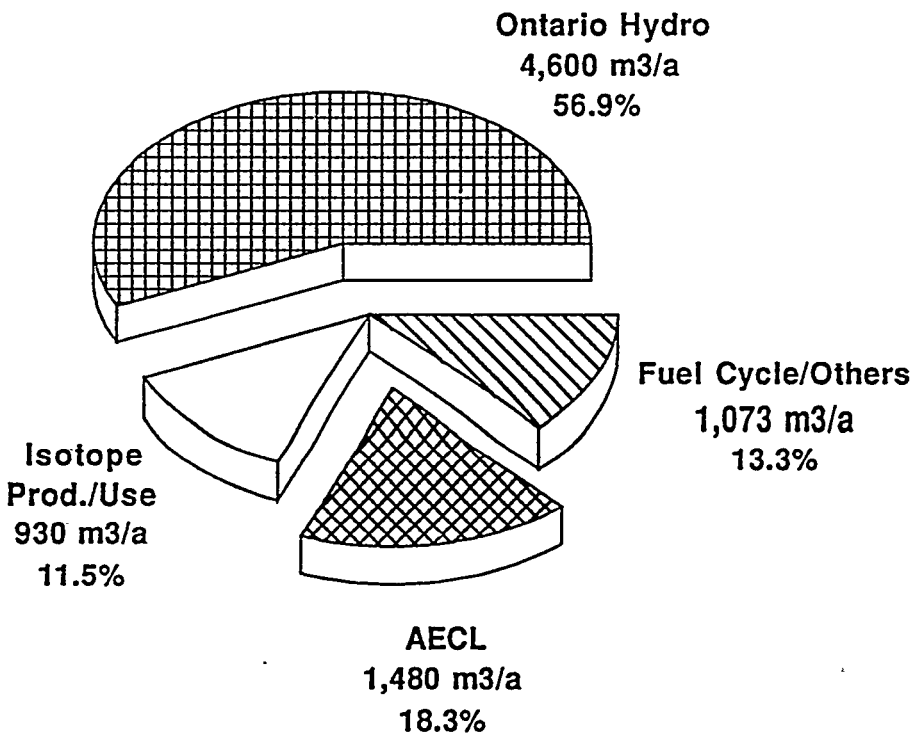


US Commercial Generators

SE: Southeast Compact	AP: Appalachian Compact
NW: Northwest Compact	MW: Midwest Compact
NE: Northeast Compact	CM: Central Midwest Compact
SW: Southwest Compact	NY: New York State
CS: Central States	TX: Texas State
MA: Massachusetts State	RM: Rocky Mountain Compact

Figure 4, Current Rate of Waste Generation by Generators Category

Total: 8,086 m3/a



Radioactive Mixed Waste Storage

J. M. Hennig
Waste Management Division
U.S. Department of Energy,
Richland Field Office

W. G. Jasen
W. H. Hamilton
Westinghouse Hanford Company
Richland, Washington 99352

ABSTRACT

Various types of waste have been generated during the 50-year history of the Hanford Site. Regulatory changes in the last 20 years have provided the emphasis for better management of these wastes. Interpretations of the Atomic Energy Act of 1954 (AEA)[1] and the Resource Conservation and Recovery Act of 1976 (RCRA)[2] have led to the definition of a group of wastes called radioactive mixed wastes (RMW). As a result of the radioactive and hazardous properties of these wastes, special projects have been initiated for the management of RMW. This paper addresses the storage of solid RMW. The management of bulk liquid RMW will not be described.

NOMENCLATURE

Solid waste, as referred to in this paper, is any waste that exhibits the characteristics of a solid, such as packaged solid wastes and lab-packaged liquid wastes. This definition of solid waste is different from the regulatory definition of a solid waste, which by law excludes certain wastes.

INTRODUCTION

The Hanford Site is a large [1,450.29 km^2 (560 m^2)] semiarid site located in the southeastern part of Washington State. Originally, the Hanford Site was chosen as the location for reactor and chemical separation facilities for the production and purification of plutonium. Documents DOE/EIS-0113 and ERDA-1538[3,4] describe the Hanford Site. Currently, most activities are directed toward environmental remediation and restoration and waste management. Westinghouse Hanford Company performs the operations and engineering contract for the U.S. Department of Energy. In contrast to commercial facilities, the Hanford Site is owned by the U.S. Government.

RADIOACTIVE WASTES

The DOE Order 5820.2A[5] defines the types of radioactive wastes. Without regard to source or form, waste that is contaminated with alpha-emitting transuranium radionuclides with half-lives greater than 20 years and concentrations greater than 100 nCi/g, at the time of assay, is considered transuranic. High-level waste is the highly radioactive waste material that results from the reprocessing of spent nuclear fuel, including liquid waste produced directly in reprocessing and any solid waste derived from the liquid that contains a combination of transuranic waste and fission products in concentrations requiring permanent isolation. As defined by DOE Order 5820.2,[5] waste that contains radioactivity and is not classified as high-level waste, transuranic waste, or spent nuclear fuel or byproduct material is considered low-level. Test specimens of fissionable material irradiated for research and development only, and not for the production of power or plutonium, may be classified as low-level waste, provided that the concentration of transuranic isotopes is less than 100 nCi/g. Hanford also manages uranium-233 and radiun-226 as transuranic isotopes.

HAZARDOUS WASTE

The DOE Order 5400.3[6] defines the hazardous and mixed waste program. Under RCRA, the term, "hazardous waste" identifies a solid waste or a combination of solid wastes that because of its quantity; concentration; or physical, chemical, or infectious characteristics may (a) cause or significantly contribute to an increase in mortality or an increase in serious irreversible or incapacitating reversible illness or (b) pose a substantial present or potential hazard to human health or the environment when improperly treated, stored, disposed of, or otherwise managed. Under RCRA, hazardous wastes are either characteristic or listed. Characteristic wastes are wastes that exhibit the characteristics of ignitability, corrosivity, toxicity, or reactivity, whereas listed wastes are those that are specifically listed by RCRA as hazardous. The U.S. Environmental Protection Agency has delegated its authority (in the RCRA), thus allowing individual states to manage hazardous waste programs. Washington State hazardous waste regulations are codified in the *Washington Administrative Code* (WAC), Section 173-303, "Dangerous Waste Regulations."[7] Washington State regulations are more restrictive than the federal RCRA regulations and cause many more wastes to be regulated hazardous wastes.

RADIOACTIVE MIXED WASTE

The DOE Order 5400.3[6] defines the hazardous and mixed waste program. The RMW is waste that contains both radioactive and hazardous components regulated by the AEA and RCRA, respectively. The term "radioactive component" refers only to the actual radionuclides dispersed or suspended in the waste substance. The radioactive and hazardous waste regulations provide an interesting dual regulatory climate that has necessitated a number of changes to waste management practices. The remainder of this paper describes the management of mixed wastes.

TREATMENT, STORAGE, AND DISPOSAL PERMITS

The purpose of RCRA is to reduce or eliminate the generation of hazardous waste and to treat, store, and dispose of hazardous waste to minimize the present and future threat to human health and the environment. The RCRA requires that cradle-to-grave management of wastes use a manifest system and that owners and/or operators of treatment, storage, and disposal (TSD) facilities obtain permits for continued operation of facilities. Document DOE/RL 88-20[8] is an example of an RCRA Part B Permit application submitted to Washington State for dangerous waste operations in the Low-Level Waste Burial Grounds.

WASTE ACCEPTANCE CRITERIA

Solid waste receipts at Hanford Site's solid waste TSD facilities are governed by WHC-EP-0063-3.[9] This document procedurally implements criteria by which certain RMW can be received. The main sections of this document include transuranic waste, low-level waste, RMW storage, and RMW disposal.

WASTE SEGREGATION AND EXAMPLES

As a result of the regulatory requirements, solid wastes are segregated based on their constituents. The RMW is segregated by the waste generator based on waste compatibility. When placed in storage, these wastes are grouped into various storage categories. Figure 1 depicts solid waste segregation. Solid mixed wastes typically fall into one of the following storage categories:

- Corrosive (radioactive acid)
- Corrosive (radioactive caustic)
- Radioactive flammable
- Other mixed waste (other regulated material)

- Radioactive oxidizer
- Radioactive polychlorinated biphenyl
- Radioactive poison.

An example of a corrosive RMW might be contaminated sulfuric acid or sodium hydroxide from fuel reprocessing. Reactive RMW includes contaminated metals such as sodium and potassium from liquid metal-cooled reactors. Ignitable wastes include many organic wastes such as xylene and toluene from laboratory activities and acetone used as a paint stripper. Toxic RMW might include contaminated heavy metals such as chromium, cadmium, and silver. Solid lead or lead shielding when disposed of is considered a hazardous waste. Paint and paint solvents often contain organic solvents and heavy metal pigments, which cause the uncured and cured product to be regulated.

RADIOACTIVE MIXED WASTE STORAGE

The regulatory climate emphasizes that best management practices be applied to the management of RMW. These management practices include the following activities in decreasing level of preference or acceptability:

- Minimize the generation of RMW
- Recycling wastes
- Physically, chemically, or biologically treat
- Thermally treat
- Stabilize and solidify waste
- Landfill.

Before landfilling or disposing of a waste, the waste must meet waste disposal criteria. In Washington State, the disposal criteria are very strict. Currently, few RMWs meet the disposal criteria; therefore, these wastes must be stored until treatment is available to condition these wastes for disposal. The Central Waste Complex (CWC), described in WHC-EP-0300 (Reference 10), is designed to provide interim and long-term storage of RMW. When completed, the CWC will have the capacity to store more than 75,000 208.19-L (55-gal) drums of waste. These drums will remain in storage until treatment and disposal facilities are available.

The CWC consists of an outdoor RCRA-compliant staging area, low-flashpoint flammable waste storage modules, 371.6 m^2 (4,000 ft^2) storage buildings, and other larger storage buildings [greater than 3,158.6 m^2 (34,000 ft^2)]. These RCRA-compliant facilities consist of sealed concrete floors with curbing and runoff control for waste containment. With the exception of the outdoor pad, all the facilities have walls and a roof to protect waste from wind and rain.

The outdoor storage pad is used primarily as a staging and unloading area. This pad is 8361.1 m^2 (9,000 ft^2) in area and can hold approximately two thousand five hundred 208.19-L (55-gal) drums of waste stacked two drums high. This pad is not intended for long-term storage.

Currently, there are eight low-flashpoint flammable RMW storage modules. These modules are designed to store flammable wastes with flashpoints below 38°C (100°F). The modules are small pre-engineered buildings with 16.35 m^2 (176 ft^2) of floor space each and collectively store approximately 246 208.19-L (55-gal) drums of waste. These modules are used to store lab-packaged containers of flammable waste. Additional

storage modules are planned for the storage of unreacted alkali metal. These modules will store small quantities of sodium metal wastes.

There are 13 371.6-L (4,000-ft^2) storage buildings with a minimum capacity of 750 208.19-L (55-gal) drums of waste. These pre-engineered storage buildings are used to store any of the segregated classes of RMW. Typically the waste is banded four drums to a pallet and stacked three drums high. A 0.91-m- (3-ft-) wide aisle space is maintained between rows of stacked drums to allow for periodic surveillance of the waste containers. Different classes of waste are segregated to maintain compatibility of the different types of waste. These facilities also are designed to meet Toxic Substances Control Act of 1976 (TSCA)[11] requirements for the storage of TSCA wastes.

The large RMW storage buildings are being built in four phases. They will store all categories of RMW (except certain polychlorinated biphenyl-contaminated wastes) with a 12,000-drum capacity each for phase I, III, and IV buildings and a 19,000-drum capacity for the phase II building (55,000-drum total capacity).

Additional storage capacity is planned as part of a fiscal year 1994 major systems acquisition. This large project will provide RMW storage capacity, infrastructure, and retrieval of certain legacy wastes. Wastes to be retrieved include stored transuranic waste from one burial ground trench. The storage capacity will be tied to the solid waste treatment facilities and provide staging for waste treatment.

RADIOACTIVE MIXED WASTE TREATMENT

Wastes are treated by generators when feasible and when allowed by law (e.g., neutralization or absorption) before receipt at the CWC. Certain treatments may be prescribed to provide a stable waste form to ensure long-term stability. In many cases a waste generator may not be able to meet the treatment standards to allow waste disposal. Solid Waste Management will treat some of these wastes in the Waste Receiving and Processing Facility before disposal.

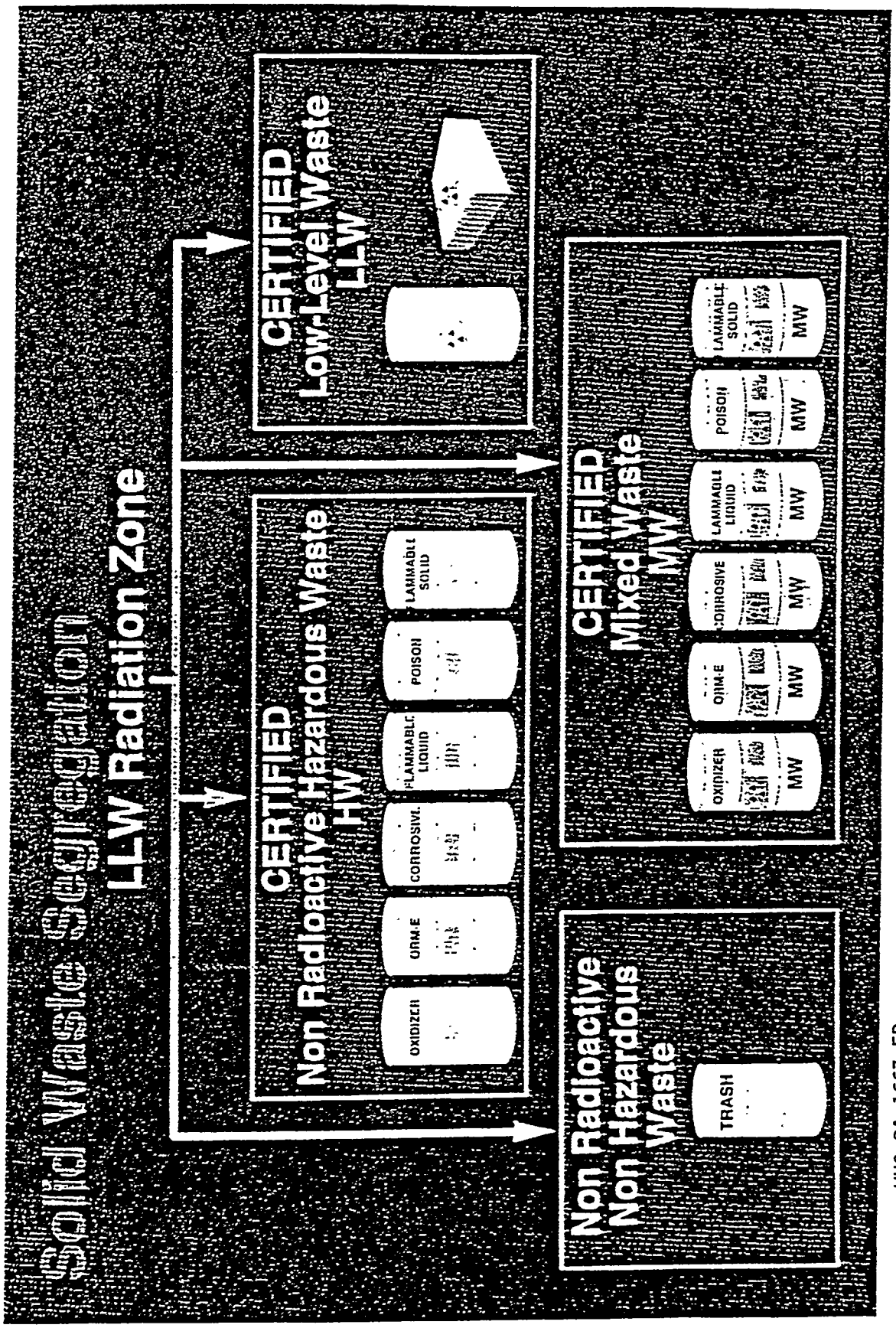
New TSD facilities are planned for effective management of RMW. Figures 2 and 3 describe solid waste management in 1992 and the year 2000. These figures depict construction of various facilities over the next decade. Figure 4 depicts the future Solid Waste Operations Complex, which will consist of various solid waste TSD facilities.

RADIOACTIVE MIXED WASTE DISPOSAL

Shallow land disposal of RMW is the least preferred option for the management of these wastes. Both federal (e.g., RCRA[2]) and state (e.g., WAC 173-303[7]) regulations stringently control and regulate shallow land disposal of hazardous wastes. The RCRA prescribes waste form requirements, packaging requirements, and disposal facility requirements. The disposal facility requirements have been incorporated into an RMW RCRA-compliant disposal facility. This facility is scheduled to be constructed in 1994.

SYSTEMS APPROACH TO WASTE MANAGEMENT

The goal of solid waste management is to provide a systems performance approach to waste management that uses best-demonstrated available technology and best management practices. This approach stresses cradle-to-grave management of wastes. The intent is to "know your waste" before and as it is generated and, to the extent practical, minimize the generation of wastes. For existing wastes and future generated wastes, technology will be applied to safely store and treat the wastes. The final outcome is a system that safely manages wastes in a manner that is protective of human health and the environment.



WHC-SA-1667-FP

Figure 1. Solid Waste Segregation.

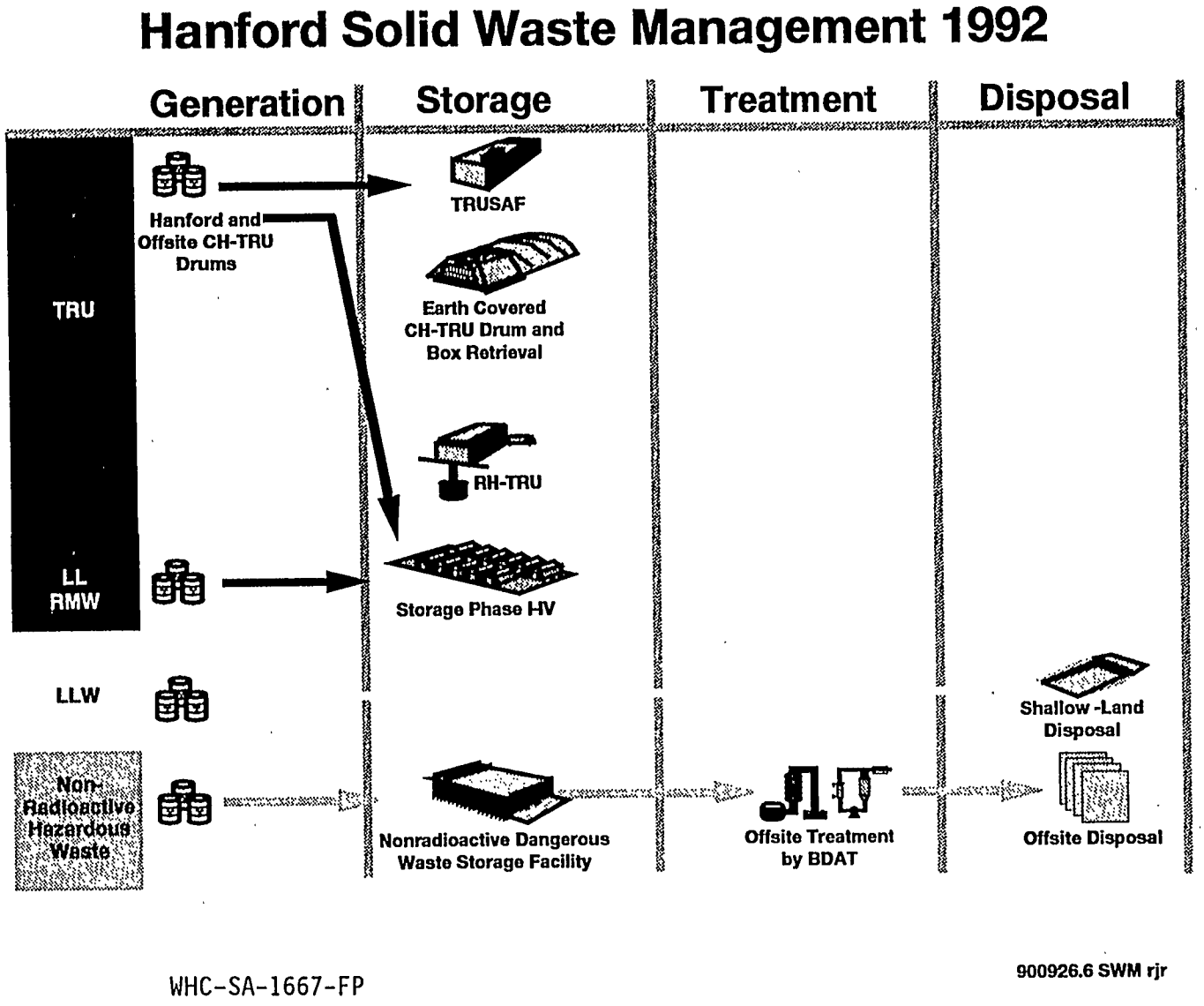
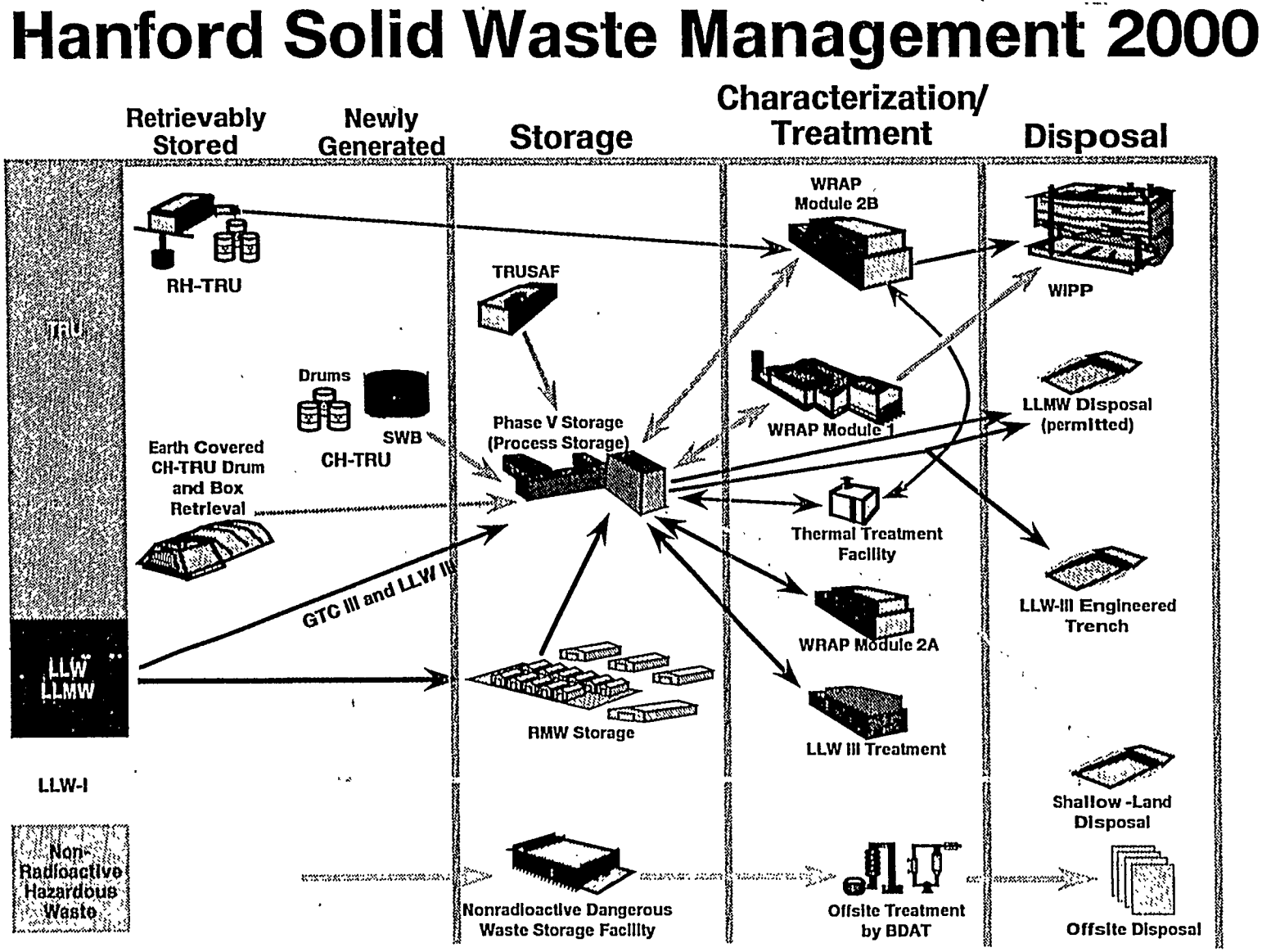
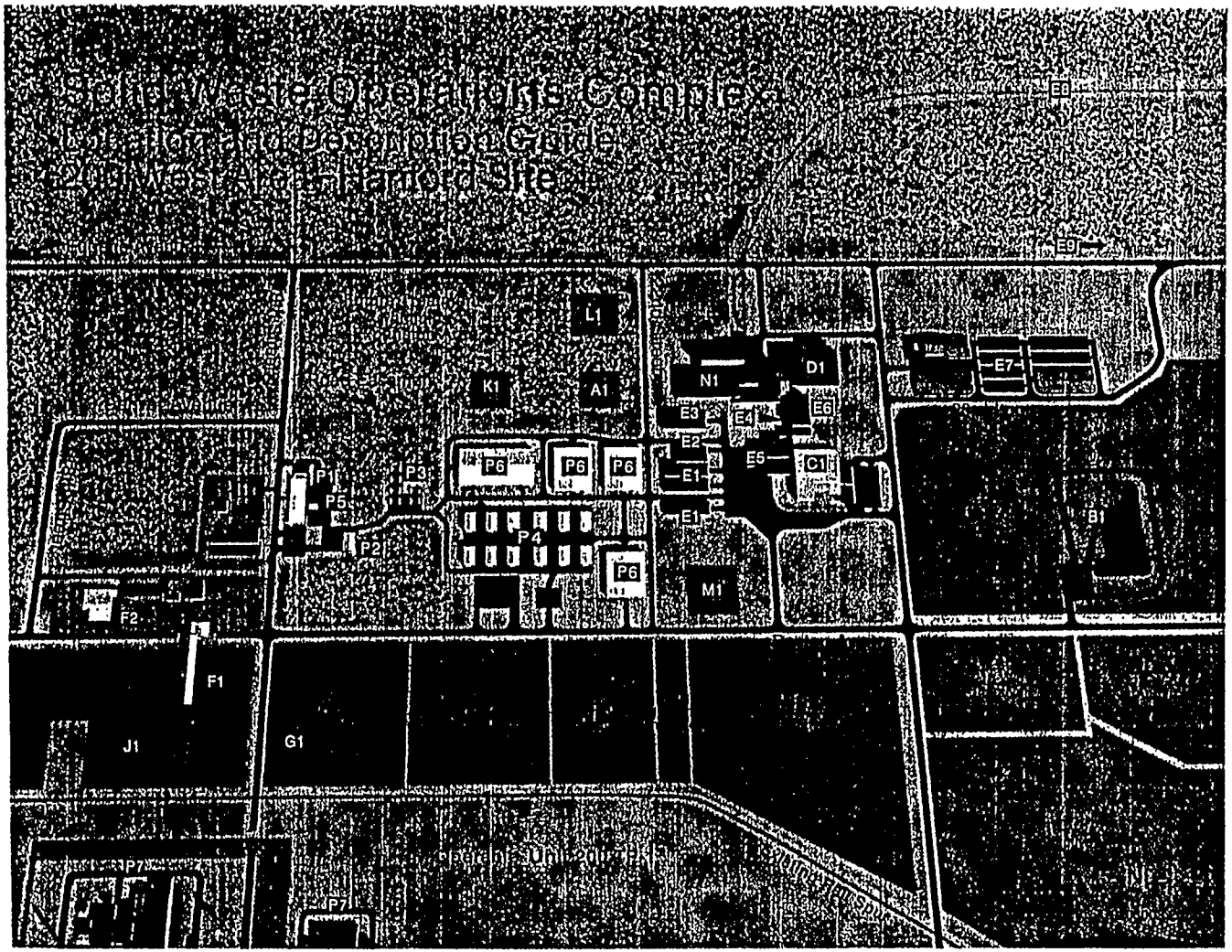


Figure 2. Hanford Site Solid Waste Management 1992.



WHC-SA-1667-FP

Figure 3. Hanford Site Solid Waste Management 2000.



Project W-272 (Capital Work Order)
- A1 Special Case Waste Storage Facility

Project W-025 (Expense Funded)
- O B1 Radioactive Mixed Waste Disposal Facility (218-W-5/T31)

Project W-026 (91 LI)
- C1 Waste Receiving and Processing (WRAP) Module 1

Project W-100 (94 LI)
- + D1 WRAP Module 2A

Project W-112 (94 LI)
- + E1 Long-Term Drum Storage
- + E2 Ignitable Drum Storage
- + E3 Box Storage
- + E4 Transfer Corridor
- + E5 Shipping and Receiving
- + E6 Automated Stacker Retriever System (AS/RS)
- + E7 Hanford Central Waste Support Complex
- + E8 Railroad Extension
- + E9 North Perimeter Gate, Guard Station, and Road to Route 11-A (not depicted)
- + E10 Infrastructure (not depicted)

Project W-113 (94 LI)
- O+ F1 Solid Waste Retrieval Facility (218-W-4C/T04)
- + F2 NDE/NDA Building

Project W-156 (97 LI)
- O G1 Alpha Caisson Retrieval

Project W-174 (TBD)
- O H1 Enhanced Solid Low-Level Radioactive and Mixed Waste Disposal (not sited)

Project W-219 (Expense Funded)
- I1 Temporary Office and Change Rooms

Project W-221 (97 LI)
- O J1 Solid Waste Retrieval Phase II

Project W-300 (94 GPP)
- K1 Alkaline Metal Storage

Project W-242 (97 LI)
- L1 Thermal Treatment Facility

Project W-247 (97 LI)
- M1 Waste Reduction and Reclamation Facility

Project W-255 (97 LI)
- N1 WRAP Module 2B

Existing Facilities
- P1 272-WA
- □ P2 2401-W PCB and Mixed Waste Storage
- □ P3 Low Flash-Point Mixed Waste Storage Units
- □ P4 Radioactive Mixed Waste (RMW) Storage Buildings (2402-W series)
- P5 213-W Compactor Building
- □ P6 Mixed Waste Storage Phase I-IV (2403-W series)
- P7 Z Plant Operations (Non-solid Waste Facilities)

LI = Line Item
GPP = General Plant Project
TBD = To Be Determined

O LLBG = Low Level Burial Ground
□ CWC = Central Waste Complex
+ SWOC1 = Solid Waste Operations Complex Phase I MSA

79203003.25

WHC-SA-1667-FP

Figure 4. Solid Waste Operations Complex.

REFERENCES

1. *Atomic Energy Act of 1954*, 42 USC 2011 et seq.

2. *Resource Conservation and Recovery Act of 1976*, 42 USC 6901 et seq.

3. DOE/EIS-0113, *Final Environmental Impact Statement - Disposal of Hanford Defense High-Level, Transuranic and Tank Waste, Hanford Site, Richland Washington*, 5 vols, U.S. Department of Energy, Washington, D.C. (December 1987).

4. ERDA-1538, *Final Environmental Statement: Waste Management Operations Hanford Reservation, Richland, Washington*, 2 vols, U.S. Energy Research and Development Administration, Washington, D.C. (December 1975).

5. DOE Order 5820.2A, *Radioactive Waste Management*, U.S. Department of Energy, Washington, D.C. (September 26, 1988).

6. DOE Order 5400.3, *Hazardous and Radioactive Mixed Waste Program*, U.S. Department of Energy, Washington, D.C. (February 22, 1989).

7. WAC 173-303, "Dangerous Waste Regulations," *Washington Administrative Code*, as amended.

8. DOE/RL 88-20, *Low-Level Burial Grounds Dangerous Waste Permit Application*, U.S. Department of Energy, Richland Operations Office, Richland, Washington (December 1989).

9. WHC-EP-0063-3, *Hanford Site Radioactive Solid Waste Acceptance Criteria*, Westinghouse Hanford Company, Richland, Washington (September 1991).

10. WHC-EP-0300, *Alternatives to Land Disposal of Solid Radioactive Mixed Wastes on the Hanford Site*, Westinghouse Hanford Company, Richland, Washington (March 1990).

11. *Toxic Substances Control Act of 1976*, 15 USC 2601 et seq.

Disposal of Low-level Radioactive Waste at the Savannah River Site

Virgil W. Sauls
United States Department of Energy
Savannah River Field Office

INTRODUCTION

An important objective of the Savannah River Site's low-level radioactive waste management program is to isolate the waste from the environment both now and well into the future. A key element in achieving this is the disposal of low-level radioactive waste in sealed concrete vaults.

Historically the Site has disposed of low-level radioactive waste via shallow land burial. In 1987, it was decided that better isolation from the environment was required. At that time several options for achieving this isolation were studied and below grade concrete vaults were chosen as the best method.

This paper will discuss the performance objectives for the vaults, the current design of the vaults and plans for the design of future vaults, the cost to construct the vaults, and the performance assessment on the vaults.

Construction of the first set of vaults is essentially complete and readiness reviews before the start of waste receipt are being performed. Startup is to begin late in calendar year 1992 and continue through early CY 1993. The performance assessment is under way and the first draft is to be completed in early 1993.

BACKGROUND

The Savannah River Site occupies approximately 325 square miles along the Savannah River in central South Carolina. The Site was established in 1950 by the United States Atomic Energy Commission to produce material for nuclear defense. The Site is currently managed by the United States Department of Energy and operated by the Westinghouse Savannah River Company. The Site includes fuel and target fabrication facilities, low temperature/low pressure reactors, chemical separations facilities, tritium extraction, loading and recovery facilities, high-level radioactive waste facilities, and low-level radioactive waste facilities.

Approximately 195 acres in the center of the Site are used for the storage and disposal of solid radioactive waste. Low-level solid radioactive waste is currently disposed of via shallow land burial. Low-activity waste (<200 mR at 3 inches) is disposed of in containers in engineered low-level trenches. The trenches are 22 feet deep with other dimensions adjusted to maximize the available space. Waste containers used are 55-gallon drums, 90-cubic-foot and 45-cubic-foot metal boxes, and engineered steel boxes for bulky components. Intermediate-level solid radioactive waste (>200 mR at 3 inches) is disposed of in slit trenches. The trenches are approximately 20 feet deep, 20 feet wide and up to 1000 feet long. Waste forms placed into the slit trenches are not necessarily containerized. However, the engineered low-level trenches and the slit trenches may not fully meet all the performance objectives of DOE Order 5820.2A, "Radioactive Waste Management" (September 26, 1988). Those objectives are:

1. Protect public health and safety according to standards specified in DOE orders.

2. Ensure that external exposure from the waste and concentrations of radioactive material that may be released into surface water, groundwater, soil, plants and animals results in an effective dose equivalent that does not exceed 25 mrem/yr to any member of the public. Releases to the atmosphere shall meet the requirements of 40 CFR 61. Reasonable effort should be made to maintain releases of radioactivity in effluents to the general environment as low as is reasonably achievable.

3. Ensure that the committed effective dose equivalents received by individuals who inadvertently may intrude into the facility after the loss of active institutional control (100 years) will not exceed 100-mrem/yr for continuous exposure or 500 mrem for a single acute exposure.

4. Protect groundwater resources, consistent with Federal, State, and local requirements.

In the 1980s, the Savannah River Site began to study alternatives to shallow-land burial. Requirements for low-level radiological waste disposal were developed based upon technical and regulatory requirements in place or anticipated. Additionally, societal requirements were considered to increase public acceptance. Consideration was given to several technologies for disposal, including the use of containers or not, grouting waste in place or not, and the type of structure to contain the waste.

In 1987, the decision was made to implement waste disposal activities that would eliminate contact of untreated solid fission products and tritium products with the soil environment to ensure protection of the ground water. The Site determined that below grade concrete vaults would be the most effective method to accomplish this objective.

PERFORMANCE OBJECTIVES

The vaults were designed to meet the following performance objectives:

- Maximum individual dose of less than or equal to 4 mrem per year from groundwater at the disposal area boundary
- Maximum offsite individual dose of less than or equal to 10 mrem per year from atmospheric releases
- Maximum individual dose of less than or equal to 25 mrem per year along all pathways at the disposal area boundary
- Maximum doses of less than 100 mrem per year continuous exposure or 500 mrem/yr for a single, acute exposure to an intruder after loss of institutional control (100 yr)
- Continued commitment to the Site's as low as reasonably achievable (ALARA) exposure level program.

The following design requirements were implemented to facilitate satisfaction of the performances objectives:

- Ten feet of minimum distance between the bottom of the waste and the groundwater
- A drainage and sump system inside the vaults
- A subdrain system to reduce the likelihood of a positive water head buildup
- A vault grouping orientation relative to the groundwater flow direction that will minimize groundwater impact.

CURRENT VAULT DESIGN

Solid waste material that has become contaminated with beta-gamma and/or low levels of alpha activity is defined as Low-level Radioactive Waste. The Waste is further divided into three types as defined below:

Low-activity waste	<200 mR/hr from an unshielded container at 3 inches and does not contain, or is not suspected to contain, tritium waste
Intermediate-level nontritium waste	>200 mR/hr from an unshielded container at 3 inches and does notcontain, or is not suspected to contain, tritium waste
Intermediate-level tritium waste	>200 mR/hr from an unshielded container at 3 inches and contains, or is suspected to contain, tritium waste

A separate concrete vault has been designed for disposal of each of the waste types. The design and construction of these vaults is described below.

Low-Activity Waste Vault

The low-activity waste vault (LAWV) (Figures 1 and 2) is a 643-foot-long x 145-foot-wide x 27-foot-high concrete structure located on grade within an excavated area. The vault consists of three modules subdivided into four cells each. Approximately 144,000 cubic feet of waste can be disposed of in each cell.

The vault is designed to withstand a 0.2g ground acceleration earthquake and to allow closure with a minimum of 8 feet of soil overburden without depending upon the disposed waste to prevent collapse.

The side walls of each module are 2.5 foot thick with a 2-inch expansion joint between adjacent module walls. The front/back and interior walls are 2 foot thick.

All module exterior and interior walls are structurally mated to a 2.5-foot-thick x 9–12-foot-wide continuous concrete footer under each module with an additional 2.5-foot-thick footer under adjacent module walls. The base slab of each module is 1 foot thick. The base slab rests on a bed of crushed stone placed on compacted backfill. The bed of stone varies from 7.5 foot thick at the edges (extends under the footer) to 3.5 foot thick at the center.

The roof of the vault is 3.5-inch-thick precast, prestressed, concrete deck plates installed on 4.5-foot-thick precast, prestressed concrete roof beams with 12.5 inches of cast in place concrete overlayed. The total roof thickness is 16 inches. The roof is slightly peaked to allow for drainage. As with the walls there is a 2-inch expansion joint between modules. Flashing is installed over the expansion joints for waterproofing. The roof is covered with a bonded-in-place layer of insulation and a waterproof membrane.

Concrete used in construction complied with American Concrete Institute (ACI) 350R-89, "Environmental Engineering Concrete Structures," and ACI-301-89, "Specifications for Structural Concrete for Buildings." Other ACI standards related to pumping methods, temperature control, inspection, and framework were used where appropriate.

To mitigate water entry, continuous waterstop seals were used at all joints and no horizontal joints were allowed in vertical walls. Exterior walls that will be exposed to soil were coated with waterproofing.

Three drainage systems were built into the vault to prevent water buildup. An in-cell system drains any water from within the cell to a sump. The floor of the vault is sloped 2% toward the open side. Along the open side is a drainage trench and drains that route the water away from the vault to a concrete sump via

underground plastic pipe. Two cells are tied into each sump. Water collected within the sump is emptied via portable pump.

Water from the slightly peaked roof drains via gutters to an underground drainage system that empties into a sediment basin. Water that may collect in the crushed stone under the base slab flows into a perforated drain pipe within the stone along the vault edges. From there the water flows through a drainage system to a stone filled sump where it seeps into the ground.

The vault has one 26-foot-wide access opening in a side cell wall to allow for personnel and equipment entry during the placement of waste. Interior cell walls have two personnel openings with doors to allow access between cells during waste placement operations. In the wall opposite the 26-foot-wide access opening are two 30-inch-square openings to allow for the placement of ventilation fans during operations. All exterior openings will be sealed with concrete at cell closure. There are no openings in the end walls.

An electrical distribution system (electrical conduit with receptacles) is installed along the roof beams to provide power for interior lighting and ventilation fans. Temporary lights will be suspended from the roof beams and temporary ventilation fans will be installed in the rear wall during waste placement operations. These will be removed before cell closure. Power will be supplied by a portable generator located outside the cell.

Intermediate-Level Nontritium Vault

The intermediate-level nontritium vault (ILNTV) (Figures 3 and 4) is a 189-foot-long x 48-foot-wide x 29-foot-deep concrete structure located mainly subgrade with approximately 4 feet above grade. The vault contains seven cells. Approximately 28,000 cubic feet of waste can be disposed of in each cell. As with the low-activity waste vault, the ILNT vault is designed to withstand a 0.2g ground acceleration earthquake and to allow closure with a minimum of 8 feet of soil overburden without collapse.

The end walls of the vault are 2.5 foot thick, the side walls are 2.0 foot thick, and the intercell walls are 1.5 foot thick. The walls are structurally mated to a 2.5-foot-thick base slab that extends beyond the exterior walls approximately 2 feet. The base slab rests on a bed of crushed stone placed on compacted backfill. The bed of stone varies in thickness from 1.5 feet to 4.5 feet with the thickness increasing from one side to the other.

The top of the vault is open to allow placement of waste via a gantry-type crane during operation. During waste disposal operations shielding T-blocks and roof-truss type steel raincovers will be used to provide shielding and prevent the entry of water. The vault will be sealed with a permanent 2–3-foot-thick slab cast in place at final closure.

The concrete used during construction complied with the same ACI standards as that used in the low-activity waste vaults.

The vault contains two drainage systems as well as design features to prevent water buildup. An in-cell system drains any water from within the cell to a sump. The base of each cell is sloped toward a drain in the center. The drain is connected to an in-cell sump in the base slab beneath a side wall. A 6-inch-diameter vertical riser pipe running vertically through the side wall provides access to the sump from the surface. Water collected within the sump is emptied via an installed submersible sump pump.

The base slab of each cell is covered with two layers of washed stone separated by a geotextile fabric. The top layer of stone is level to allow placement of waste. The interior walls of each cell are lined with drainage netting to route moisture forming on the walls to the base slab for drainage to the sump.

A subdrainage system is installed to prevent water buildup beneath the vault. The bed of stone beneath the base slab extends beyond the side wall on the 4.5-foot side and overlays an additional approximately 2-foot-deep trench of stone. A perforated drain pipe runs through the trench and connects to a sump between the

ILNT vault and the intermediate-level tritium vault. The base of the sump rests on crushed stone and is approximately 7 feet below the level of the base slab. A 5-foot-diameter manhole connects the sump with the surface.

Intermediate-Level Tritium Vault

The intermediate-level tritium vault (ILTV) (Figures 3 and 4) is identical to the intermediate-level nontritium vault except for the length. The intermediate-level tritium vault is 57 feet long and contains only two cells.

The intermediate-level tritium vault and the intermediate-level nontritium vault are adjacent (separated by approximately 33 feet). The area between the vaults contains the manhole to the common subdrainage sump and is used for laydown of T-shields during operations. The area is covered with a 6-inch base slab of concrete over a 4-inch layer of crushed stone on top of backfill.

PERFORMANCE ASSESSMENT

Because of the scheduled need for the vaults, it was not possible to complete a performance assessment of the design before the start of construction. However, a performance assessment was initiated and a review draft is expected in early 1993. The allowable waste streams will be adjusted based upon the results of the Performance Assessment. Current results indicate that historically disposed of waste streams will be acceptable with some limitations. Waste acceptance criteria are being developed and waste will be certified to meet the criteria before being placed into the vaults.

FUTURE PLANS

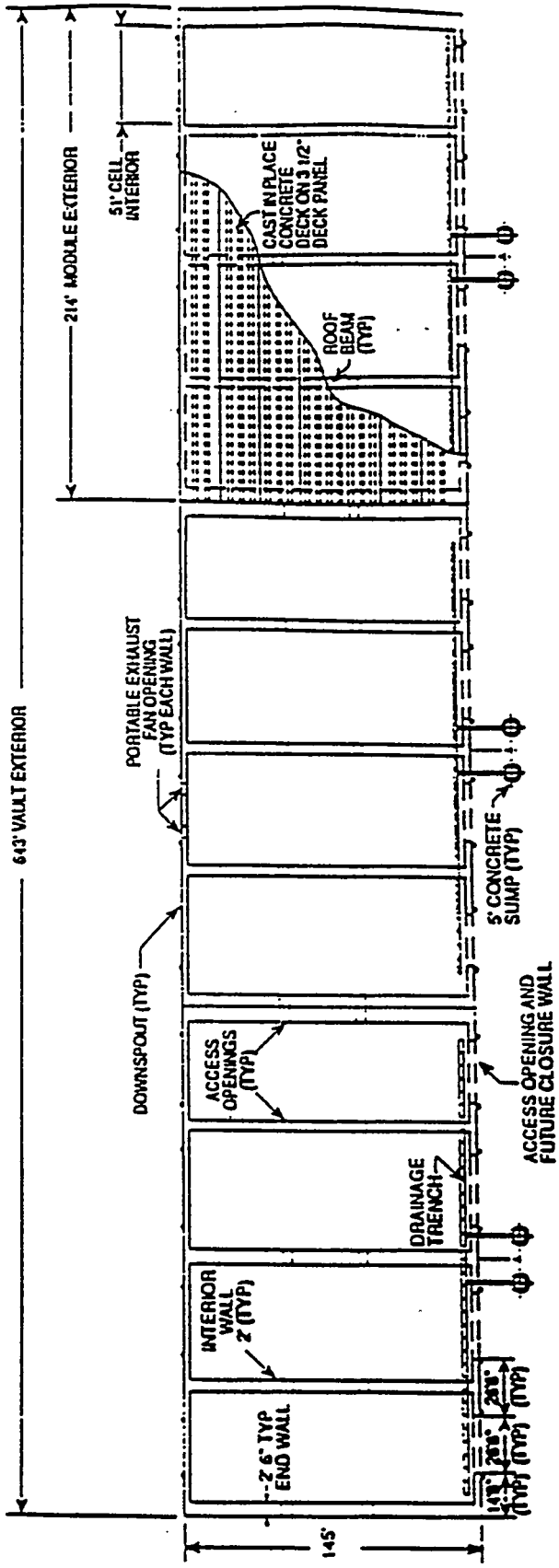
The cost to construct the low-activity waste vault was $23 million and the cost for the intermediate-level nontritium/intermediate-level tritium vaults was $12 million. Since the Savannah River Site plans to construct a total of 21 low-activity waste vaults and 10 intermediate-level nontritium/intermediate-level tritium vaults over the next 20 years to handle projected volumes of waste, ways to reduce these costs are being investigated. The primary focus is to develop a standardized design that will optimally meet regulatory requirements while minimizing construction costs. Area being investigated include:

- Structural conservatism
- Design overburden
- Seismic resistance criteria
- Wall thickness
- Volume of rebar.

At the same time, efforts are being made to minimize the design engineering cost between vaults and to use a fixed price contract for construction. Lessons learned from the first set of vaults, improved waste characterization, and the soon to be completed Performance Assessment will provide information helpful in determining if the vaults were over- or underdesigned.

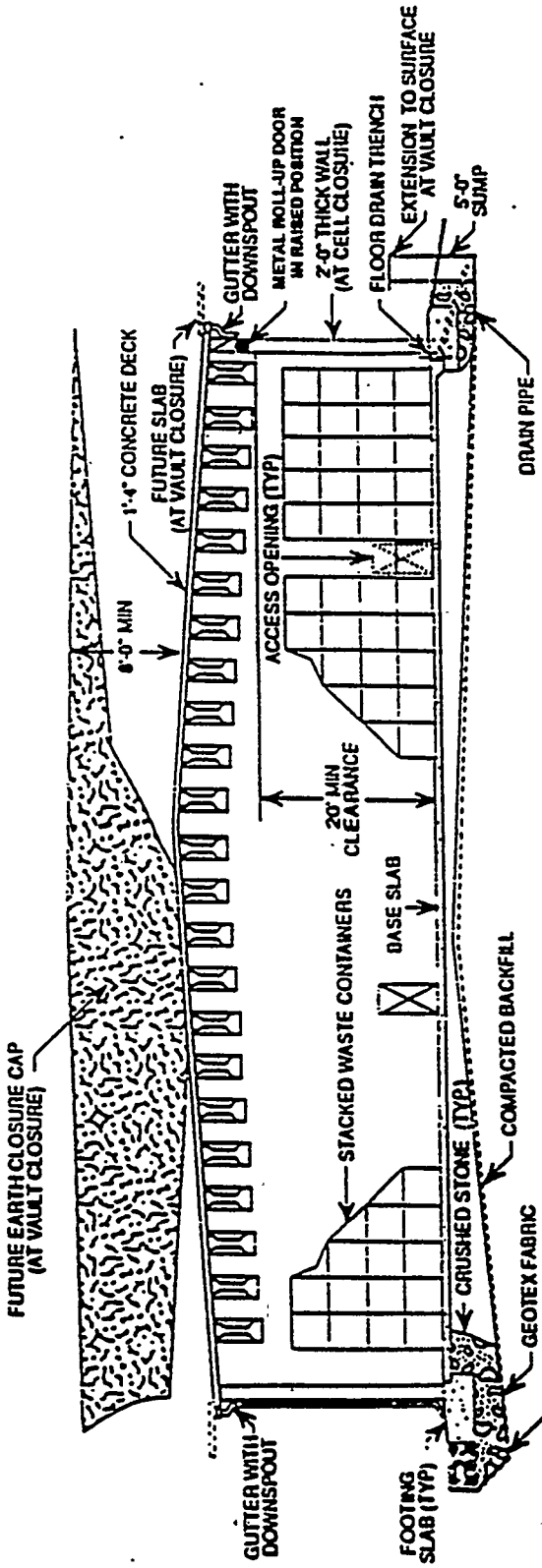
ACKNOWLEDGMENT

Information on the development of the vault concept is based upon DPST-87-456, *Low-Level Waste Disposal: Cost Comparison of Alternative Technologies*, June 26, 1987, by E. L. Wilhite. Information on the design and construction of the vaults is based upon DPSTSA-200-10, SUPP-8, Addendum 1 (DRAFT) *Burial Ground Operations Safety Analysis Report Addendum*, May 1992.



Not to Scale

Figure 1 Three-Module LAWV Plan



Not to Scale

Figure 2 Typical Section Through LAWV Cell

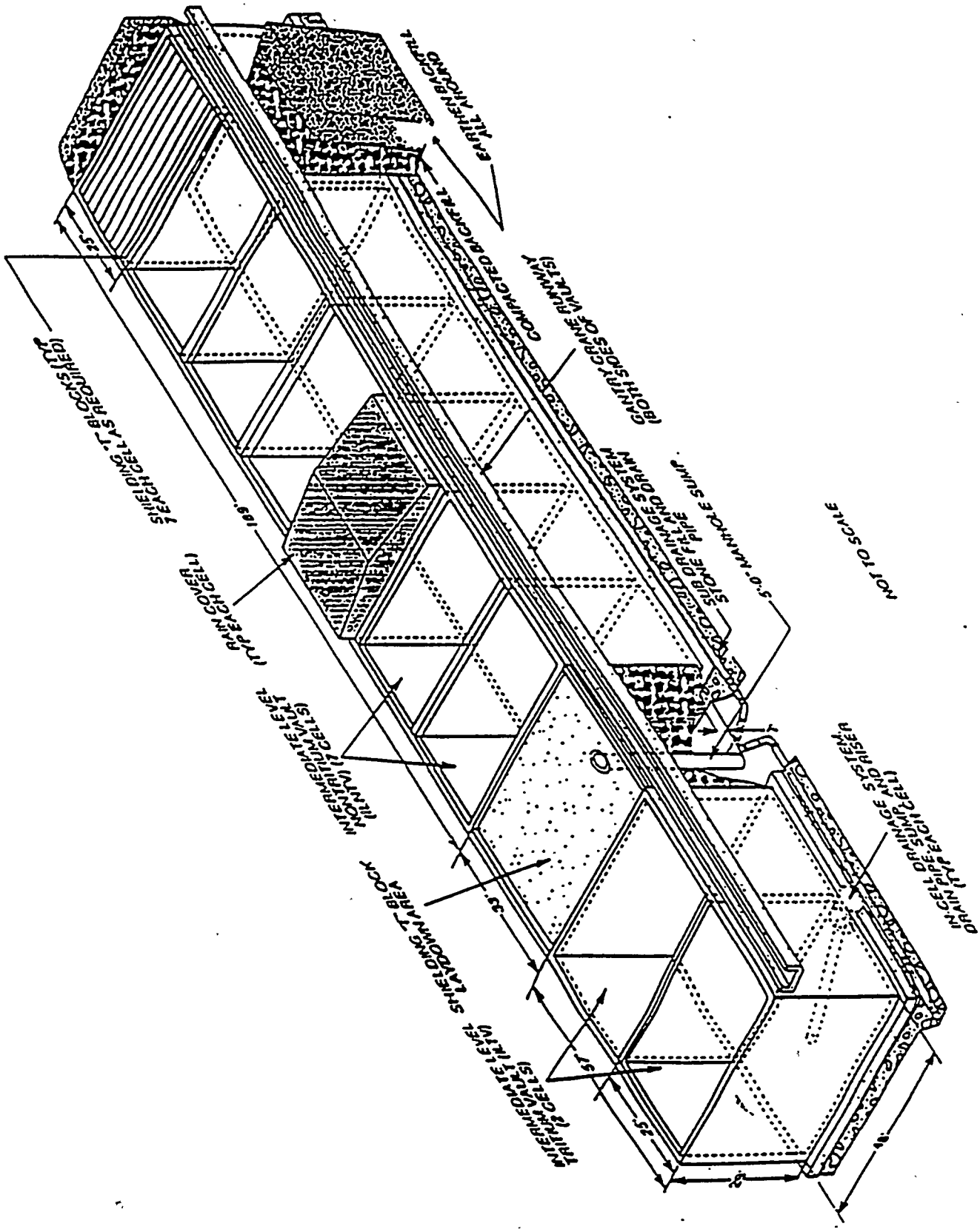


Figure 3 General Arrangement of ILNTV and ILTV

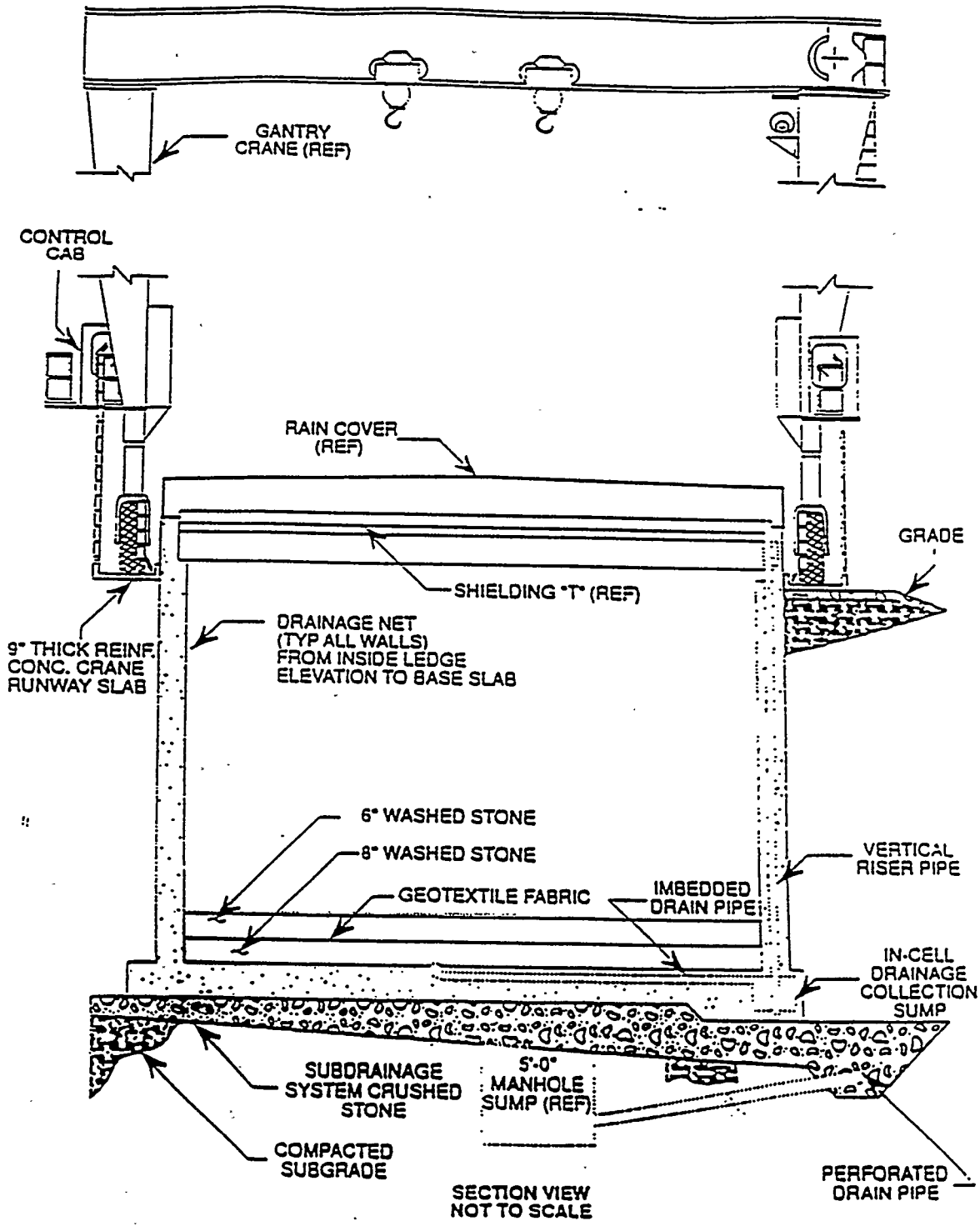


Figure 4 Typical INTV/ILNTV Cell Arrangement

Contaminated Graphite Waste Incineration

by Hélène Garbay
Institut de Protection et de Sûreté Nucléaire
Département de Protection de l'Environnement et des Installations
Service d'Etudes et de Recherches sur la Géosphère et l'élimination des Déchets
IPSN/CEA, 92265 FONTENAY-AUX-ROSES CEDEX, France

Jean-Jacques Guiroy
Components Department
FRAMATOME

TOUR FIAT - Cédex 16 - 92084 PARIS LA DEFENSE (FRANCE)
FAX: (33.1.47.96.33.19) - PHONE: (33.1.47.96.26.48)

INTRODUCTION AND BACKGROUND

A certain number of French gas-cooled reactors (GCRs) that were commissioned during the 1950s and 1960s are presently shut down. During operation, however, these reactors generated a large quantity of graphite wastes, essentially consisting of the sleeves of spent fuel elements.

Some of these reactors are to be dismantled (such as the G2 and G3 reactors at Marcoule), and there is also a large volume of accumulated graphite wastes that needs to be appropriately processed. The following table provides several examples of the present situation in France.

Reactor or other source of graphite	Mass of graphite wastes	Form of these graphite wastes
Marcoule G2 and G3	2400 tonnes	0,2 x 0.2 x 1.5 m blocks, each weighing 100 kg
EDF's Saint-Laurent "A" GCR units	2000 tonnes	Sleeves with ext. dia. of 137 mm, int. dia. of 112 mm, and length of 600 mm each.
Stored at La Hague	2000 tonnes	Unit weight = 6 kg

In addition, a certain number of other European countries are facing similar situations.

Several solutions have been envisaged for processing these graphite wastes:

- Immersion at sea after packing them in watertight containers
- Deep underground storage, after waterproofing and putting them into appropriate containers
- Incineration.

Onsite surface storage is not possible, because the site operating life of 300 years is incompatible with the half-life of carbon 14, which is 5730 years. In France, although the graphite sleeves of the Bugey 1 unit (32 sleeves weighing 18 kg each) were stored at the La Hague storage site, after packing in 5 m^3 containers, such storage is not accepted for the new Aube department storage center, to be opened in 1992. It is estimated that only two moderator loads would saturate this site's capacity for long-lived radioelements.

As for the other possibilities, the situation is as follows:

- Immersion at sea has been forbidden by a moratorium agreed to by the European countries, notably Spain.
- Deep underground storage would require such a site to be available, which is not presently the case.

Incineration, on the other hand, is an elegant solution, because it enables:

a. Considerably reducing the volume of wastes to be stored, because the solid secondary residues represent only about 1 or 2% of the initial volume. The graphite bums completely, and the residual contamination of the secondary wastes is due to cobalt 60, cesium 137, and iron 55.

b. Ensuring trapping of the contaminants (cobalt, cesium, iron, residual γ particles) in filters.

c. Ensuring rapid dispersion and dilution in the atmosphere of the β emitters: C_{14} in the form of carbon dioxide and tritium.

It should be noted that carbon dioxide is dispersed uniformly throughout the earth's atmosphere (average concentration 350 ppm).

The pilot installation is shown in Figure 1.

INCINERATION PROCESS

Dense or Circulating Fluidized Bed (CFB) Combustion Process:

The graphite elements are crushed in two or three stages, depending on their size, to an average particle size of one to a few mm. These particles are then placed in the fluidized bed combustor.

The combustor is of the dense or circulating fluidized bed type, whose features include a high fluidization air flow rate and high turbulence in the combustion region. The fluidized bed consists of powdered grog. Solids are separated from the combustion gases by a cyclone separator, and recycled via a recirculation loop that contains nonmechanical parts.

The combustion gases leaving the recirculation cyclone separator have a low concentration of dust. This dust contains fly ash, fine grog particles arising from slight wear of the fluidized bed, as well as a small quantity of unburned graphite. Incineration of the graphite is completed in a post-combustion chamber.

This system was selected for the following reasons:

- Existing industrial installations.
- Excellent combustion performance. Due to the high degree of turbulence and long residence time, the combustion temperature can be kept relatively low, well below the point at which melting of the ash occurs, and this also reduces Nox emissions.
- Inherently very good operating stability, due to the design.
- Accepts a wide range of particle size distribution, including varying proportions of crusher fines.
- Does not require very fine crushing, thereby reducing the risk of explosion and facilitates it's containment.

- Turndown ratio 1.3.
- Simple, with no moving parts, therefore greater safety and reduced maintenance.
- In the event of a filtration system malfunction, the fluidization air flow is stopped, and the fluidized be sinks and smothers the combustion, thus preventing any radioactive release to the atmosphere. It can be started up again easily.

VALIDATING THE PROGRESS

The above-described elements and the results obtained in preliminary testing led the French Atomic Energy Commission (CEA) and Electricité de France (EDF) to sign an agreement with FRAMATOME to perform an experimental process validation program, using a pilot installation of preindustrial size located at Le Creusot, France.

The pilot installation is shown in Figure 1.

Depending on the fluidization air rate, the reactor can be operated with either a dense phase fluidization or circulating fluidization bed.

An additional fluidized bed located at the bottom of the recirculation conduit permits reinjecting circulating particles removed by the primary cyclone.

If necessary, the combustion can be maintained by a gas burner. The combustion rate can also be reduced by injecting water into the bed.

The validation program was defined on the basis of an approach that involved identifying and analyzing the independent parameters of the process, simulating the operating transients and incidents, and evaluating the industrial conditions of incinerator operation.

The validation program included 22 twelve-hour tests and one 120-hour test and was built around four phases:

1. Search for the stable operating points
2. Sensitivity of the parameters and the limiting values
3. Behavior during transients and incidents
4. Simulation of industrial operation (the 120-hour test).

MAIN RESULTS

Search for the Stable Operating Points

These tests led to adopting the following standard operating conditions, which were later confirmed by the long-duration test under automatic control.

Parameter	Setpoint
Graphite feed rate	30 kg/h
Combustion temperature	1075°C
Post-combustion temperature	1100°C
Temperature of cooled smoke	160°C
Reactor negative pressurization	-10 mmCE

Sensitivity of the Parameters and Limiting Values

The sensitivity of the parameters was evaluated on the basis of three criteria: process stability, combustion efficiency, and the consumption of the fluidization support material.

Limiting values

Parameter	Recommended stamdard value	Limiting value	
		Low	High
Graphite feed rate	30 kg/h	<20 kg/h	40 kg/h
Graphite granulometry (content of fines <200 μm)	<10%	None	25%
Support mass	100 kg	75 kg	130 kg
Support granulometry	800/1000 μm	400/600 μm	800/1000 μm
Combustion temperature	1075°C	1000°C	1150°C
Cyclone temperature	1050°C	1000°C	1150°C
Filter temperature	160°C	100°C	180°C

Behavior During Transients and Incidents

Small disturbances of the process input parameters (feed rate, graphite granulometry, recirculating air flow, etc.) are automatically taken into account by the process controls.

The identified risks are the degradation of fluidization at high temperature (1200°C) or the decrease in the filtering efficiency due to excessively high smoke temperature, which can lead to atmospheric releases of radioactivity.

The simulations of incident conditions, along with an analysis of the possible consequences and the actions to be taken, have led to situations that can always be controlled and to the establishment of specific procedures that can be automated.

The 120-Hour Test

Combustion efficiency

The combustion efficiency is calculated on the balance of residual carbon collected by the filters. It is expressed in percentage of the mass of graphite introduced into the incinerator.

Startup efficiency (0 to 40 hours)	99.28%
Instantaneous efficiency (after 40 hours)	99.80%
Efficiency over the entire test duration	99.54%

Solid wastes

The consumption of the fluidization material is evaluated at 100 g/h. Longer operation enables minimizing the startup effects, where the material wear is greater and where the combustion efficiency is the lowest.

The mass-reduction factor between the incinerated graphite and the filter residues (residual carbon, ashes, and fluidization material) is about 100.

Gaseous releases

	N_2	CO_2	O_2	CO[a]	NO_x[b]	Dust[a]
Atmospheric releases	79%	1.5%	19.5%	28 mg/Nm^3	36 mg/Nm^3	$<10^{-4}$ mg/Nm^3
Admissible limits	—	—	—	100 mg/Nm^3	1300 mg/Nm^3	200 mg/Nm^3

a. Values with respect to 11% O_2.

b. Values with respect to 6% O_2.

EXTRAPOLATION TO AN INDUSTRIAL INSTALLATION

The construction of a working incinerator at Marcoule could now be launched for processing the G2 and G3 reactor blocks. This operational facility would have an incineration capacity of 150 kg/h, or about 750 to 1000 tonnes per year of graphite.

For processing the graphite sleeves, the method would be as follows:

- Removing the sleeves from the storage bins
- Crushing the sleeves and extracting the stainless steel saddle wires
- Compacting the saddle wires and their immobilization in a protective matrix
- Incinerating the crushed graphite
- Packing the ashes and residues for storage.

Dimensioning Aspect

The objective for the incineration capacity of an industrial-scale facility is 150 kg/h. The extrapolation is based on:

- Conservation of the fluidization parameters.

  The granulometry of the fluidization support and the speed of the fluidization would be conserved to obtain the same hydrodynamic conditions as for the pilot facility.

  The mass of the support would be adapted to the incinerator volume.

- Conservation of the control parameters (temperature and pressure).

Safety Aspect

A preliminary list of the envisageable incidents, possible consequences, and the procedures to follow has been drawn up.

The double confinement would be ensured by

- The negative pressurization of the process equipment
- The negative pressurization of the rooms in which the equipment is installed.

The ash would be collected by an automated system, without any need for operator action. Biological protection would be installed in positions where the dose rate would be high (filters, crushing machine, etc.).

Maintenance Aspects

Except for the crushers, the moving process equipment (ventilators, separators, etc.) would be located outside of the zones contaminated by the radioactive fluids or products and would require only conventional maintenance.

The refractory linings of the equipment (high-alumina concrete) would be subjected to quarterly inspections during which maintenance operations would be scheduled for the internal accessories of the incinerator subject to wear (metal accessories):

- Cyclone internal shell ring
- Fuel-injection pipe
- Instrumentation probes (thermocouple, pressure sensor).

The over-dimensioned crushers would be capable of processing 10,000 tonnes of graphite without maintenance.

The filter cartridges would be changed every six months.

IMPACT ASSESSMENT

An impact assessment was performed with the help of the French Institute for Protection and Nuclear Safety.

Source Term

This chapter presents a calculation of the radiological consequences due to the atmospheric release of gases and aerosols during the incineration of the graphite blocks of the CEA's G2 and G3 gas-cooled reactors and the sleeves of EDF's GCRs.

Based on the spectra supplied by the CEA and EDF, the activities of the radionuclides susceptible of being released into the atmosphere during the incineration were established and are presented in Table 1. The activities are calculated at the dates indicated. Radionuclides whose behavior in the incinerator is poorly known are taken into account. The alpha emitters are taken into account, but present no interest. The incineration of the graphite from the CEA could be done starting in 1993 and that of the graphite from EDF starting in 1996.

The analysis has been established for an operating year during which 800 tonnes of graphite are incinerated, at a rate of 150 kg/h.

Impact on the Environment

The atmospheric concentration at ground level resulting from releases at stack level depends on the atmospheric transfer phenomena. The atmospheric transfer coefficient (ATC) depends on the stack height, the wind speed, the diffusion conditions, and the distance from the point of release.

At present, there is an existing stack on the building in which the incineration facility could be built. The height of the stack is 60 meters, the building itself having a height of 55 meters. This building thus causes strong disturbance of the smoke plume over short distances. It is habitual, under such conditions, to consider that the effective height of emission of the smoke is on the order of only one-half or one-third of the real

Table 1. G2-G3—Graphite blocks and graphite sleeves activity.

Radionuclide	Half life (year)	G2 specific activity (Bq/g)	G2 activity per year (Bq)	G3 specific activity (Bq/g)	G3 activity per year (Bq)	EDF Specific activity (Bq/g)	EDF Activity per year (Bq)
H3	$1.2\ 10^{1}$	$2.9\ 10^{5}$	$2.3\ 10^{14}$	$3.5\ 10^{5}$	$2.8\ 10^{14}$	$1.6\ 10^{5}$	$1.2\ 10^{14}$
C 14	$5.7\ 10^{3}$	$2.0\ 10^{4}$	$1.6\ 10^{13}$	$2.4\ 10^{4}$	$1.9\ 10^{13}$	$6.7\ 10^{4}$	$5.3\ 101^{3}$
Cl 36	$3.0\ 10^{5}$	$1.1\ 10^{3}$	$9.1\ 10^{11}$	$14\ 10^{3}$	$1.1\ 10^{12}$	$2.0\ 10^{3}$	$1.6\ 101^{2}$
Mn 54	$8.5\ 10^{-1}$	—	—	—	—	$2.2\ 10^{0}$	$1.8\ 10^{9}$
Co 60	$5.3\ 10^{0}$	$3.7\ 10^{3}$	$3.0\ 10^{12}$	7.4 104	$6.0\ 10^{12}$	$6.7\ 10^{4}$	$5.3\ 10^{13}$
Ni 63	$1.0\ 10^{2}$	$3.5\ 10^{3}$	$2.8\ 10^{12}$	$4.2\ 10^{3}$	$3.3\ 10^{12}$	$2.8\ 10^{4}$	$2.2\ 10^{13}$
Zn 65	$6.7\ 10^{1}$	—	—	—	—	$8.6\ 10^{0}$	$6.9\ 10^{9}$
Ru 106	$1.0\ 10^{0}$	—	—	—	—	$1.9\ 10^{1}$	$1.5\ 10^{10}$
Cs 134	$2.0\ 10^{0}$	—	—	—	—	$9.9\ 10^{2}$	$7.9\ 10^{11}$
Cs 137	$3.0\ 10^{1}$	$5.9\ 10^{1}$	$4.7\ 10^{10}$	$7.1\ 10^{1}$	$5.7\ 10^{10}$	$3.0\ 10^{2}$	$2.4\ 10^{11}$
Ba 133	$1.0\ 10^{1}$	$6.4\ 10^{1}$	$5.1\ 10^{10}$	$1.2\ 10^{2}$	$6.2\ 10^{10}$	$1.7\ 10^{2}$	$1.3\ 10^{11}$
Ce 144	$7.78\ 10^{-1}$	—	—	—	—	$1.2\ 10^{1}$	$9.8\ 10^{9}$
Eu 154	$8.6\ 10^{0}$	$3.7\ 10^{2}$	$2.7\ 10^{10}$	$4.0\ 10^{2}$	$3.2\ 10^{11}$	$6.5\ 10^{2}$	$5.2\ 10^{11}$
Eu 155	$5.0\ 10^{0}$	$1.1\ 10^{1}$	$8.6\ 10^{9}$	$1.3\ 10^{2}$	$1.0\ 10^{11}$	$4.0\ 10^{2}$	$3.2\ 10^{11}$

height. For the assessment, the most unfavorable situation is taken into account (i.e., a height of 20 meters). Calculations are also made for a 100-meter stack, which would greatly exceed the building height.

The calculations of radiological consequences are performed first for a member of the general public living near the site. For this case, the different villages located near the site have been compared and the calculation performed for the most unfavorable situation, 1500 meters from the site, downwind in the dominant wind direction. The second set of calculations are made for a person working on the site, who is outdoors on the site 1,800 hours per year.

In the case of aerosols, account is taken of the efficiency of the filters, evaluated at 10^{4}. For the sake of prudence, a factor of 10^{3} is used for ruthenium and cesium, which, being volatile, may not be totally recondensed during their passage through the filters.

In the case of gases (H3-carbone, chlorine) the filters are considered not efficient.

The behavior of the radionuclides varies in the environment as a function of the elements. For those calculations due to carbon and tritium, account must be taken of the natural presence of their stable isotopes in the atmosphere. It should be noted that the quantity of carbon 12 added by the graphite incineration is negligible with respect to the normal carbon content of air.

In the case of tritium, it is assumed that all of the tritium is emitted in the form of tritiated water vapor. It is also assumed that the radioactivity of water in nearby plants is equal to the average radioactivity of the water vapor.

In the case of chlorine and aerosols, the releases lead to a deposit on vegetables and on the soil. The deposit is evaluated on the basis of the concentration in the air and the speed of the deposit. The deposit on plants is subject to biological and physical elimination modeled by an exponential decrease.

Exposure Paths

The members of the general public are exposed by inhalation in the plume, external irradiation by the ground deposits and the plume, and by eating exposed vegetables. In the cases of inhalation and external irradiation, the exposure rate is reduced by a factor of 2 when the individual is inside a building.

The on-site worker is exposed to the plume only by inhalation and by external irradiation due to the ground deposits. External irradiation by the plume is negligible.

The release of tritium leads to exposure by contamination due to immersion in the plume, by absorption of the contaminated water vapor through the skin. The dose due to such exposure is estimated in a first approximation to be equal to the dose received by inhalation.

Results

The Individual Radiological Evaluation for Scenarios in the Company and in the Environment (CERISE) computer program was used. It enables calculating the dose equivalent for the different exposure paths.

For incineration of the graphite from the G3 reactor, the results are presented in Table 2 for the different gases and aerosols, as a function of the exposure path, for the two scenarios—workers on the site and members of the general public—and for the two stack heights considered.

It can be seen that half the dose rate on the site is given by tritium and chlorine, carbon and aerosols contributing only a negligible part. A member of the general public will receive a higher dose than will the onsite worker, the latter being mainly due to the ingestion of carbon. Tritium and chlorine contribute about 4% each and the aerosols are responsible for only a negligible dose.

The maximum effective dose is 0,5 mSv/yr and 0,04 mSv/yr respectively for stack heights of 60 and 100 meters, for a member of the general public.

Following the publication of new recommendations by the CIPR,[a] the regulations will soon be modified and the maximum admissible effective dose will become 1 mSv/yr.

Under these conditions, the releases from the present 60 meter high stack do not seem to be acceptable. On the other hand, the doses corresponding to releases from a 100 meter high stack due to incineration of the graphite from the G2 reactor, the G3 reactor, and EDF GCRs would then represent respectively 3%, 4%, and 10% of this limit.

In conclusion, from the health physics standpoint, on the basis of the source term considered, such graphite incineration is feasible, provided that a 100 meter high stack is built and that the quantities incinerated annually are perhaps somewhat reduced.

CONCLUSION

The analyses and tests presented herein show that it is feasible to incinerate contaminated graphite wastes in a safe manner.

---

a. International Radiological Protection Commission, "Commission Recommendations," CIPR No. 60, Vol. 21, no. 1-3, Pergammon Press, 1991.

Table 2. Annual equivalent dose rate (SV/y) resulting from G3 graphite blocks, with a 60 m high and a 100 m high stack.

		Stack height 60 M		Stack height 100 M	
Nuclide	Type of exposure	Scénario site	Scénario public	Scénario site	Scénario public
H3	Inhalation	$8.5\ 10^{-6}$	$6.0\ 10^{-6}$	$5.9\ 10^{-7}$	$4.8\ 10^{-7}$
	Immersion	$8.5\ 10^{-6}$	$6.0\ 10^{-6}$	$5.9\ 10^{-7}$	$4.8\ 10^{-7}$
	Ingestion	—	$5.8\ 10^{-6}$	—	$4.6\ 10^{-7}$
	Total	$1.7\ 10^{-5}$	$1.8\ 10^{-5}$	$1.2\ 10^{-6}$	$1.4\ 10^{-6}$
C14	Inhalation	$2.0\ 10^{-7}$	$1.4\ 10^{-7}$	$1.36\ 10^{-8}$	$1.1\ 10^{-8}$
	Ingestion	—	$4.6\ 10^{-4}$	—	$3.6\ 10^{-5}$
	Total	$2.0\ 10^{-7}$	$4.6\ 10^{-4}$	$1.36\ 10^{-8}$	$3.6\ 10^{-5}$
C136	Inhalation	$1.1\ 10^{-5}$	$8.0\ 10^{-6}$	$7.9\ 10^{-7}$	$6.3\ 10^{-7}$
	Extern. Exp.	$5.8\ 10^{-6}$	$4.8\ 10^{-6}$	$4.1\ 10^{-7}$	$3.8\ 10^{-7}$
	Ingestion	—	$6.9\ 10^{-6}$	—	$5.4\ 10^{-7}$
	Total	$1.7\ 10^{-5}$	$2.0\ 10^{-5}$	$1.2\ 10^{-6}$	$1.55\ 10^{-6}$
Aerosols	Inhalation	$5.1\ 10^{-8}$	$3.64\ 10^{-8}$	$3.6\ 10^{-9}$	$2.9\ 10^{-9}$
	Extern. Exp.	$9.35\ 10^{-7}$	$4.6\ 10^{-7}$	$6.5\ 10^{-8}$	$3.64\ 10^{-8}$
	Ingestion	—	$6.8\ 10^{-8}$	—	$5.3\ 10^{-9}$
	Total	$9.9\ 10^{-7}$	$5.7\ 10^{-7}$	$6.9\ 10^{-8}$	$4.5\ 10^{-8}$
Total		$3.5\ 10^{-5}$	$5.0\ 10^{-4}$	$2.5\ 10^{-6}$	$3.9\ 10^{-5}$

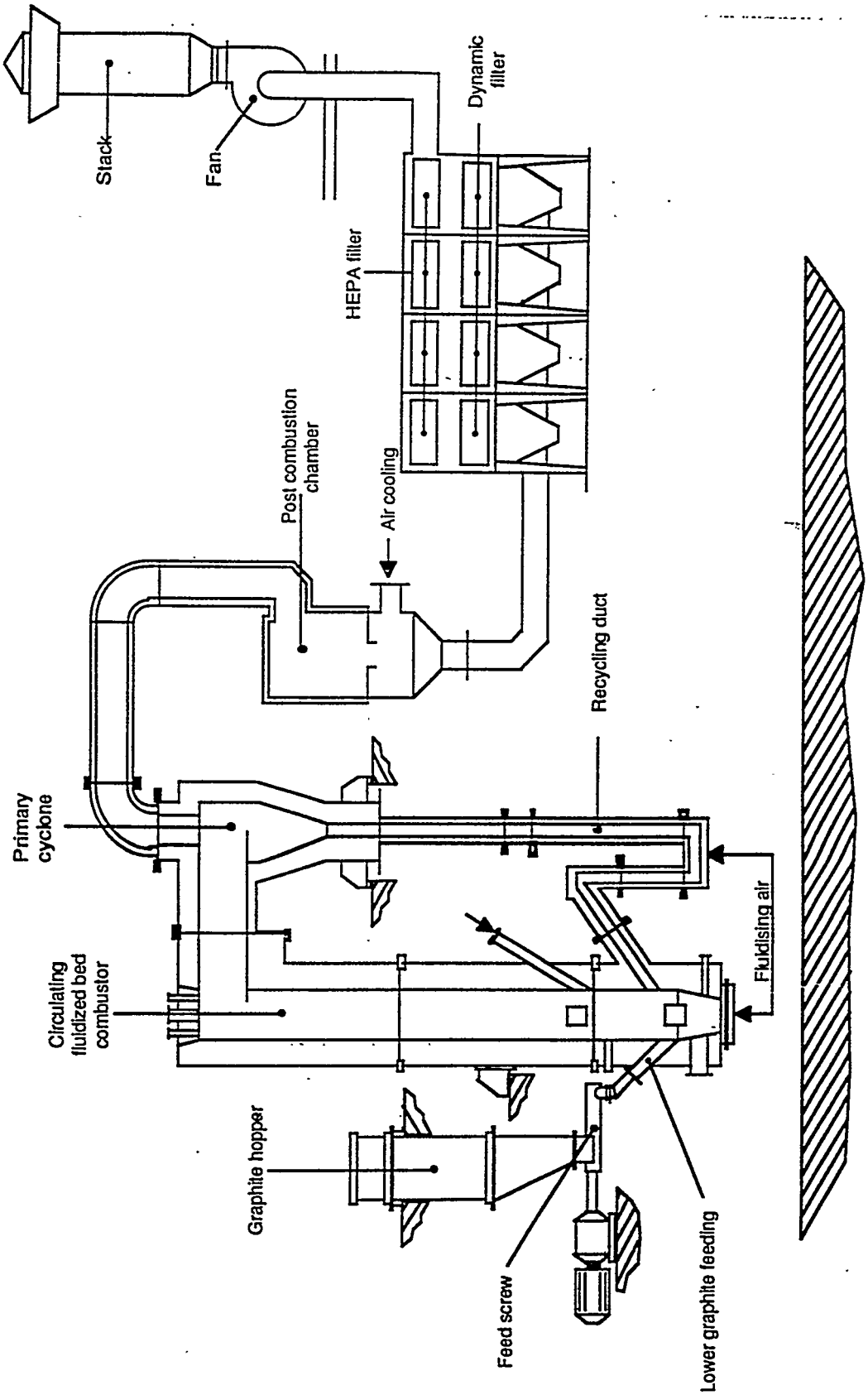


Figure 1. Framatome CFB pilot plant facility.

Preliminary Design of a Biological Treatment Facility for Trench Water from a Low-Level Radioactive Waste Disposal Area at West Valley, New York

R. Rosten, D. Malkmus
Pacific Nuclear, Inc.

T. Sonntag
New York State Energy
Research & Development Authority

J. Sundquist
Ecology and Environment, Inc.

INTRODUCTION

The New York State Energy Research and Development Authority (NYSERDA) owns and manages a State-Licensed Low-Level Radioactive Waste Disposal Area (SDA) at West Valley, New York. Water has migrated into the burial trenches at the SDA and collected there, becoming contaminated with radionuclides and organic compounds. The U.S. Environmental Protection Agency issued an order to NYSERDA to reduce the levels of water in the trenches. A treatability study of the contaminated trench water (leachate) was performed and determined the best available technology to treat the leachate and discharge the effluent. This paper describes the preliminary design of the treatment facility that incorporates the bases developed in the leachate treatability study.

HISTORY AND BACKGROUND

The SDA is located in the NYSERDA maintained portions of the Western New York Nuclear Service Center (WNYNSC) which occupies 3,345 acres of land approximately 30 miles south of Buffalo, New York. NYSERDA holds title to the WNYNSC on behalf of the people of the State of New York. Under the West Valley Demonstration Project Act of 1980, the United States Department of Energy (DOE) has exclusive use and possession of approximately 200 acres of the WNYNSC for the performance of the West Valley Demonstration Project (WVDP) which is operated by the West Valley Nuclear Services Company (WVNS). The remainder of the WNYNSC is maintained by NYSERDA.

The SDA consists of two sets of parallel trenches occupying approximately 15 acres of WNYNSC property (Figure 1). The SDA was constructed and operated by Nuclear Fuel Services Company, Inc. (NFS) as a commercial low-level radioactive waste (LLW) disposal facility from 1963 to March 1975, when waste disposal operations were terminated. NFS monitored and maintained the SDA until March 1983, when management responsibility was transferred to NYSERDA.

During its operational life, the SDA received approximately 2.4 million cubic feet of LLW initially containing from 700,000 to 1.25 million curies. The waste was received from various sources, including institutions, industries, governmental facilities, nuclear power plants, waste brokers, and decontamination facilities. The physical forms of the waste were extremely diverse. Most of the waste was disposed of in the original shipping containers, including 5-, 30-, and 55-gallon steel drums, wooden crates, cardboard boxes, cartons, fiber drums, and plastic bags.

Packaged waste was placed in long trenches excavated in the highly impermeable, silty till soil native to the site, and covered with 1.2 to 2.4 meters of excavated soil. Due to the character of the soil and the wet climate, water management problems were experienced from the very early years of operation. Despite efforts to address the problem, water accumulated in open, uncompleted trenches, as well as in covered, completed trenches. Trench 14 has historically exhibited the most significant increases in water levels.

Water has collected in Trench 14 due to the lateral migration of ground water and the percolation of precipitation through the trench cap. As the water contacts and percolates through the disposed trench wastes, it becomes contaminated with radionuclides and organic compounds. The resulting leachate, with its radiological and hazardous constituents, will be the subject of the treatment system described in this report.

EXISTING FACILITIES

NYSERDA has installed emergency pumping and storage capabilities for storing trench leachate immediately adjacent to Trench 14 between the trench and the access road (west side). The storage capacity consists of the 9,200 gallon collection tank and two 21,000 gallon stainless steel tanks.

The collection tank is housed in a weatherproof, heated building with the lower portion built of concrete to form a waterproof enclosure. In addition to the tank, a pumping system has been installed to pull leachate from the trench to the 9,200 gallon collection tank.

A ventilation system has been provided with the pump skid to ensure safe venting of the tank during fill operations. The ventilation system consists of a charcoal filter to remove organic pollutants and a HEPA filter to remove particulate matter. A tritium monitoring system measures the amount released during operation of the pump skid, as well as during normal tank venting operation.

The two storage tanks are installed in a steel walled synthetic berm. A non-heated, weatherproof building protects these tanks from the environment. Both tanks have immersion heaters installed for freeze protection. Each tank is connected to the pump skid and ventilation system in the collection tank building. Local high level and remote high-high level alarms are designed into the system.

TREATABILITY STUDY RESULTS

The preliminary design presented in this paper is based on literature review, accepted engineering practices, and the treatability studies conducted by Ecology and Environment, Inc. (E&E) in 1990 and 1991-1992. The initial treatability study, reported in "Treatability Testing of Trench 14 Leachate, West Valley State-Licensed Low-Level Radioactive Waste Disposal Area" (E&E 1991) was limited to the treatment technologies of carbon adsorption and ion exchange. The initial study, conducted in a trailer-based field laboratory at the SDA, showed that while carbon was effective in removing target indicator volatile organic compounds (VOCs), it was not effective in reducing the five-day biochemical oxygen demand (BOD_5) without consequent generation of unacceptably large quantities of spent carbon residue. Ion exchange was found to be effective in reducing cesium-137 (Cs-137) concentrations.

Based on the results of the initial treatability study, NYSERDA elected to perform more extensive bench-scale treatability studies to examine a greater range of treatment technologies—specifically, biological treatment, UV oxidation, and evaporation/distillation, as well as additional studies of carbon adsorption and ion exchange. One of the goals of the additional treatability studies was to identify and develop treatment technologies that, unlike direct carbon treatment, minimized the amount of waste generated. Waste minimization is an important goal, considering that all wastes generated by this process will likely be regarded as mixed wastes, for which disposal options are limited. Thus, technologies that destroy the hazardous component of the waste—such as biological treatment and UV oxidation—were pursued. The goal of waste minimization has been further pursued throughout the preliminary design of the selected treatment process.

The second treatability study demonstrated that biological treatment, followed by filtration, carbon polishing, and ion exchange is capable of treating the Trench 14 leachate.

The preliminary design is also based on the flow rate constraints resulting from the presence of tritium in the effluent. Due to the dilution required for discharge, an estimated 23,000 to 350,000 gallons of treated leachate can be discharged per year. To handle this range of annual leachate volumes, the daily batch treatment size basis has been set at 2,000 gallons. Operating at five batches per week, 2-1/2 weeks of operation

would be required to treat 23,000 gallons of leachate; and up to 35 weeks would be required to treat 350,000 gallons of leachate.

The system has also been designed to be flexible. Batch system biotreatment, rather than continuous treatment provides flexibility in operational schedule, mainly by varying the aeration duration. Lower throughputs can be achieved by increasing aeration duration to two days or more. Higher throughputs can be achieved by either increasing the amount of leachate charged to the bioreactor (this is allowed due to bioreactor oversizing) or, if operational experience allows, by decreasing the aeration time—possibly doing two batches per day. Operational flexibility is also enhanced by the fixed-bed processes of the downstream physical treatment train. The rate of flow through the fixed beds can be changed, up to a point, without affecting their performance. The treatment train is sized to handle over three times the design basis throughput of 2,000 gallons per day.

PRELIMINARY DESIGN OF TREATMENT SYSTEM

General Process Description

Using the existing system, leachate is pumped from the sump in Trench 14 through a filter and then to the 9,200 gallon collection tank. The leachate is pumped to the bioreactor tank in the adjacent biotreatment facility.

The bioreactor system receives the leachate in a 6,000 gallon bioreactor tank where the liquid is batch-processed to remove organic contaminants. The process uses mixing and aeration, which enhances the development of a microbial biomass to biologically destroy organics. This mixing process is followed by a settling time. The entire process can be completed in a one day time frame.

The bioreactor supernatant is pumped to a 10,000 gallon holding tank in the physical treatment system. This tank operates as an interface surge tank that links the biotreatment system with the continuous physical treatment system. Continuous operation of the carbon and zeolite beds of this system maximizes the life of these media and minimizes the amount of waste by-products produced. Particulates in the supernatant process stream are then treated through activated carbon columns. The final treatment pass is through zeolite ion exchange units where radionuclides (Sr-90 & Cs-137) are removed. The clean water is pumped to storage tanks for subsequent discharge to the permitted outfall.

Gases and vapors produced during system processes are exhausted through an air dryer, HEPA filter, and activated carbon chamber within the off-gas system. This discharge is continuously monitored to detect any potential breakthrough.

The sludge produced in the bioreactor is pumped to a 2,000 gallon aerobic digestion and holding tank in the waste sludge system from where it is subsequently dewatered and packaged. The packaged waste is stored within the facility for further disposition.

Process control of the system will be provided by a combination of online monitors and analysis of grab samples. Online monitoring will be limited to pH and dissolved oxygen measurement of the bioreactor and the aerobic digester/sludge holding tank. The analysis of process samples will be conducted in an onsite laboratory, by the WVNS analytical laboratory, and, to a lesser extent, outside analytical laboratories.

For the preliminary design, including provisional laboratory requirement, the analyses to be conducted onsite have been selected. The parameters to be analyzed onsite are:

- 5-day biochemical oxygen demand
- VOCs by gas chromatography
- Total and volatile suspended solids

- Total phenols
- Total organic carbon.

In addition, the laboratory will be designed to allow the execution of limited bench scale tests should they be necessary during the pilot phase of operation. The only potential tests that may be considered at this time include column testing of ion exchange to identify ways to further minimize the zeolite consumption rate, sludge flocculation and settling tests, and possibly limited biomass development activities. The need for these tests will be evaluated and defined during the planning of pilot phase activities during the final design stages.

Bioreactor Phase

The bioreactor will be a completely enclosed aerobic batch suspended-growth system. The bioreactor is a 6,000 gallon vessel equipped with ports for acid, base, nutrient, polymer or other chemicals, and leachate addition (see Figure 3). The bioreactor will receive leachate from the 9,200 gallon leachate storage tank through the leachate transfer pump. The leachate storage tank will normally be kept full utilizing the existing Trench 14 sump pump. This action will keep the leachate temperature essentially constant at the leachate storage building temperature. Process flow to the bioreactor will go through a flow totalizer, which monitors the leachate volume removed from Trench 14. Since a portion of the leachate transfer piping will be located outdoors, process line heat tracing and spill/pipe break containment will be provided. The contents of the bioreactor will be agitated/mixed during leachate addition, but not aerated. Aeration will commence once the full charge of leachate has been added to the bioreactor. Dissolved oxygen and pH are monitored, but not controlled, in the bioreactor. Acid or base addition will be performed on a batch-specific basis if the pH exceeds the preferred range of 6 to 9. The dissolved oxygen level will be monitored and used to set the bleed rate. If high levels of dissolved oxygen (i.e., greater than 6 mg/L) are recorded, the bleed and make-up air flow rates will be reduced. Bioreactor exhaust air will be recycled to minimize the amount of tritiated-water-laden gas sent to the off-gas treatment system. After sixteen to twenty hours of aeration, agitation will stop and the mixed liquid allowed to settle. After settling, supernatant will be decanted through multiple ports located at varying elevations or through a floating decanter mechanism.

Sludge settled at the end of each batch run will be retained in the bioreactor for the next batch. Should sludge levels increase and necessitate sludge wasting, sludge will be transferred to an aerobic digester/holding tank. Based on the Treatability Study results, it is estimated that 1,250 gallons of sludge will be produced per 60,000 gallons of leachate processed. This tank will aerobically digest the biological solids to minimize the amount of sludge to be further processed. The tank would also act as a biomass source for re-inoculation of the bioreactor in case of loss of viability of the bioreactor biomass.

Physical Treatment Phase

The primary source of fluid in the physical treatment process is from the bioreactor (see Figure 4). At the completion of each bioreactor batch cycle, the tank suction is provided via a multipoint decant manifold. Tank discharge is supplied to the decant hold tank. Supernatant is withdrawn from successively lower decant ports (or, depending on the bioreactor selected, a floating decanter) until the sludge level is reached. The point at which sludge has been reached will be determined visually through a sight glass in the decant line.

The physical treatment feed pump provides sufficient head to process the water from the decant hold tank through the treatment train to the treated water storage tanks. A manual flow control valve is used to establish flow as required for the configuration in use. The physical treatment train is a three stage arrangement, normally aligned for series flow. Each vessel is fitted with drain, test/flush, isolation and bypass valves.

The first physical treatment stage consists of two back-washable filter vessels capable of providing mechanical filtration to remove suspended solids. Valves for the filters are capable of remote operation and will provide automatic backwash capability when high differential pressure across the filter(s) is encountered. The backwash line is routed to the physical treatment drains tank. This tank is also utilized to drain the

treatment system vessels (filter, carbon beds and ion exchangers) when required for maintenance. The contents of the drains tank can be transferred to the bioreactor by manual operation of the drains transfer pump.

Downstream of the filters are two activated carbon polishing beds that remove any remaining organic contaminants. These units provide the treatment system with the capability to compensate for bioreactor upsets and the availability to remove non-biodegradable contaminants, regulated under State Pollutant Discharge Elimination System (SPDES) permit, should they be present in the bioreactor effluent. The carbon beds will remove organics that are normally destroyed in the bioreactor to less than the discharge permit concentrations, if for some reason (i.e., process upset) the organics escape destruction in the bioreactor. Based on the Treatability Study results it is expected that a minimal amount of carbon will be utilized to treat the leachate and therefore the vessel size was determined based on required residence time for the particular process flow rate. The carbon beds will be operated in a series flow configuration with the first vessel as the primary polisher and the second acting as a backup in case of breakthrough.

When carbon bed breakthrough occurs, the valves will be realigned to establish flow to the backup vessel. This vessel will now act as the primary bed. The carbon in the original primary polisher will be sluiced out and replaced with fresh carbon. This column would then be returned to service, acting as the backup column. This arrangement will allow operation and maintenance flexibility during upset conditions.

The final stage of the treatment train consists of two ion exchange columns which contain zeolite medias. These units are designed to remove the radionuclides Sr-90 and Cs-137. The ion exchange unit valves will be capable of remote operation. Remove valve operation will be used during sluicing operations and when vessels need to be switched in and out of service. The ion exchange vessels will be operated in series. When breakthrough of the first vessel occurs, the second vessel will be aligned to remove the radionuclides, with spent vessel sluiced, refilled with fresh zeolites, and returned to service as the second vessel. Based on the Treatability Study results, it has been estimated that 78.5 pounds of zeolites will be used to treat 2,000 gallons of leachate.

Both the carbon and ion exchange columns are designed for sluicing the media to the spent media tanks. The sluicing operation is conducted using the backwash/sluice pump with fully treated water as the process fluid. The spent media storage tanks are sized to accommodate multiple vessel sluicings. The storage tanks are commercially available radwaste liners typically used in the nuclear power industry for storage, dewatering, and transportation of ion exchanger medias. After the contents of the ion exchange vessels and carbon beds are sluiced to the spent media tanks, the tank will be dewatered utilizing a vacuum dewatering pump then discharged to the decant hold tank.

The treated water flows through a flow measuring device into the two 20,000 gallon treated water storage tanks. A discharge pump will process the treated effluent to an approved outfall. The piping will also be designed with a discharge path local to the treated water storage tanks, in case transport by tank truck is required.

Off-Gas Treatment Phase

During operation approximately 16 cfm of bioreactor sparging air will be exhausted through the offgas system (see Figure 5). The system is designed to handle up to 30 cfm offgas to account for possible increased treatment rates and vapors from process vents. This sparging air will be drawn through a flow control valve downstream of the bioreactor vent moisture separator where it will be mixed with air vented from various contaminated tanks. The volume of bioreactor offgas will decrease over the course of the daily biotreatment cycle, as less substrate remains for consumption.

The offgas will pass through an air treatment train consisting of a dryer, HEPA filter, and activated carbon chamber. The dryer will be a refrigerant industrial gas dryer. This unit will condense half the vapor contained in the offgas, reduce the tritium content and return the condensate to the physical treatment system for further processing. The dry offgas will be directed into HEPA filter. Particulate carryover from the offgas will be removed. This particulate will remain in the filter until periodic filter replacement. The offgas will then

proceed through the activated carbon chamber where volatile organics will be removed. The activated carbon beds will also require periodic replacement. Based on the Treatability Study results, it has been estimated that 3.3 pounds of carbon will be consumed per 2,000 gallons of treated leachate.

At this point, the offgas will be drawn through the offgas fan and mixed with dilution air to further reduce the radioactive concentration of the remaining uncondensed tritiated water vapor.

An air sampling port, located downstream of the dilution air supply and inside the treatment structure, will allow analysis of the offgas to monitor releases and provide indication of offgas filtration breakthrough.

Waste Sludge System

Aeration and mixing are stopped for a period of time during the final phase of the bioreactor cycle to allow the solids to settle to the bottom of the bioreactor vessel as sludge. Since the bioreactor is designed to operate with up to 2,000 gallons of accumulated sludge, this settling action will occur for several cycles before the sludge is moved to the sludge hold tank. See Figure 6 for the waste sludge process diagrams.

The 2,000 gallon sludge hold tank will hold 1,000 gallons of sludge from the bioreactor. The sludge in the hold tank is aerated to keep the biomass viable and digested to minimize the amount of solids requiring ultimate storage/disposal. The bleed air from the sludge hold tank is routed to the bioreactor offgas system for subsequent filtration, dilution and release.

The next step in the process is drying the sludge in a volume reduction system utilizing an evaporator to dry the waste stream to a powder form.

The sludge will be introduced to the dryer through a waste supply valve. When the liquid level in the dryer reaches a predetermined level, (high level) a differential pressure switch will automatically shut the waste valve. The sludge is then heated and steam vapor is pulled from the dryer through the condenser heat exchanger. This condenser is cooled by a chilled water system. The condensate is routed to the condensate reservoir from which it can be returned to the decant hold tank. After approximately three hours the dryer will boil down to the low level. At this time, the waste supply valve will be opened and additional waste will enter the system, bringing the concentration back up to the high level. Three transfers will be performed for each batch cycle.

The dry out phase begins with the end of the third transfer—the dryness of the material is verified by monitoring several system parameters, as well as a visual observation through the site glass.

Upon verification of dryness, the agitator helix moves the material to the pneumatically operated discharge valve located at the bottom center of the dryer shell. The material is discharged into the burial container using gravity.

The packaging enclosure, which houses the burial container, is kept under a negative pressure and vented through a HEPA system. This allows the operator to open the enclosure door to cap and remove the burial container without releasing contaminated particulate. This subsystem will work as a totally contained unit.

GENERAL ARRANGEMENT

The major design considerations implemented in the facility layout are personnel radiation exposure/equipment contamination (ALARA) design features, process flow logistics, flexibility for future operation at increased process flows, and adequate space for operations and maintenance of equipment.

The general arrangement of the biotreatment equipment is shown in Figure 7. The majority of the biotreatment system equipment will be housed in the new 1875 square foot facility. This building will be located south of the existing leachate storage building. The building will be constructed of a steel frame with

insulated sheet metal siding and built on a reinforced concrete slab. The exterior walls will enclose the spent media tanks and ion exchange units will be made of reinforced concrete to provide radiation shielding.

The equipment layout has been arranged to provide a waste processing flow path from the north side of the south side of the building. The bioreactor will be located in the northeast corner of the building. The auxiliary equipment required to support the bioreactor operation will be located adjacent to the bioreactor tank. This arrangement will minimize piping around the bioreactor and simplify system operation, equipment monitoring, and maintenance.

The decant hold tank will be adjacent to the bioreactor tank to minimize process piping between equipment. The decant hold tank will be located in the northwest corner of the building where it will have the least impact on floor space.

The filters and carbon beds are skid mounted and will be situated to optimize the space necessary for ease of operation and maintenance. The drains tank will receive filter backwash and will be in close proximity to the filters to minimize pipe routing. The ion exchange units are located in a separate cubicle in an effort to shield radiation and reduce exposure to personnel in the building.

The southern section of the building is arranged to house the sludge holding and dewatering/ treatment equipment. A separate cubicle will be set-up to shield the spent media tanks. Large overhead doors have been incorporated into the design and will be located in the southeast and southwest walls. These doorways will be sized to facilitate handling/removal of the spent media tanks and the sludge storage containers.

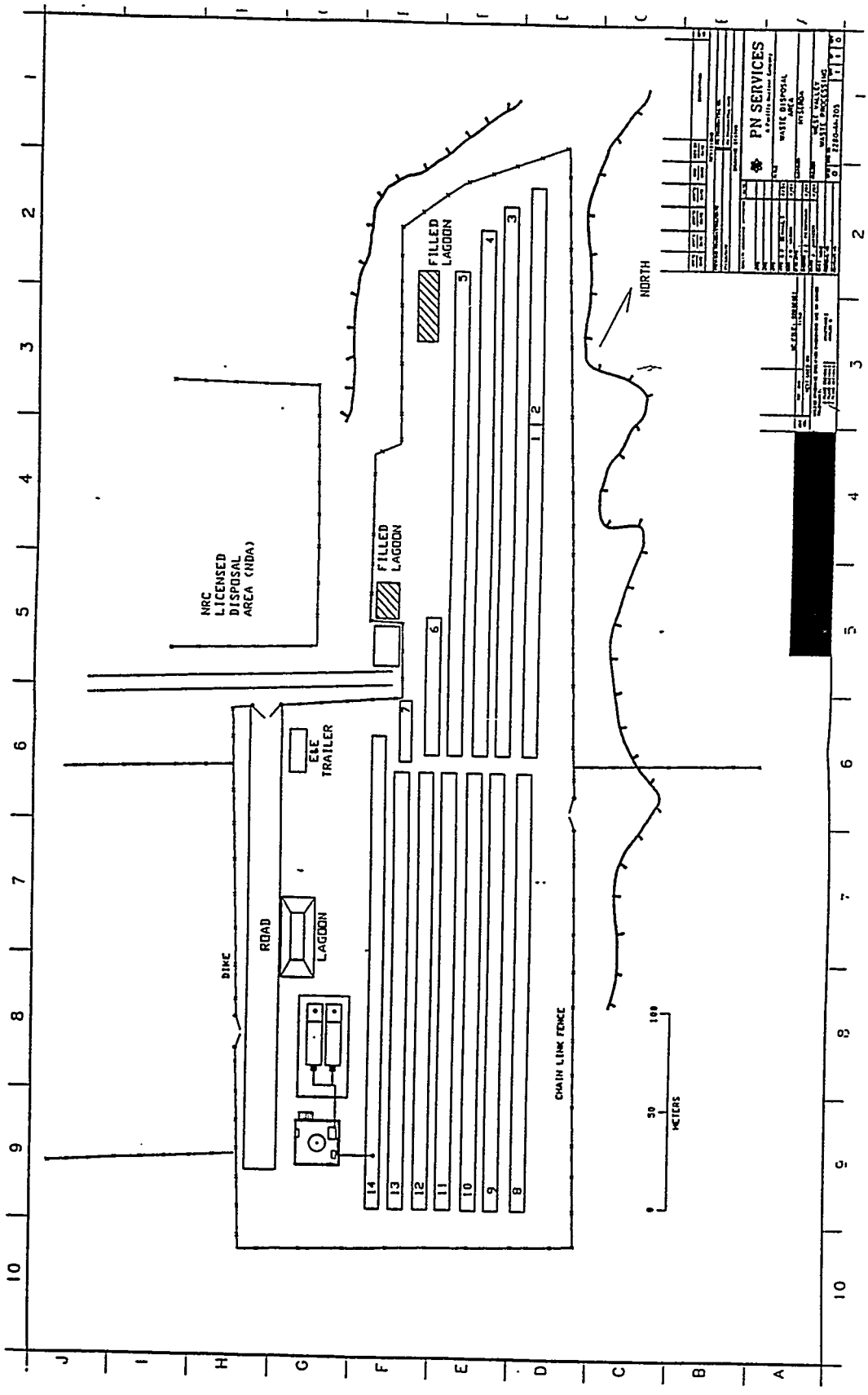
Adequate space has been provided in the floor plan for equipment laydown and maintenance. Aisle space has been provided along the west wall to facilitate equipment/spent media handling with a forklift.

The building design will also include a curbing feature which will have the capacity to contain a spill of the full contents of the largest tank in the building should catastrophic failure occur. An additional six inch free board is included in the curbing design.

The building is usually uninhabited and as such will be maintained at 60°F/90°F during winter and summer conditions. Although temperatures may vary, they will not pose an adverse effect on the treatment system process. Auxiliary heaters will be installed to provide heat during winter conditions.

CONCLUSION

The preliminary design of a mixed waste treatment system at the SDA has successfully incorporated the technologies identified in the bench-scale Treatability Study. This design provides the flexibility necessary to fully process the specified range of influent leachate flows while minimizing the resultant waste volumes. The resultant effluent water stream will meet the SPDES discharge criteria for all compounds except tritium (which will be diluted at the site outfall).


PN SERVICES
NRC LICENSED DISPOSAL AREA (NDA)
FILLED LAGOON
FILLED LAGOON
NORTH
E&E TRAILER
ROAD
DIKE
LAGOON
CHAIN LINK FENCE
50
100
METERS

"FIGURE 1"

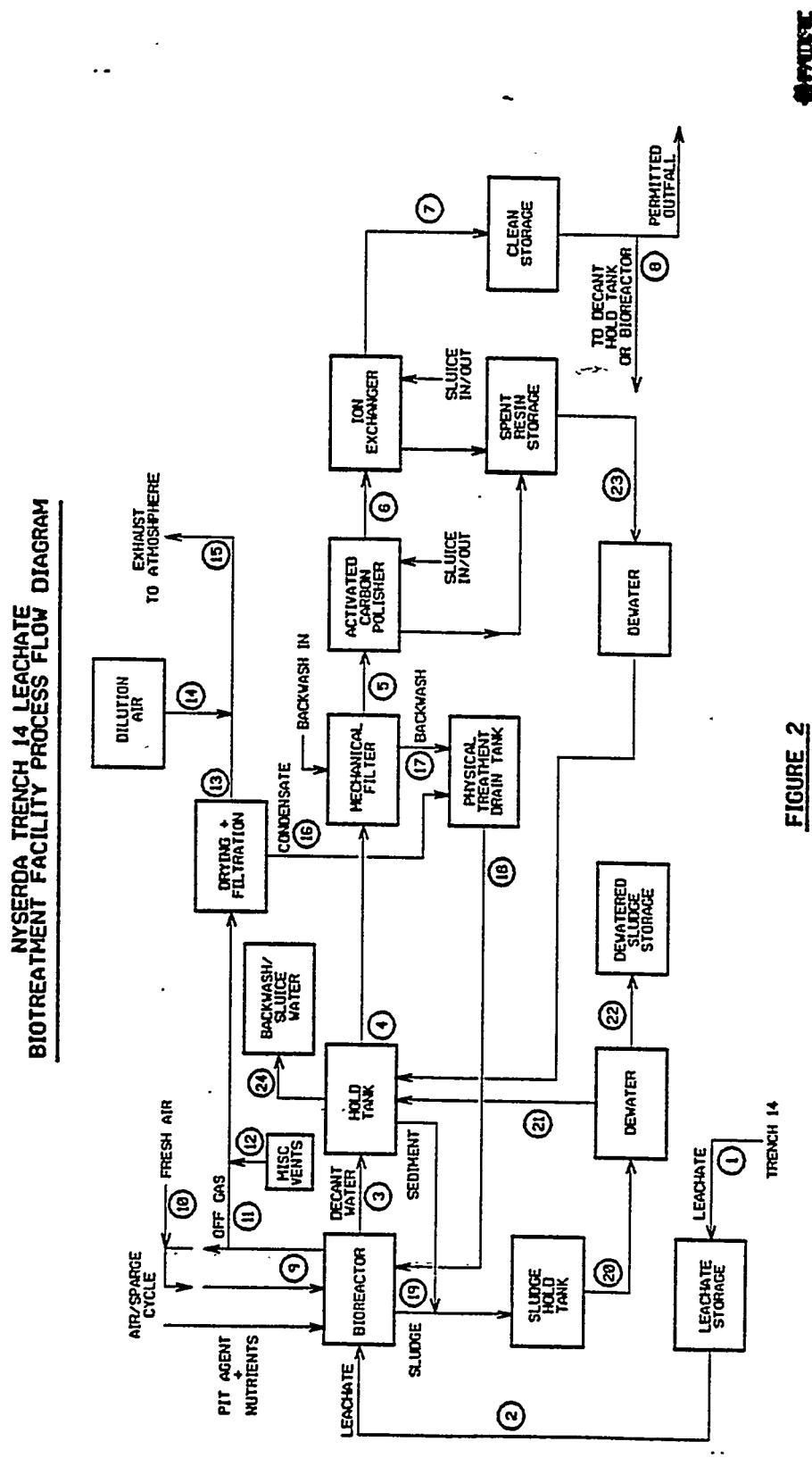

NYSERDA TRENCH 14 LEACHATE
BIOTREATMENT FACILITY PROCESS FLOW DIAGRAM
TRENCH 14
LEACHATE
LEACHATE STORAGE
BIOREACTOR
SLUDGE
SLUDGE HOLD TANK
DECANT WATER
SEDIMENT
HOLD TANK
DEWATER
DEWATERED SLUDGE STORAGE
BACKWASH/ SLUICE WATER
MISC VENTS
OFF GAS
FRESH AIR
AIR/SPARGE CYCLE
PIT AGENT + NUTRIENTS
DRYING + FILTRATION
DILUTION AIR
EXHAUST TO ATMOSPHERE
CONDENSATE
MECHANICAL FILTER
BACKWASH IN
BACKWASH
PHYSICAL TREATMENT DRAIN TANK
ACTIVATED CARBON POLISHER
SLUICE IN/OUT
ION EXCHANGER
SLUICE IN/OUT
SPENT RESIN STORAGE
DEWATER
CLEAN STORAGE
TO DECANT HOLD TANK OR BIOREACTOR
PERMITTED OUTFALL

FIGURE 2

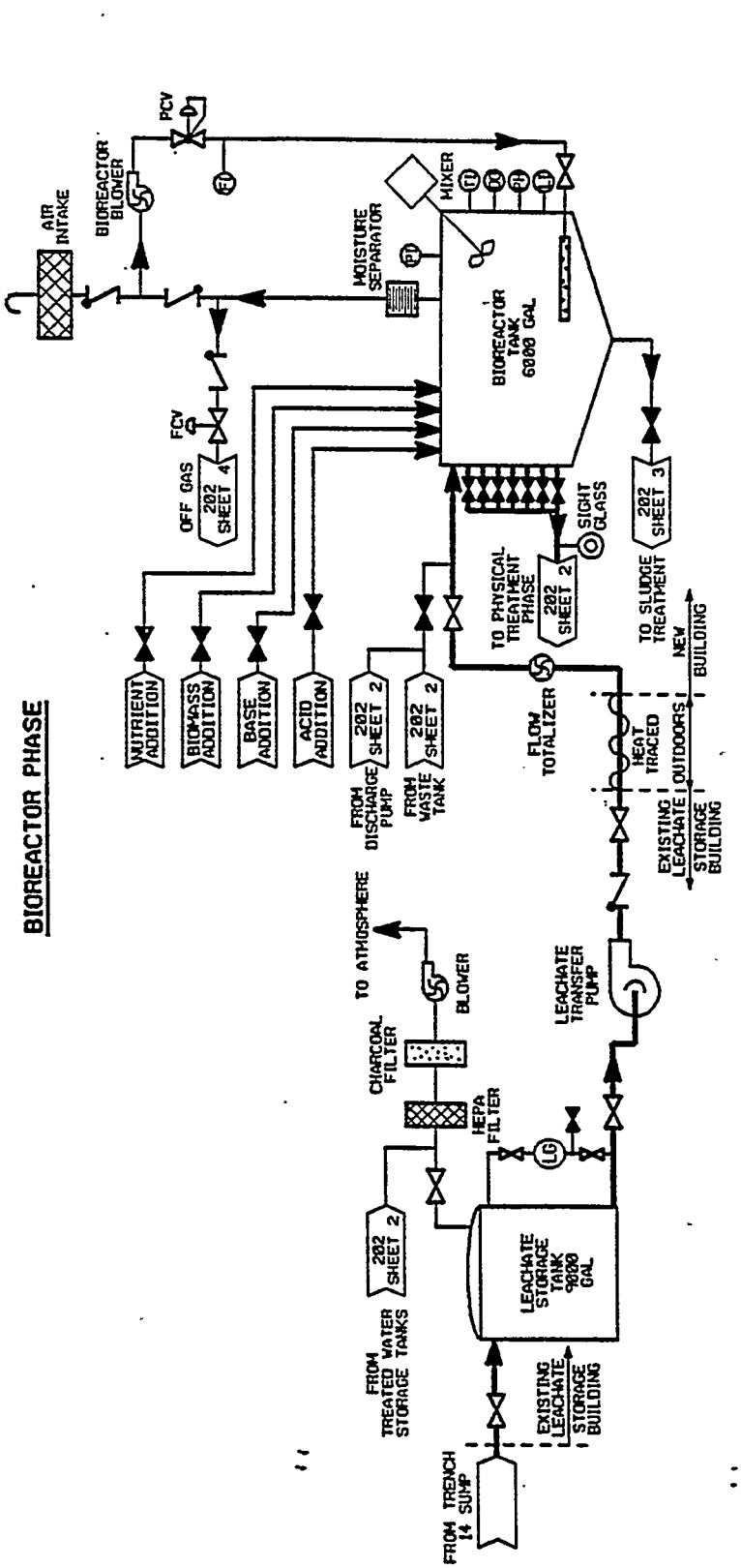

BIOREACTOR PHASE
AIR INTAKE
BIOREACTOR BLOWER
PCV
FE
MOISTURE SEPARATOR
MIXER
BIOREACTOR TANK 6000 GAL
FCV
OFF GAS
202 SHEET 4
SIGHT GLASS
202 SHEET 3
TO PHYSICAL TREATMENT PHASE
202 SHEET 2
TO SLUDGE TREATMENT
NEW BUILDING
NUTRIENT ADDITION
BIOMASS ADDITION
BASE ADDITION
ACID ADDITION
FROM DISCHARGE PUMP
FROM WASTE TANK
FLOW TOTALIZER
HEAT TRACED
EXISTING LEACHATE STORAGE BUILDING OUTDOORS
TO ATMOSPHERE
BLOWER
CHARCOAL FILTER
HEPA FILTER
LEACHATE TRANSFER PUMP
LG
LEACHATE STORAGE TANK 4000 GAL
FROM TREATED WATER STORAGE TANKS
EXISTING LEACHATE STORAGE BUILDING
FROM TRENCH 14 SUMP

FIGURE 3

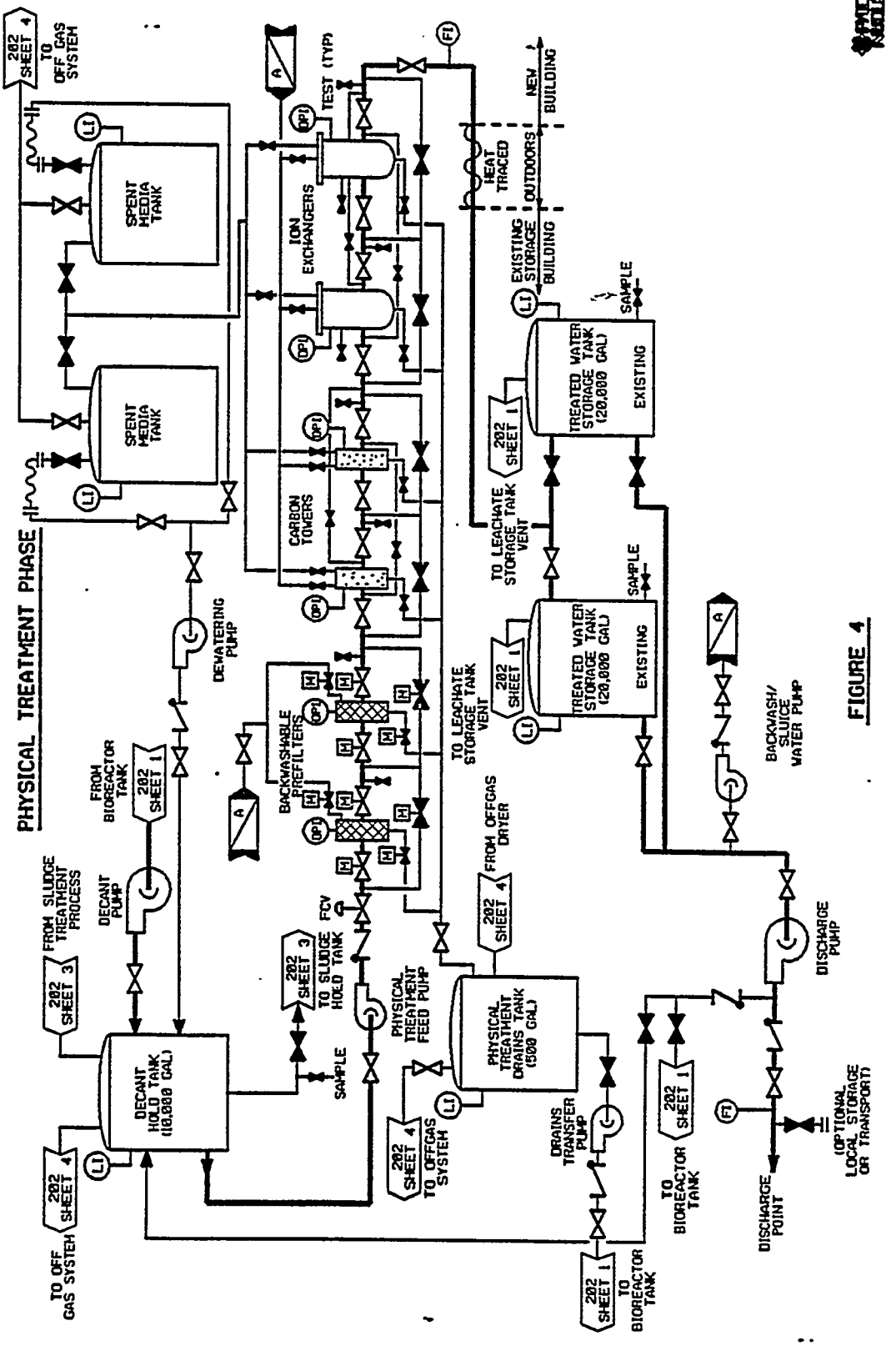

PHYSICAL TREATMENT PHASE
202 SHEET 4 TO OFF GAS SYSTEM
SPENT MEDIA TANK
SPENT MEDIA TANK
ION EXCHANGERS
CARBON TOWERS
TEST (TYP)
HEAT TRACED
OUTDOORS
NEW BUILDING
EXISTING STORAGE BUILDING
TREATED WATER STORAGE TANK (20,000 GAL)
EXISTING
SAMPLE
TO LEACHATE STORAGE TANK VENT
DEWATERING PUMP
BACKWASHABLE PREFILTERS
FROM BIOREACTOR TANK
202 SHEET 1
FROM SLUDGE TREATMENT PROCESS
DECANT PUMP
202 SHEET 3
DECANT HOLD TANK (10,000 GAL)
FCV
202 SHEET 3 TO SLUDGE HOLD TANK
SAMPLE
PHYSICAL TREATMENT FEED PUMP
202 SHEET 4 TO OFFGAS SYSTEM
FROM OFFGAS DRYER
202 SHEET 4
PHYSICAL TREATMENT DRAINS TANK (500 GAL)
DRAINS TRANSFER PUMP
202 SHEET 1 TO BIOREACTOR TANK
202 SHEET 4 TO OFF GAS SYSTEM
BACKWASH/ SLUICE WATER PUMP
DISCHARGE PUMP
TO BIOREACTOR TANK
DISCHARGE POINT
(OPTIONAL LOCAL STORAGE OR TRANSPORT)

FIGURE 4

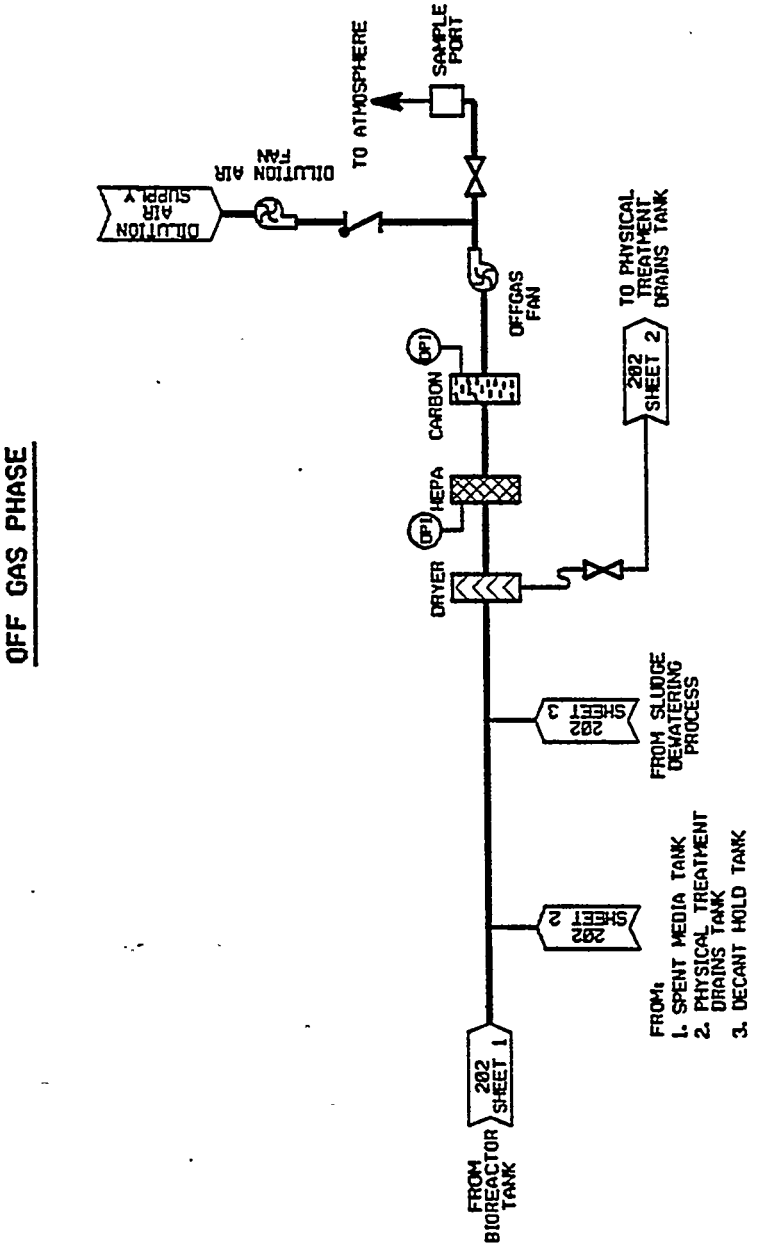

OFF GAS PHASE
FROM BIOREACTOR TANK
202 SHEET 1
FROM:
1. SPENT MEDIA TANK
2. PHYSICAL TREATMENT DRAINS TANK
3. DECANT HOLD TANK
202 SHEET 2
202 SHEET 3
FROM SLUDGE DEWATERING PROCESS
DRYER
HEPA
CARBON
DPI
OFFGAS FAN
TO PHYSICAL TREATMENT DRAINS TANK
202 SHEET 2
DILUTION AIR SUPPLY
DILUTION AIR FAN
TO ATMOSPHERE
SAMPLE PORT

FIGURE 5

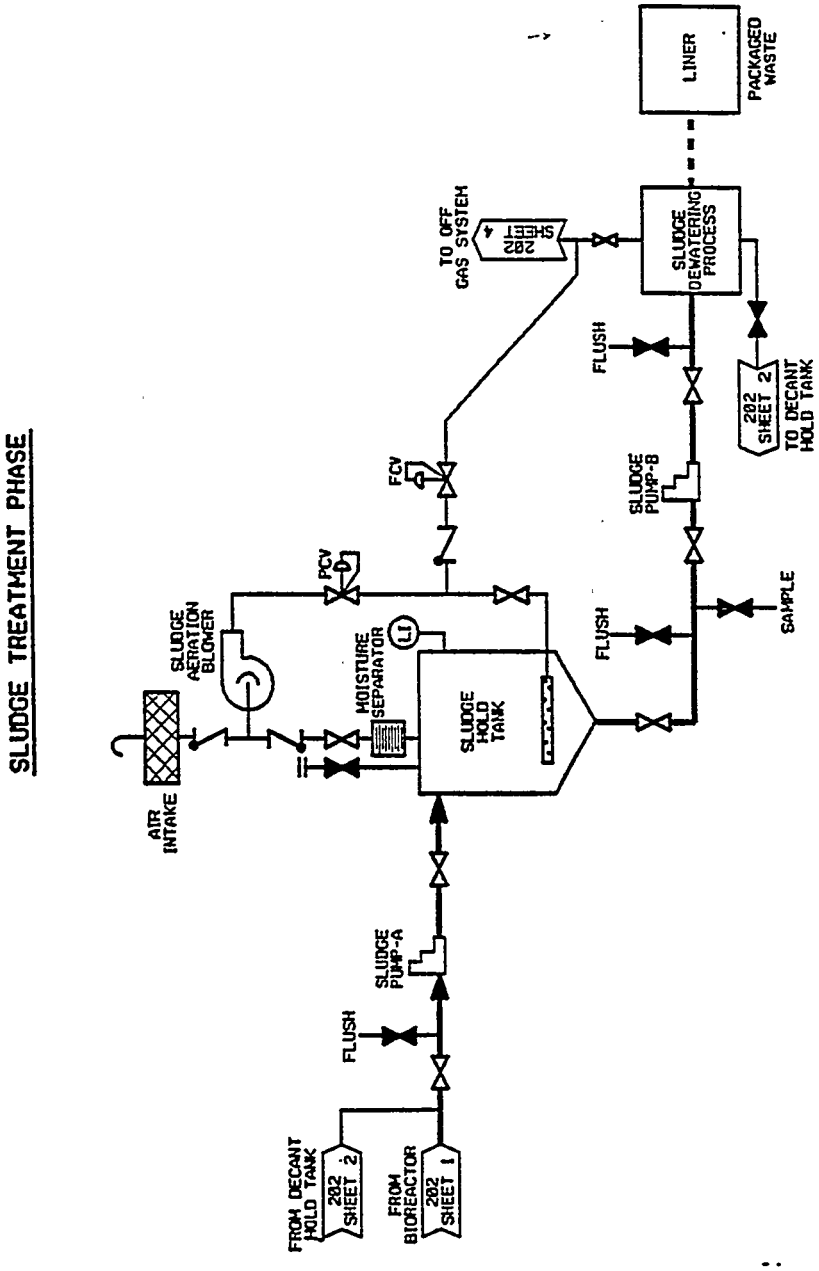

SLUDGE TREATMENT PHASE
LINER
PACKAGED WASTE
TO OFF GAS SYSTEM
282 SHEET 4
SLUDGE DEWATERING PROCESS
FLUSH
282 SHEET 2
TO DECANT HOLD TANK
FCV
SLUDGE PUMP-B
PCV
SLUDGE AERATION BLOWER
MOISTURE SEPARATOR
LI
SLUDGE HOLD TANK
FLUSH
SAMPLE
AIR INTAKE
SLUDGE PUMP-A
FLUSH
FROM DECANT HOLD TANK
282 SHEET 2
FROM BIOREACTOR
282 SHEET 1

FIGURE 6

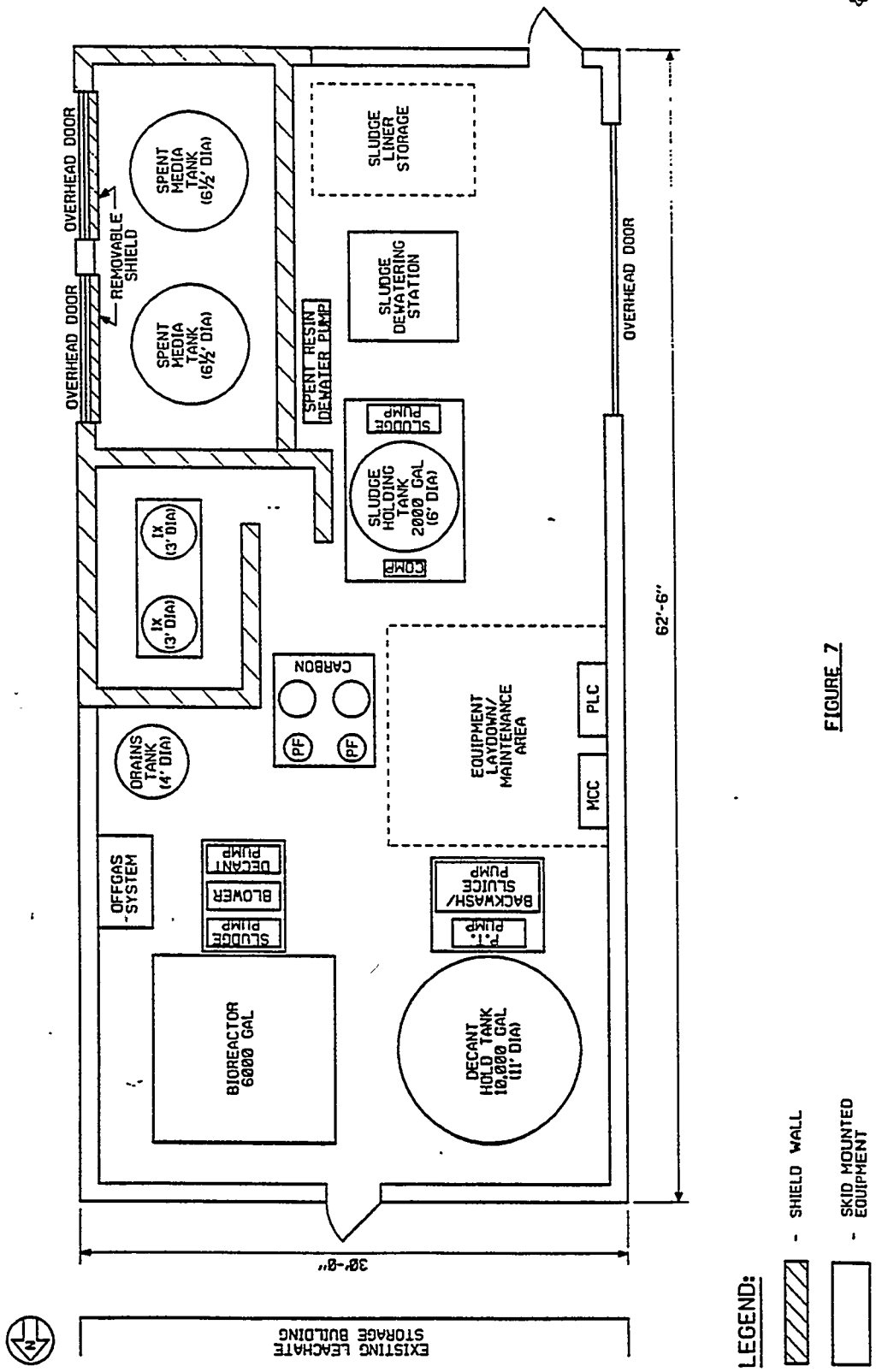

TREATMENT FACILITY GENERAL LAYOUT
EXISTING LEACHATE STORAGE BUILDING
30'-0"
62'-6"
OVERHEAD DOOR
REMOVABLE SHIELD
OVERHEAD DOOR
OVERHEAD DOOR
SPENT MEDIA TANK (6½' DIA)
SPENT MEDIA TANK (6½' DIA)
SLUDGE LINER STORAGE
SLUDGE DEWATERING STATION
SPENT RESIN DEWATER PUMP
SLUDGE PUMP
SLUDGE HOLDING TANK 2000 GAL (6' DIA)
COMP
1X (3' DIA)
1X (3' DIA)
CARBON
PF
PF
DRAINS TANK (4' DIA)
EQUIPMENT LAYDOWN/ MAINTENANCE AREA
PLC
MCC
OFFGAS SYSTEM
SLUDGE PUMP
BLOWER
DECANT PUMP
BACKWASH/ SLUICE PUMP
P.T. PUMP
BIOREACTOR 6000 GAL
DECANT HOLD TANK 10,000 GAL (11' DIA)
LEGEND:
- SHIELD WALL
- SKID MOUNTED EQUIPMENT

FIGURE 7

Bench-scale Treatability Testing of Biological, UV Oxidation, Distillation, and Ion-Exchange Treatment of Trench Water from a Low-Level Radioactive Waste Disposal Area at West Valley, New York

J. A. Sundquist
J. C. Gillings
Ecology and Environment, Inc.

T. L. Sonntag
New York State Energy Research and Development Authority

R. P. Denault
Pacific Nuclear, Inc.

INTRODUCTION

Ecology and Environment, Inc. (E&E), under subcontract to Pacific Nuclear Services (PNS), conducted for the New York State Energy Research and Development Authority (NYSERDA) treatability tests to support the selection and design of a treatment system for leachate from Trench 14 of the West Valley State-Licensed, Low-Level Radioactive Waste Disposal Area (SDA). In this paper E & E presents and discusses the treatability test results and provides recommendations for the design of the full-scale treatment system.

History and Background

The SDA occupies approximately 15 acres of Western New York Nuclear Service Center (WNYNSC) property approximately 1,000 feet southeast of a former spent fuel reprocessing plant located within the West Valley Demonstration Project (WVDP) premises. The SDA was constructed and operated by Nuclear Fuel Services Company, Inc. (NFS) as a commercial low-level radioactive waste (LLW) disposal facility from 1963 to March 1975, when waste disposal operations at the SDA were terminated. NFS monitored and maintained the SDA until March 1983, when management responsibility was transferred to NYSERDA.

SDA and Trench 14

During its operational life, the SDA received approximately 2.4 million cubic feet of LLW initially containing approximately 700,000 curies. The waste was received from various sources, including institutions, industries, governmental facilities, nuclear power plants, waste brokers, and decontamination facilities. The physical forms of the waste were extremely diverse. Most of the waste was disposed of in the original shipping containers, including 5-, 30-, and 55-gallon steel drums, wooden crates, cardboard boxes, cartons, fiber drums, and plastic bags.

Packaged waste was placed in long trenches excavated in the highly impermeable, silty till soil native to the site, and covered with 1.2 to 2.4 meters of excavated soil. Due to the character of the soil and the wet climate, water management problems were experienced from the very early years of operation. Despite efforts to address the problem, water accumulated in open, uncompleted trenches, as well as in covered, completed trenches. Trench 14 has historically exhibited the most significant increases in water levels and the reduction of these water levels, through pumping and treatment, has become the objective of an interim measure to be performed per the provisions set forth in the Resource Conservation and Recovery Act Section 3008(h) Administrative Order-on-Consent No. 92-0202 (Consent Order).

Contamination Description

The trench water is contaminated by a wide range of organic chemicals. The principal contaminants (those above 1 milligrams per liter [mg/L]) are methylene chloride, benzene, toluene, xylene, acetone, and

some phenols. The biochemical oxygen demand (BOD) is significantly higher, in the range of 1,000 to 10,000 mg/L. Radionuclide contaminants include tritium (H-3), cesium-137 (Cs-137), and strontium-90 (Sr-90). Tritium is by far the most abundant radionuclide at concentrations up to 0.5 microcurie per milliliter (μCi/mL). There are, however, no practical techniques for tritium removal. Removal of this radionuclide is not addressed by this program.

Summary of Treatability Tests

The treatability tests discussed in this report examined four types of treatment technologies:

- Biological treatment testing
- UV oxidation treatment testing
- Evaporation treatment testing
- Ion-exchange treatment testing.

The biological treatment tests examined both basic biodegradability of the leachate and the effectiveness of certain specific types of biological treatment, including aerobic and anoxic batch activated sludge treatment. Several experimental parameters were altered during the performance of these tests. UV oxidation, which uses UV light to catalyze the reaction between organic compounds and an oxidizer, was tested as treatment for the organic contaminants. The evaporation testing examined whether organic contaminants may be concentrated in the still bottoms, resulting in a relatively large proportion of clean distillate. Ion-exchange tests were performed to remove the radionuclides of concern in Trench 14 leachate, specifically Sr-90 and Cs-137, and estimate the ion-exchange media usage rates.

The biological, ion-exchange, and precipitation tests were performed by E&E in a laboratory leased from the Buffalo Materials Research Center (BMRC) in Buffalo, New York. The evaporation tests were conducted by a chemist at PNS's Richland, Washington laboratory under the direction of E&E. The UV oxidation treatment tests were performed by a vendor, ULTROX International, at the PNS Laboratory in Richland, Washington. Both of these facilities were properly licensed to receive and store radioactive materials such as Trench 14 leachate.

Due to the presence of tritium and VOCs, all leachate handling activities (opening containers, sampling, etc.) had to be performed in a ventilated fume hood. The biological testing apparatus, including two bench-top bioreactors, was too large to be located in the laboratory's hood and was designed as a closed-loop system. Considerable pre-experimental planning went into the development and construction of completely enclosed feed and withdrawal systems. Provisions were made to conduct sampling through lines that ran from the bioreactors to the ventilated hood. Spent air bled from the bioreactors was directed through a silica gel column in the hood to remove tritiated water vapor. Subsequent to the biological system start-up, modifications to the design were not possible because reopening of the batch bioreactors would have contaminated the ambient atmosphere of the laboratory. Due to the inherent difficulties in handling large quantities of radioactive materials, the bioreactor volumes were kept as small as possible. The small size of the equipment, the radioactive and volatile nature of the leachate, and the operational constraints of the bench-scale bioreactor system impacted the number of samples and types of analyses that could be performed throughout the study.

The goals of the treatability study were to identify technologies that could destroy or remove the leachate contaminants. To measure the effectiveness of the technologies tested, certain parameters were measured during the course of the studies. These parameters were chosen because they were the principal contaminants present and/or because treatment of these parameters would indicate effective treatment of other similar compounds present in the leachate. The contaminant parameters analyzed during the treatability study were:

- BOD_5
- Total organic compound (TOC) (measured as a surrogate for BOD_5)
- Phenols by GC method 604
- Benzene, toluene, xylene, ethylbenzene, and methylene chloride by on-site GC, method 8020, modified for external standards calibration and use of serial detectors
- VOCs by GC methods 601/602 (by outside laboratory for confirmatory analysis)
- Gross alpha and beta radioactivity
- Gamma-emitters (including Cs-137)
- Sr-90.

BIOLOGICAL TREATMENT

Experimental Procedures

Description of Bioreactors

Two 4-liter batch bioreactors (with a normal working volume of 3 liters) were used for the biological treatment tests. These bioreactors were fabricated out of 3/8-inch Plexiglas. The bioreactors were fitted with ports for air introduction, air effluent, mixed liquor and supernatant sampling, and sludge sampling and removal. The bioreactors were completely sealed to prevent the release of radioactive water vapor.

Bioreactor Operation Procedures

Over the course of three months, 85 bioreactor batch runs were completed. Each run proceeded through a general operational sequence during which certain experimental parameters were altered. The general operational sequence and the specific experimental conditions that were tested are identified below.

1. Clarified supernatant from the previous run was decanted.
2. Fresh leachate was added.
3. Phosphates were added as inorganic nutrients (sufficient nitrogen was determined to be present within the leachate).
4. Aeration and mixing commenced. Most of the effluent air was recycled back to the bioreactor to reduce vapor vase radioactive emissions. A fraction of the air was continuously bled off and an equal amount of make-up air introduced.
5. Sampling was generally performed at the beginning and end of each run. Intermediate run samples were obtained from some intensive sampling runs.
6. At the end of the run, aeration and mixing ceased and the suspended solids were allowed to settle to the V-shaped bottom of the bioreactor.

The following are experimental conditions that were tested during the bioreactor batch runs:

- Standard batch tests with variation of run duration

- Removal of sludge from the bioreactors (sludge wasting)
- Operation with anoxic intervals
- Cotreatment with powdered activated carbon (PAC)
- Operation with pretreated leachate.

BOD_5 Correlation

Several runs were conducted to generate split samples for analysis of BOD_5 and TOC. The objective of these analyses was to develop a correlation between these parameters so that TOC measurements could be used to estimate BOD_5 levels of the many samples generated during the study.

Samples were collected for BOD_5/TOC correlation from five separate runs. Also, throughout the course of this study, other samples were analyzed for both BOD_5 and TOC, including samples from carbon isotherm tests and end-of-run confirmatory samples. All BOD_5 and TOC data generated during the biological tests are graphically presented on Figure 1. As shown on the graph, the data fall either in the high range or low range of the scale, even though samples were taken throughout the entire course of the runs. Most of the points presented are end-of-run samples, with or without subsequent carbon treatment, and are thus clustered in the low BOD_5 range. In this low range, the magnitude of potential analytical variability is equivalent to the absolute magnitude of the result, resulting in a fair amount of scatter.

As expected, the shape of the curve includes a relatively horizontal portion near the origin before it rises with an appreciable slope, indicating finite TOC levels at low BOD_5 levels. This is a manifestation of not all the organic carbon in the system being biodegradable. Although there are insufficient data to accurately draw the slope of this linear section, an x-axis intercept of approximately 250 mg/L TOC would be found upon extrapolation. In fact, biodegradation was able to consistently reduce TOC to the range of 100 to 200 mg/L.

In the low range of BOD_5 samples, most BOD_5 values were below 20 mg/L, with many 10 mg/L or lower. Comparing this with the proposed discharge criteria of 5 mg/L, and starting BOD_5 levels of over 1,000 mg/L, all TOC levels in the range of 0 to 200 mg/L indicate nearly complete removal (>98%) of the BOD_5. Although the actual value of TOC in this range cannot be used to estimate a BOD_5 value, the study showed that TOC can be an operational parameter with a target operating point of 200 mg/L or less.

Standard Batch Test Results

The standard daily and extended-duration (more than one day) runs comprised the first 14 runs of bioreactor A (daily runs) and the first seven runs of bioreactor B (extended-duration runs). Four additional standard daily runs were conducted in bioreactor B and were designated as runs B20 through B23. Runs with wasting of settled sludge comprised runs designated A21 through A25 and B13 and B14.

The oxygen uptake rate, TOC, and mixed liquor volatile suspended solids (MLVSS) results from these runs are presented on Tables 1 and 2. These results show that for all types of runs, TOC was reduced to the range of 90 to 200 mg/L. For these levels, BOD_5 is expected to be in the range of 2 to 25 mg/L according to the correlation presented in the previous section. Oxygen uptake rates were consistently too fast to measure (i.e., oxygen was consumed at a rate faster than the dissolved oxygen meter's response time or dissolved oxygen concentrations in the bioreactor were too low at the time) at the start of each run. By the end of each run, the uptake rate had decreased to very low levels (i.e., typically less than 0.1 mg/L-min).

Although there was a high substrate level in the leachate, settleable sludge did not continue to accumulate from run to run, despite the addition of fresh substrate (i.e., leachate contaminants) on a regular basis. At the end of each run, there was consistently 300 to 500 mL of sludge present for each 3,000 mL batch. Both starting and ending MLVSS levels were relatively constant—typically in the range of 1.5 to 2.5 g/L. Extended-duration runs did not reduce the volume of sludge or the MLVSS concentrations at the end of the

runs. The sludge volume and MLVSS levels remained constant even when some sludge was wasted. Although the starting MLVSS levels would be lower, the ending concentrations would recover to (or slightly exceed) the typical MLVSS range. The need to not waste settled sludge is apparently due to some auto-oxidation of the biomass during the relatively long durations of each run, plus the fact that some solids were lost in the supernatant, as discussed below.

The presence of iron in the leachate promoted good flocculation and settling. However, the supernatant generally was not completely clean. Although settling concentrated the solids 100 times greater in the sludge than in the supernatant, an average of approximately 0.1 g/L VSS remained in the supernatant. These volatile solids (i.e., biomass) were removed from the system. Assuming 2,500 mL of supernatant was removed from a typical run with an MLVSS of 2.0 g/L, the amount of biomass removed with the supernatant would be 4.2% of the total. Not coincidentally, the average percentage reduction in the MLVSS from the end of a daily batch run (no sludge wasting) to the start of the next batch run was also 4.2%. These data show that despite an apparently constant settled sludge volume and MLVSS concentration, a fraction of the biomass was removed every day, with an equivalent amount of new biomass produced.

The results of the VOC analyses from these runs are presented on Table 3. Not all samples collected were analyzed in the treatability laboratory because of equipment problems and associated time constraints. Also, it was determined that sufficient data had been collected from which conclusions could be drawn and recommendations made. The data on Tables 3 and 4 show high but variable levels of toluene and methylene chloride in the starting samples, along with lower levels of benzene, ethylbenzene, and xylenes. The variability of the starting concentrations is most likely due to the fact that the starting samples were not always taken immediately after startup. Occasionally, due to other ongoing responsibilities, starting samples may have been taken up to 30 minutes after the start of aeration and some volatiles may have been lost in the interim.

The end-of-run samples were uniformly low in VOCs. For nearly all runs, benzene, ethylbenzene, and xylenes were not detectable in end-of-run samples. Some toluene and methylene chloride remained at the end of the daily runs, and toluene remained in some of the extended runs. However, the levels observed were well below the proposed discharge criterion of 200 μg/L for each of these compounds. Although the benzene and ethylbenzene levels were lower, the occasional detected levels exceeded their proposed discharge levels of 6 and 10 μg/L, respectively. Xylene was consistently below its proposed discharge criterion of 50 μg/L.

The degree of VOC removal extended beyond the six compounds for which the GC was calibrated. Many other volatile compounds were present, which were detected as peaks on the start-of-run chromatograms. For example, the start-of-run chromatograms for run A13 (a standard daily run) are presented on Figure 2 [electron capture detector (ELCD) for methylene chloride] and 3 [photoionization detector (PID) for the aromatics]. These chromatograms illustrate that many peaks besides the calibrated compounds are present. With the ELCD, the peaks are very large. These chromatograms may be contrasted to the end-of-run chromatograms also presented on Figures 2 and 3. These figures illustrate virtual complete removal of all detectable VOCs, except for two unidentified peaks on the PID.

VOC removal during the biotreatment runs probably occurred through physical removal (i.e., stripping) and biological degradation. The aromatics were likely biologically degraded, as has been observed during other applications of biological treatment, such as treatment of gasoline-contaminated groundwater. The chlorinated organics, however, are generally not very biodegradable and were likely stripped off and vented through the bleed.

Results of Intensive Sampling Runs

Two daily batch runs were conducted in which samples were collected once an hour for 6 or 7 hours (runs designated as B22 B23). Oxygen uptake rates, TOC, VOCs, and cumulative acid addition results are presented on Tables 4 and 5. An apparent lag period of about 1 hour is seen at the start of each run, which is typical of batch biological tests. The data show that TOC reduction is complete within 5 to 6 hours. The cumulative volume of acid added for pH control correlates well with this time frame. Oxygen uptake rates were too fast to measure for the first 5 hours of operation, with reduction to a moderate range after 6 hours.

The results of volatiles analyses show, in most cases, a rapid decline within the first two hours of operation. The aromatics, which are removed primarily by biological action, are reduced faster than methylene chloride, which is removed by volatilization. Removal by volatilization is limited by the fact that most of the air going through the system is recycled to the bioreactor and only a small bleed is taken off. This limits the amount of VOCs that can be removed from the system as vapor.

Phenols Removal

Phenols were measured in two untreated leachate samples, using GC method 604. Phenol, 2-chlorophenol, 2,4-dichlorophenol, and 2,4,6-trichlorophenol were detected (see Table 5). Phenols were measured again in two samples taken from the composite of effluents from several batch runs. These two samples showed that no phenols remained, with the exception of one detection of 2-4 dinitrophenol. The detection of this compound was unusual in that it was not detected in the untreated samples (although higher detection limits were encountered with the untreated samples), nor was it detected in the duplicate treated samples. Phenols analyses were conducted on 18 other occasions during this study—specifically during tests for UV oxidation, PAC biotreatment, and carbon treatment of biotreated leachate. The 2,4-dinitrophenol was detected only in the two samples collected from the end of the PAC biotreatment test runs. It was not found in any other biotreated or UV oxidation-treated samples, even though certain UV oxidation test conditions were not effective on the phenols known to be present in the leachate. Thus, it is doubtful that 2,4-dinitrophenol is truly present in the three samples for which it was reported; this finding may be an analytical artifact.

Other Batch Operation Strategies

The batch biological reactors were also operated under three additional conditions to examine whether even greater amounts of contaminant reduction could be obtained: anoxic intervals, addition of PAC, and use of pretreated leachate.

Anoxic Interval Runs

Four runs were conducted with intervals of no aeration, allowing the system to go anoxic. Anoxic intervals of one day, two days, three days, and another three days were conducted. In each case, the bioreactor was operated aerobically for 4 to 6 hours, then switched to anoxic operation for the specified interval.

Starting with the second anoxic interval run, the biomass apparently began to produce gases anoxically. Within 15 minutes of cessation of aeration, settled biomass rose to the top of the liquid, and adsorbed to bubbles. This generation of gas suggests that anoxic activity had been induced in the biomass, most likely denitrification, producing nitrogen gas. However, none of the anoxic runs reduced organic contaminant levels any lower than the strictly aerobic runs. In fact, the ending TOC values are slightly higher than the strictly aerobic runs (data not shown). This suggests that most of the treatment occurred during the aerobic segment of the run.

PAC Runs

Four batch runs were conducted with increasing amounts of PAC (up to 4 g/L) added to the bioreactors. The objective of these runs was to see if the added PAC could further improve the effluent quality by removing nonbiodegradable organics and organics that may be toxic or otherwise inhibit the growth of biomass. Organics that have been so removed from solution would have to be ultimately removed from the bioreactor in this form of wasted biomass/PAC mixed sludge. These runs did not, however, reduce the ending TOC, BOD_5, or VOC levels more greatly than conventional batch aerobic treatment (data not shown) and thus were not pursued further.

Pretreated Leachate Run

Several runs were performed with leachate that had been pretreated by aeration and pH elevation. Aeration of the leachate was performed to prestrip some VOCs and to oxidize some of the iron; the pH was raised to 8.6 to ensure the precipitation of the oxidized iron. The pretreated leachate was then filtered prior to use. Results from the bioreactor runs utilizing pretreated leachate demonstrated contaminant reduction levels similar to the non-pretreated leachate runs. The pretreated leachate runs yielded less bioreactor sludge, but the fact that a precipitation residue is generated as a result of the leachate pretreatment process means that a net reduction in the quantity of treatment residues was not observed.

Biological Treatment Conclusions and Design Parameters

Batch biological treatment was found to remove both specific compounds (e.g., toluene and phenol) as well as those unspecified organic compounds that collectively contribute to the BOD_5 level.

Biological treatment was found to effectively remove BOD_5. The BOD_5 level of the leachate was measured at a range of 1,900 to 2,600 mg/L during UV oxidation tests conducted as a separate component of this treatability study (see Section 3) and up to as high as 1,200 mg/L during biological tests (samples collected for BOD_5/TOC correlation). Actual starting BOD_5 levels may be higher since some toxicity towards the BOD_5 test seed may have been present during the analyses of these starting samples. Of the seven end-of-run samples analyzed for BOD_5 (four confirmatory samples and three end-of-run BOD_5/TOC correlation samples), all but one was found to be 6 mg/L or less. The seventh sample was 41 mg/L. Thus, most of the effluents from these batches would approach or meet the proposed discharge criterion for the parameter (5 mg/L) with little to no post-treatment (e.g., carbon polishing).

VOCs of concern included benzene, toluene, xylene, ethylbenzene, and methylene chloride. The levels of these compounds were reduced significantly during biotreatment. Volatilization likely plays some role in their removal, especially for methylene chloride. Toluene and methylene chloride are the highest concentration VOCs in the leachate. Both of these compounds were consistently reduced below their proposed discharge criterion of 200 μg/L with biotreatment alone. Concentrations of benzene and ethylbenzene sometimes exceeded their proposed discharge criteria of 6 and 10 μg/L, respectively. However, carbon isotherm tests have indicated that these compounds could readily be removed with minimal carbon consumption (data not shown).

Phenols present in the leachate included phenol (4,100 μg/L), 2-chlorophenol (15,000 μg/L), 2,4-dichlorophenol (7,800 μg/L), and 2,4,6-trichlorophenol (approximately 1,000 μg/L). All of these compounds were removed to below detection limits. However, due to limited sample size, the detection limits were 50 or 100 μg/L, which are higher than the proposed discharge criterion of 5 μg/L total phenols. 2,4-Dinitrophenol was detected in one sample (with no carbon added) and in both end-of-run samples taken from the PAC tests (data not shown). This result is surprising because it was not found in any other samples, including the UV oxidation test samples.

Based on these data, biological treatment is deemed appropriate in removing most, if not all, of the target contaminant parameters present in the Trench 14 leachate. Carbon adsorption may be needed to polish the effluent from some batches, in order to reduce some residual amounts of contaminants or to remove trace recalcitrant contaminants that are not expected to be present in the leachate but are nonetheless regulated under the terms of the proposed discharge permit (e.g., certain pesticides).

UV OXIDATION TREATMENT

UV oxidation treatment uses ozone and/or hydrogen peroxide to chemically oxidize organic compounds. UV light functions as a catalyst in the oxidation reactions. This technology was investigated due to its potential for generating reduced quantities of treatment residues compared to biological treatment. Two rounds of batch UV oxidation treatment were conducted by Ultrox International, a vendor of this technology.

During the first round of tests, the amount of ozone, the amount of hydrogen peroxide, and the duration of UV irradiation were varied. Start and end samples were analyzed for BOD_5, total organic carbon (TOC), and a wide range of VOCs and phenols.

The results from the principal contaminants of concern are presented on Table 6. The test read to show a clear trend of increasing contaminant removal with longer treatment durations and higher oxidant doses. Run 4B, with the highest oxidant dose and 2-hour run duration, reduced virtually all identified compounds to below 5 μg/L or below detection limits, except for toluene, the highest specific compound contaminant. In contrast to the effective removal of specific contaminants, however, BOD_5 and TOC were unaffected by any level of treatment.

A second round of tests was performed, with increased concentrations of the oxidizers and extended durations. As part of the second round of testing, Fenton's oxidation reagent (hydrogen peroxide with an iron catalyst at low pH) was tested. Again, no reduction in BOD_5 was demonstrated. Thus, it was concluded that this technology could not be used for the treatment of the organic compounds in Trench 14 leachate.

EVAPORATION TESTING

A fractional distillation test was conducted in the PNS Richland laboratory to determine whether significant amounts of adequately treated leachate could be segregated in condensed fractions. This test indicated that some low TOC/chemical oxygen demand (COD) liquids could be collected in later condensate fractions. As the distillation process progressed, both TOC and COD concentrations increased in the still bottom (see Figure 4). This indicates that the contaminants concentrated in the still bottom fraction during distillation. TOC and COD levels of the condensate samples, however, show the opposite trend. Although the initial condensates showed very high levels of contamination, TOC and COD decreased with increasing condensate fraction. TOC and COD values leveled out at below 80 mg/L and 400 mg/L, respectively, after the fourth of nine condensate samples. Each condensate fraction represented approximately 9% of the initial charge to the still. Condensate quality decreases slightly towards the end of the distillation run as shown by the slight rise in TOC and COD concentration. This is due to the release of some less volatile contaminants as they become more concentrated in the still pot towards the end of the run. However, the volume of inadequately treated leachate, composed of the still bottoms and early condensate fractions, was at least equivalent to the volume of "clean" fractions that were collected. The more highly contaminated byproduct liquids, requiring further treatment, represented as much as 50% of the original leachate volume. This technology was therefore deemed an inappropriate treatment alternative for Trench 14 leachate.

ION EXCHANGE TREATMENT

Ion-exchange treatment was tested twice: once during a preliminary treatability study with nonbiotreated leachate, and again using biotreated leachate during the treatability study presented in this paper. The first treatability test focused specifically on the Cs-137 contamination. Union Carbide Ionsiv IE95 was selected for testing. This zeolite medium is selective for Cs-137 removal. The Cs-137 isotherm from these tests is plotted on Figure 5. This graph shows classic equilibrium behavior with logarithmic linearity at lower liquid concentrations while reaching saturation or encountering competition at levels greater than approximately $10^{-4}\mu$Ci/mL.

Ion-exchange isotherms were again generated during the second treatability study, using biotreated leachate so as to mimic as much as possible the proposed treatment system. These tests were designed to remove both the principal radionuclides Cs-137 and Sr-90. To remove both of these radionuclides, a mixture of two zeolites was used. Ionsiv IE95 was again used for Cs-137 removal, and Ionsiv A5I was used for Sr-90 removal. A5I is selective for Sr-90 removal. Using equal amounts of each zeolite, isotherms for Cs-137 and Sr-90 were developed (see Figure 6). The Cs-137 isotherm is very similar to that obtained with the nonbiotreated leachate. The biotreated leachate's isotherm had a shallower slope and demonstrated slightly higher overall amounts of Cs-137 adsorbed. The higher adsorption of the radioisotope may have been the result of competing ions (possibly iron) being removed during biotreatment.

The isotherms generated during the treatability studies demonstrated that the selected zeolites were effective in removing the two principal radionuclides of concern. Because the radioactive nature of the leachate precluded handling large amounts of leachate, no column tests were performed. The isotherms were then used to estimate the consumption of ion-exchange zeolites during radionuclide removal. Based on influent Cs-137 and Sr-90 concentrations of 1.8×10^{-4} μCi/mL and 6.4×10^{-5} μCi/mL, respectively (as seen in the second treatability study), the equilibrium loading is predicted to be 4.68×10^{-1} μCi/g for Cs-137 and 4.68×10^{-2} μci/g for Sr-90. Clearly, Sr-90 is the rate-limiting species for radionuclide removal.

To account for mass transfer limitations, a very conservative efficiency factor of 20% is assumed. Only 20% of the column is assumed to have reached saturation before breakthrough occurs. This rather low mass transfer limitation efficiency factor is selected since no small scale column data were developed for design. This conservative efficiency factor ensures that zeolite usage will not be underestimated and that the columns will not be undersized during design. Based on this assumption and the treatability study findings, total zeolite usage is predicted to be approximately 7.9 pounds per 1,000 gallons treated.

CONCLUSIONS AND RECOMMENDATIONS

Based on the findings of this study, a treatment system consisting of batch biological treatment, filtration, carbon polishing, and ion exchange has been recommended. Biological treatment has been shown to be effective in removing the target compounds, including reducing the BOD_5 to near and/or below the target level of 5 mg/L. Carbon polishing would be included to ensure treatment goals are met. Batch treatment is recommended due to the low rate of treatment (mandated by the presence of untreatable tritium), to minimize the amount of sludge (a potential mixed waste) produced, and to provide the highest level of process control. Ion exchange, using a mixture of two zeolites, will effectively remove Cs-137 and Sr-90 contaminants.

Additional treatability tests (e.g., pilot scale) are not recommended prior to full-scale design. The rate of leachate extraction and treatment is expected to be in the range of only 30,000 to 300,000 gallons per year. Therefore, a relatively small scale (essentially pilot scale) treatment facility is required. Additional process optimization steps may be made during the initial operation of this facility, if needed.

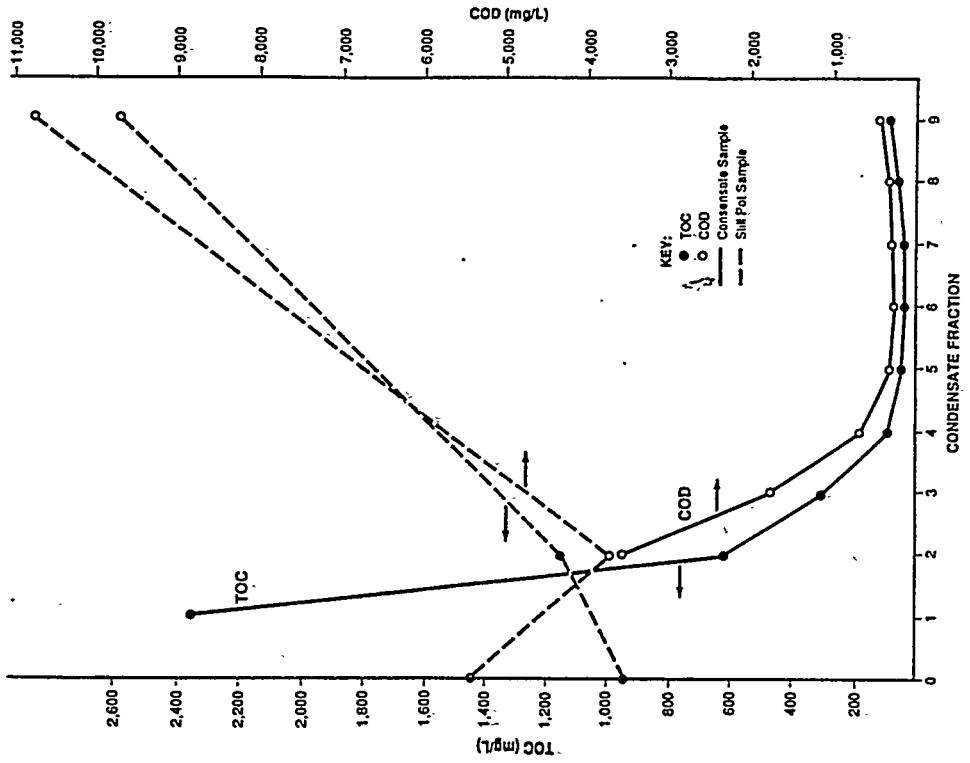


Figure 4
RESULTS OF EVAPORATION TESTING

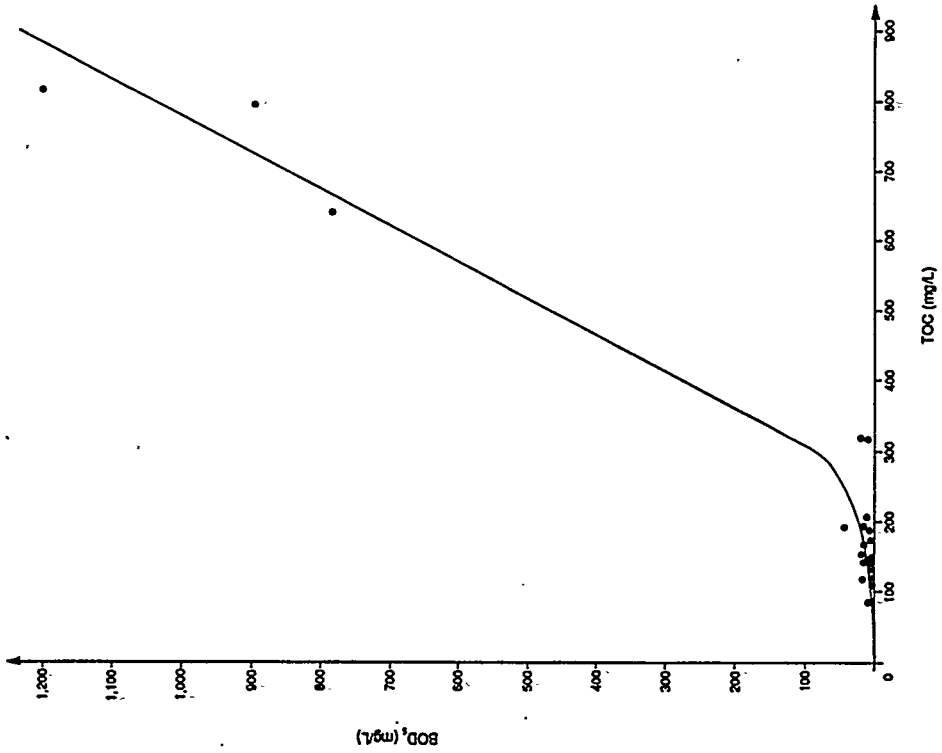
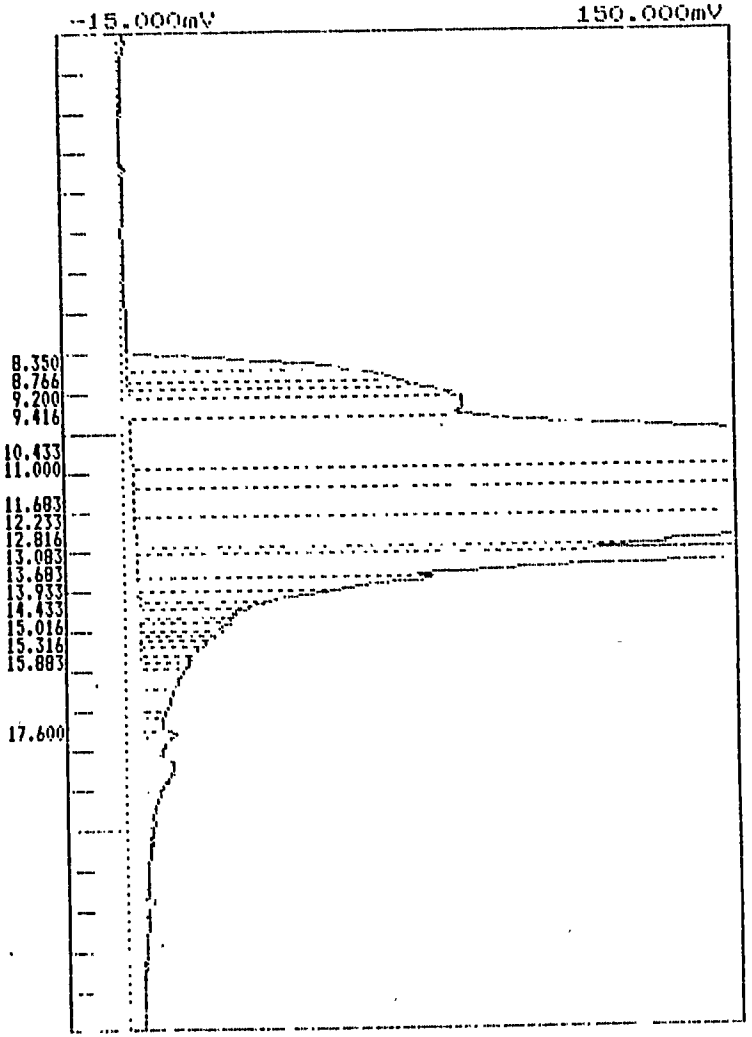
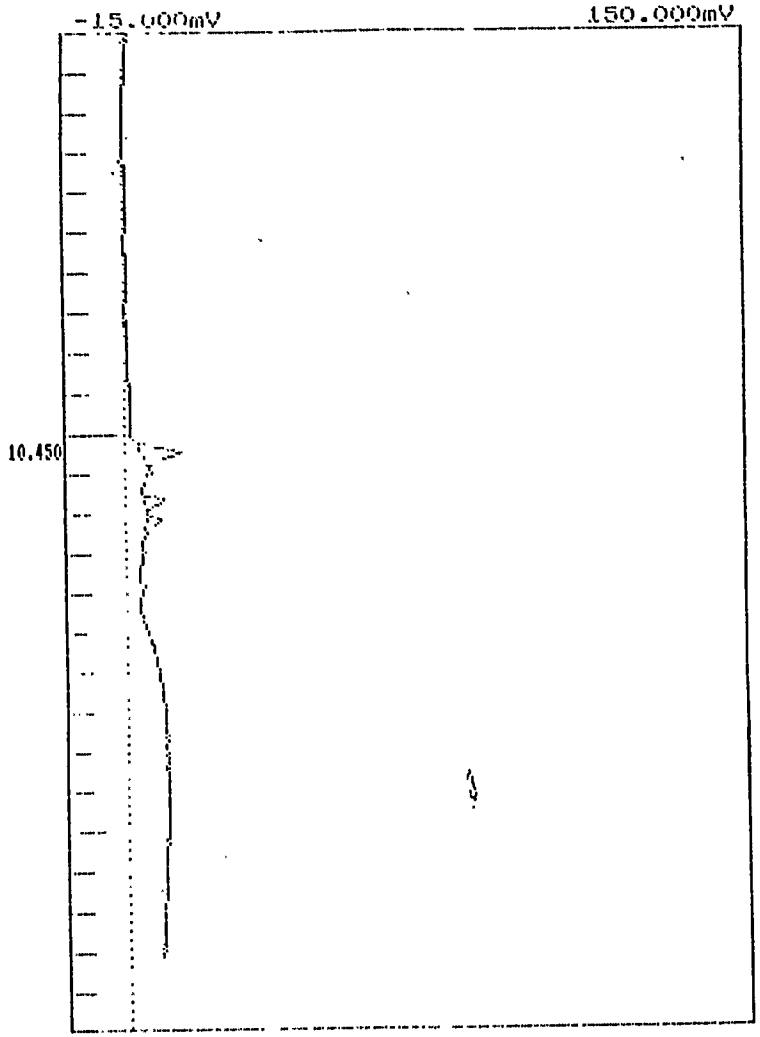


Figure 1
BOD_5/TOC CORRELATION



CALIBRATED COMPOUNDS:
Methylene Chloride: 10.433 minutes

ELCD CHROMATOGRAM, START OF RUN A13



CALIBRATED COMPOUNDS:
Methylene Chloride: 10.450 minutes

ELCD CHROMATOGRAM, END OF RUN A13

Figure 2

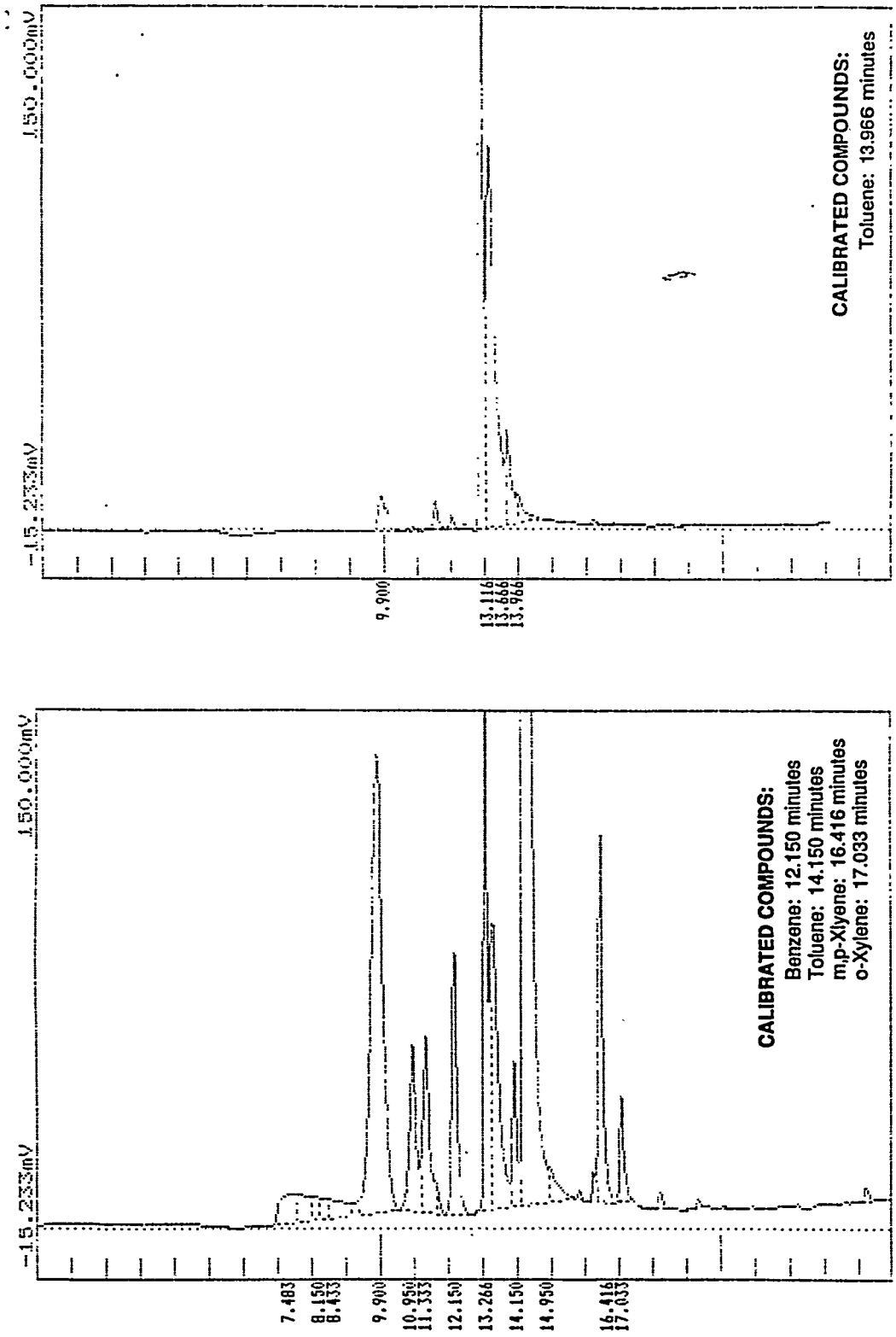

150.000mV
-15.233mV
9.900
13.116
13.666
13.966
CALIBRATED COMPOUNDS:
Toluene: 13.966 minutes
PID CHROMATOGRAM, END OF RUN A13
150.000mV
-15.233mV
7.483
8.150
8.433
9.900
10.950
11.333
12.150
13.266
14.150
14.950
16.416
17.033
CALIBRATED COMPOUNDS:
Benzene: 12.150 minutes
Toluene: 14.150 minutes
m,p-Xlyene: 16.416 minutes
o-Xylene: 17.033 minutes
PID CHROMATOGRAM, START OF RUN A13

Figure 3

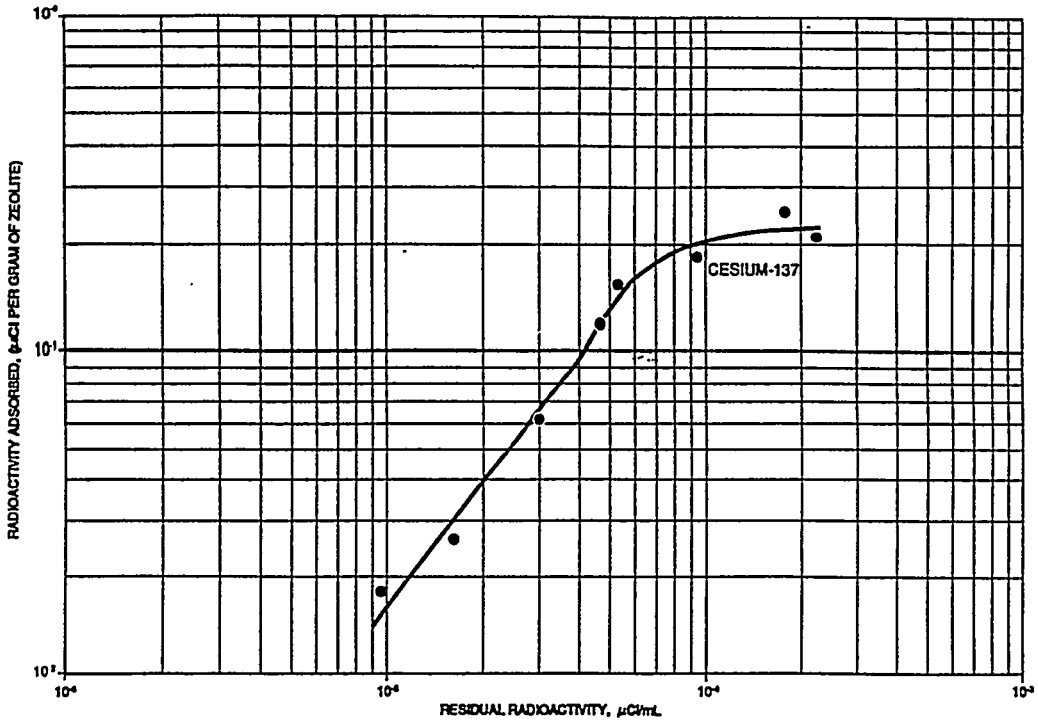


Figure 5
Cs-137 ION EXCHANGE ISOTHERM
(with Nonbiotrated Leachate IE-95 Zeolite)

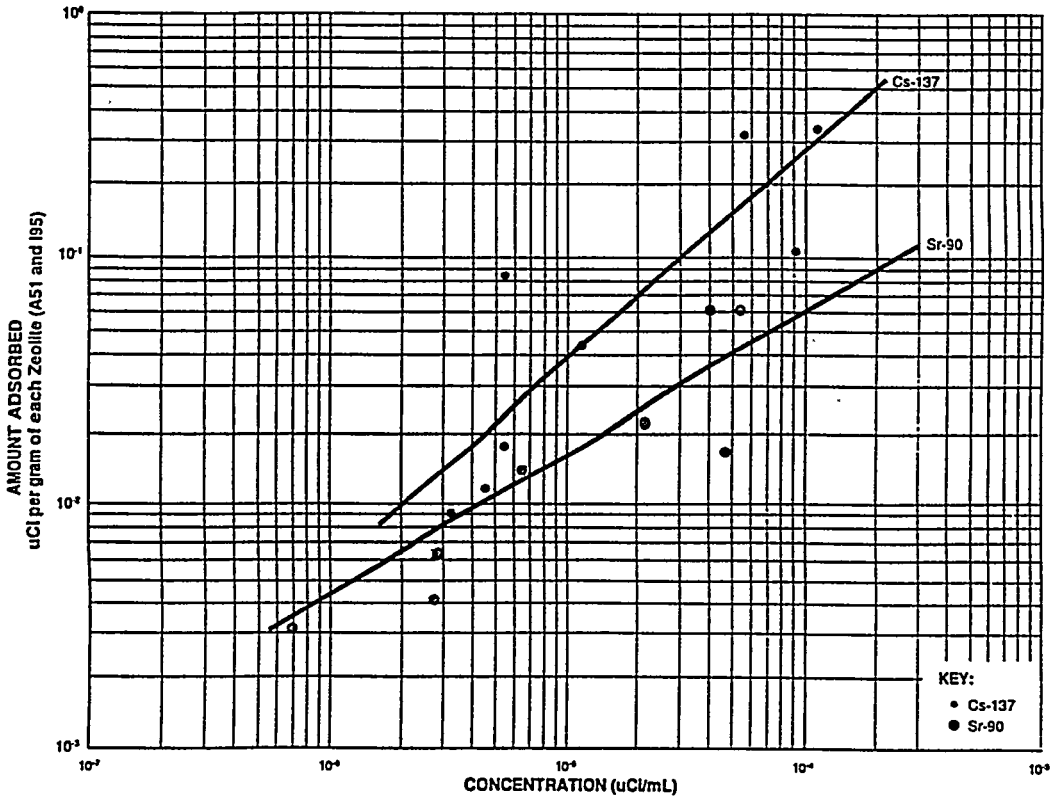


Figure 6
Cs-137 AND Sr-90 ION EXCHANGE ISOTHERMS

Table 1

DAILY RUNS WITH AND WITHOUT SLUDGE WASTING

Type of Run	Run Number	Oxygen Uptake (mg/L-min) (end)	TOC (mg/L)		MLVSS (g/L)	
			Start	End	Start	End
Standard runs	A1	0.16	790	140	2.22	1.76
	A2[a]	0.10	1,036	92	1.68	1.48
	A3	0.15	940	110	1.67	1.65
	A4	0.20	1,035	93	2.02	3.01
	A5	0.13	--	166	2.91	2.37
	A6	0.12	988	151	2.17	2.63
	A7	--	854	--	2.45	--
	A8[c]	--	--	163	--	3.40
	A9	0.05	790	124	1.70	2.06
	A10	0.06	974	180	1.86	1.53
	A11	0.05	868	200	1.89	1.93
	A12	0.10	655	172	1.78	1.65
	A13[c]	0.30	817	257	1.66	2.49
	A14[c]	0.10	875	132	2.01	2.47
Sludge-wasting runs[b]	A21	0.07	661	192	2.76	3.29
	A22	0.10	797	117	1.98	2.49
	A23	0.10	869	163	1.30	2.74
	A24	--	779	173	1.25	--
Additional daily standard runs	B20[c]	--	749	81	1.49	1.13
	B21	--	642	91	0.84	1.12
	B22	--	707	144	2.24	2.80
	B23	--	774	126	2.08	2.37

[a] Runs ran longer than one day due to weekend or holiday.
[b] With sludge-wasting runs, approximately 50% of sludge (by volume) was wasted at the end of each run.
[c] 50% of sludge was wasted after this run.

Key:

-- = No sample taken or sample not analyzed.

Source: Ecology and Environment, Inc. 1992.

Table 2

EXTENDED-DURATION RUNS WITH AND WITHOUT SLUDGE WASTING

Type of Run	Run Number	Elapsed Time (hr)	Oxygen Uptake (mg/L-min)	TOC (mg/L)	MLVSS (g/L)
Standard extended duration	B1	0	--	640	--
		26	--	236	--
		96	0.1	120	0.64
	B2	0	--	931	0.92
		4.5	--	124	--
		21	--	205	1.36
		27	--	165	--
		46	0.1	241	1.94
	B3	0	--	1,089	2.08
		24	0.1	--	2.06
		48	0	126	2.15
	B4	0	--	131	2.09
		76	--	97	2.41
	B5	0	--	568	2.55
		20	0.05	164	1.72
		48	--	596	--
		70	0	88	1.46
	B6	0	--	467	1.38
		24	0.1	--	1.63
		96	0.1	--	1.99
	B7	0	--	1,062	1.80
		70	0.1	220	1.89
Extended duration/sludge wasting[a]	B13	0	--	909	1.66
		24	0.09	155	2.01
	B14	0	--	920	1.85
		19	0.14	111	2.49
		42	0	203	1.99
		66	--	196	--

[a] With sludge-wasting runs, approximately 50% of sludge wasted (by volume) at end of each run.

Key:

-- = No sample taken or sample not analyzed.

Source: Ecology and Environment, Inc. 1992.

Table 3

VOLATILES ANALYSES: STANDARD DAILY RUNS AND SLUDGE-WASTING RUNS

	Samples at Start of Runs (µg/L)						Samples at End of Runs (µg/L)					
Run	Benzene	Toluene	Ethyl-benzene	m,p-Xylene	o-Xylene	Methylene Chloride	Benzene	Toluene	Ethyl-benzene	m,p-Xylene	o-Xylene	Methylene Chloride
A1	440	16,000	ND	520	4,000	3,800	ND	ND	ND	6.0	ND	ND
A2	25	540	12	34	38	ND	ND	15	ND	ND	ND	ND
A3	190	560	2	1	14	440	ND	41	ND	ND	ND	ND
A4	240	10,000	810	230	ND	2,300	ND	24	ND	ND	ND	ND
A5	470	1,400	ND	340	ND	2,000	69	38	ND	ND	ND	ND
A6	500	1,400	ND	320	ND	5,200	ND	ND	ND	ND	ND	ND
A7	310	420	20	150	140	390	–	–	–	–	–	–
A8	–	–	–	–	–	–	ND	65	ND	ND	ND	ND
A9	–	–	–	–	–	–	ND	38	ND	17	ND	ND
A10	440	1,200	ND	270	ND	4,700	ND	13	ND	ND	ND	71
A11	200	3,600	ND	87	40	2,500	ND	63	ND	ND	ND	150
A12	400	10,400	ND	ND	ND	2,300	ND	40	ND	ND	ND	140
A13	98	790	ND	66	3.7	620	ND	18	ND	ND	ND	2.3
A14	300	490	61	260	200	1,600	ND	120	31	ND	7	ND
B1	3,800	106,000	ND	6,000	4,300	12,000	ND	32	ND	ND	ND	ND
B2	500	14,000	ND	340	ND	3,800	–	–	–	–	–	–
B3	280	7,300	ND	160	180	3,800	ND	ND	ND	ND	ND	ND
B4	150	ND	13	106	120	ND	ND	14	ND	ND	ND	ND

Table 3

VOLATILES ANALYSES: STANDARD DAILY RUNS AND SLUDGE-WASTING RUNS

	Samples at Start of Runs (µg/L)						Samples at End of Runs (µg/L)					
Run	Benzene	Toluene	Ethyl-benzene	m,p-Xylene	o-Xylene	Methylene Chloride	Benzene	Toluene	Ethyl-benzene	m,p-Xylene	o-Xylene	Methylene Chloride
B5	2,200	5,000	ND	1,500	28	24,000	–	–	–	–	–	–
B6	220	380	ND	150	150	3,900	ND	12	ND	ND	ND	ND
B7	–	–	–	–	–	–	ND	ND	ND	ND	ND	ND
B13	–	–	–	–	–	–	ND	31	ND	ND	ND	ND

Note: Runs B1 through B13 were extended duration runs.

Key:

– = Sample not analyzed.
ND = Not detected–detection limit of 10 µg/L.

Source: Ecology and Environment, Inc. 1992.

Table 4

VOC ANALYSES: INTENSIVE SAMPLING RUNS (µg/L)

Run	Elapsed Time (hours)	Benzene	Toluene	Ethyl-benzene	m,p-Xylene	o-Xylene	Methylene Chloride
B22	0	260	340	16	150	110	8,600
	1	45	520	11	11	11	1,600
	2	12	370	18	3.4	ND	1,700
	3	14	83	ND	6.2	ND	350
	4	13	60	ND	6.4	ND	270
	5	6.6	38	ND	3.4	ND	88
	6	7.0	40	ND	4.1	ND	43
	22.5	14	36	ND	ND	ND	ND
B23	0	320	500	23	160	140	3,600
	1	46	1,200	53	9.9	ND	5,200
	2	13	210	ND	10	12	2,200
	3	14	70	ND	5.1	7.8	420
	4	6.6	42	ND	ND	ND	140
	5	29	ND	ND	ND	ND	98
	6	ND	38	ND	ND	ND	154
	7.25	ND	36	ND	ND	ND	14
	23	–	–	–	–	–	–

Key:

– = Sample not analyzed.
ND = Not detected–Detection limit of 10 µg/L.

Source: Ecology and Environment, Inc. 1992.

Table 5

SUMMARY OF BIOTREATMENT PHENOLS ANALYSES (µg/L)

Compound	Raw Leachate Sample 1	Raw Leachate Sample 2	Biotreated Leachate Sample 1	Biotreated Leachate Sample 2
2,4,6-Trichlorophenol	<500	1,600	<50	<50
2,4-Dichlorophenol	7,500	8,100	<50	<50
2,4-Dimethylphenol	<500	<500	<50	<50
2,4-Dinitrophenol	<1,000	<1,000	<100	430
2-Chlorophenol	14,000	16,000	<50	<50
2-Methyl-4,6-dinitrophenol	<1,000	<1,000	<100	<100
2-Nitrophenol	<500	<500	<50	<50
4-Chloro-3-methylphenol	<500	<500	<50	<50
4-Nitrophenol	<1,000	<1,000	<100	<100
Pentachlorophenol	<1,000	<1,000	<100	<100
Phenol	4,100	4,000	<50	<50

Note: All samples were filtered before analysis.

Source: Ecology and Environment, Inc. 1992.

Table 6

SUMMARY OF PHASE 1 UV OXIDATION TEST RESULTS
(μg/L, unless noted)

Compound	Run:	Day 1 Feed	Day 2 Feed	1A	1B	2A	2B	3A	3B	4A	4B
	Ozone (mg/L):			1,000	2,000			1,000	2,000	2,000	4,000
	Hydrogen peroxide (mg/L):					1,000	2,000	1,000	2,000	1,250	1,250
	Duration (min.):	0	0	60	120	60	120	60	120	60	120
1,1-Dichloroethane		370	410	<1	<1	390	29	11	<1	<1	<1
Chloroform		500	350	<1	<1	350	<10	2	1	2	<1
Methylene chloride		6,700	3,900	35	4	3,000	3,200	92	3	5	3
Benzene		600	940	<100	27	380	200	11	<10	10	<10
Toluene		1,100	21,000	200	93	7,000	2,100	150	91	85	25
p-Xylene		<500	690	<100	<10	110	<100	10	12	10	<10
2,4,6-Trichlorophenol		<500	1,600	<250	350	1,000	<500	185	<100	<100	<100
2,4-Dichlorophenol		7,500	8,100	8,700	6,400	5,400	3,700	1,900	370	<100	<100
Phenol		4,100	4,000	<250	<250	2,100	<500	<100	<100	<100	<100
2-Chlorophenol		14,000	16,000	7,200	8,800	11,000	9,200	<100	<100	<100	<100
BOD_5 (mg/L)		1,800	2,000	2,300	1,900	1,700	1,600	1,600	2,000	2,000	2,000
TOC (mg/L)		300	1,600	320	300	1,600	8	1,700	1,600	1,800	1,400

Notes: Day 1 feed was used only for run 2B. Day 2 feed consisted of remaining Day 1 feed (approximately 80%) and some additional leachate (approximately 20%).

02:XM124_D4084-11/09/92-01

A Decision Methodology for the Evaluation of Mixed Low-Level Radioactive Waste Management Options for DOE Sites

Jo-Ann Bassi
U.S. Department of Energy Headquarters
Washington, DC

Mark S. Abashian, Sayan Chakraborti, Murthy Devarakonda, and Sinisa M. Djordjevic
IT Corporation
Albuquerque, NM 87108

INTRODUCTION

The Mixed Low-Level Waste Program is a U.S. Department of Energy Headquarters initiative designed to develop a system-wide integrated strategy for managing DOE's mixed low-level radioactive waste (MLLW). The primary objective of the program is to identify and implement the optimum treatment, storage, and disposal (TSD) options for MLLW. The basic approach to the Program is to:

- Develop an integrated approach to MLLW management through development of DOE-HQ guidance and DOE field office implementation
- Establish a proactive program based on development and implementation of technologies to treat wastes to the appropriate criteria and to produce a low-risk final waste form
- Establish a standardized approach to MLLW management activities throughout the DOE system that is cost effective, and set a technically sound standard of excellence for environmental protection in the DOE waste management programs
- Establish and maintain an open program for full participation of all DOE facilities, regulators, and the interested public sector.

Currently, many DOE sites are developing site-specific solutions to manage their mixed low-level wastes. These site-specific MLLW programs often result in duplication of efforts between the different sites, and consequently, inefficient use of DOE system resources. A nationally integrated program for MLLW eliminates unnecessary duplication of effort, but requires a comprehensive analysis of waste management options to ensure that all site issues are addressed. A methodology for comprehensive analysis of the complete DOE MLLW system is being developed by DOE-HQ to establish an integrated and standardized solution for managing MLLW. To be effective, the comprehensive systems analysis must consider all aspects of MLLW management from "cradle-to-grave" (i.e., from MLLW generation to disposal).

The results of the analysis will include recommendations for alternative management options for the complete DOE MLLW system based on various components such as effectiveness, cost, health and safety risks, and the probability of regulatory acceptance for an option. Because of the diverse nature of these various components and the associated difficulties in comparing between them, a decision methodology is being developed that will integrate the above components into a single evaluation scheme for performing relative comparisons between different MLLW management options. The remainder of this paper provides an overview of the roles and responsibilities of the various participants of the DOE MLLW Program, and discusses in detail the components involved in the development of the decision methodology for a comprehensive systems analysis.

ORGANIZATION OF THE MLLW PROGRAM

The Systems Analysis for MLLW, and the decision methodology being developed to support these analyses, are a technical support component of the MLLW Program. The MLLW Program is headed by DOE-HQ (EM-30), and composed of several technical support teams that will develop different aspects of the program under guidance from DOE. These technical support teams will interface with other DOE-HQ organizations and will be responsible for supporting DOE in the areas of program management and strategic planning, treatment technology and facility design, technology development, data acquisition, and a comprehensive systems analysis. This section presents the different aspects of the MLLW Program by identifying the various organizations that are currently contributing to the Program, and discussing the assigned roles of each organization.

MLLW Steering Committee

The MLLW Steering Committee is composed of representatives from DOE-HQ and each of the DOE Field Offices. The MLLW Steering Committee provides a forum for information exchange within DOE, provides oversight to the MLLW Program, and helps develop the vision for the long-term objectives of the Program. The Steering Committee will also review the collection of information on the current state of the DOE MLLW management, and will review key program actions and documentation. Finally, the Steering Committee, in conjunction with DOE-HQ, will formulate actions on both the short-term and long-term management of mixed low-level wastes. Working groups are formed to address issues raised by the Steering Committee.

Mixed Waste Treatment Project (MWTP)

The MWTP is staffed by representatives from several national laboratories, and is responsible for establishing a technology basis for the treatment of mixed wastes at all DOE sites by using a prototype treatment facility design. The goal of the MWTP is to design a prototype, production-scale facility for the treatment of mixed wastes. The facility will serve as the focal point for technology development and a key resource in site facility planning. Common baseline technologies evaluated through design analyses and modeling, and approved by the regulatory agencies, will provide for cost effective management. Common technologies enhance technology exchange, process improvements, and sharing of lessons learned from operations.

The MWTP has examined the regulatory bases, mixed waste inventories, and status of existing treatment facilities. A baseline flowsheet has been developed based on a modular approach using currently available technologies. The processing concepts are further developed through the functional and operational requirements. The MWTP has prepared costs and schedule estimates for the construction of the prototype facility.

Mixed Waste Integrated Program (MWIP)

The MWIP will provide technology development support for the prototype facility to apply existing technologies to DOE waste streams, and to develop integrated treatment modules. The MWIP also develops new technology to reduce cost relative to available technologies that are the basis for the prototype facility being designed by the MWTP. These new technologies under development have the potential for major process impacts by simplification of the baseline available process and increasing the throughput rate of the treatment process. These advanced technologies will enhance or improve the baseline technologies such that the implemented treatment system is more cost-effective and has a lower risk than the baseline technologies.

Specific technology areas being addressed by the MWIP include waste handling, physical and chemical treatment, waste destruction and stabilization, second-stage destruction and off-gas treatment, and final waste forms for storage/disposal. The technologies developed under the MWIP will be integrated, as appropriate, in the design of the MWTP prototype treatment facility.

Strategic Planning

The strategic planning process includes defining the existing or "current state" of the DOE's MLLW management activities, as well as how DOE should proceed to reach the desired "future state" for MLLW management. A long-range integrated management plan will be developed to accomplish the desired future state. Sandia National Laboratories is responsible for MLLW strategic planning.

Comprehensive Systems Analysis

The MLLW Systems Analysis Methodology is being developed to evaluate the effectiveness and feasibility of various potential TSD Options for MLLW management. The Systems Analysis will cover all components of the MLLW management process from waste generation to final disposal. The Systems Analysis is intended to serve as a decision tool by providing recommendations concerning possible optimized TSD facilities, locations, and technologies for each component of the MLLW management process. Depending upon the level of detail that serve as input into the Methodology, the analysis could be applied to either national or site-specific options analysis. The methodology will be comprised of different modules for analysis of the performance of waste forms and disposal facility technologies, life cycle cost and implementation schedule for alternative TSD options, regulatory compliance, and systemwide "cradle-to-grave" health and safety risks to workers and the public.

COMPONENTS OF THE SYSTEMS ANALYSIS METHODOLOGY

This section discusses the approach being used to develop the MLLW Systems Analysis Methodology and the different components under various stages of development.

Identification of Critical Issues and Data Needs

A population of TSD options is being defined that will be evaluated initially in the comprehensive systems analysis. These include a Reference Case TSD Option and a group of alternative TSD options selected to encompass a broad range of MLLW management alternatives. A TSD option is defined as any combination of methods used during each stage of MLLW management from waste retrieval to disposal, including transportation, treatment, characterization, and storage. Critical issues that must be considered in each stage of the waste management process have been identified and continue to be supplemented or refined as new information becomes available. Data needed to develop and apply the comprehensive systems analysis, as well as sources of existing data are being identified and collected where available. The identification of issues and data needs is expected to be iterative and an ongoing process in the systems analysis.

Development of the Pathways Analysis Model

The Pathways Analysis Model ("Model") is used to evaluate the effectiveness of a wide range of waste forms and disposal facility technologies in complying with the performance objectives of DOE Order 5820.2A. The Model simulates migration and exposure pathways. Migration pathways are routes that transport contaminants to selected locations in media (e.g., groundwater, surface water, soil, and air). Exposure pathways are routes through which contaminants are transported from these selected locations to humans. Exposure pathways include external exposure to contaminated air, water, and soil; inhalation of airborne contaminants; and ingestion of contaminated drinking water, crops, animal products, and aquatic foods. The Model is modular in structure and comprises individual codes or modules approved by the Nuclear Regulatory Commission. These codes simulate specific processes (e.g., transport of contaminants through the unsaturated zone, transport of contaminants in the saturated zone, air transport of contaminants). The modular approach provides flexibility in replacing individual modules with improved codes as they are developed.

A number of physical and chemical property values are required by the various modules and encompass waste form, disposal facility, and site properties. These properties are being compiled from existing waste characterization information and data bases, appropriate documents, applicable relationships and equations, modeling, and expert judgment, as applicable. Uncertainties in property estimates are assessed through Monte

Carlo analysis with Latin Hypercube sampling. A sensitivity analysis is performed to determine which input variables have the most effect on the Model output. The results of the Model are applied in evaluating the long-term risks associated with disposal of MLLW.

Development of Cost and Schedule Information

A generalized methodology is being developed for estimating initial costs of complete "cradle-to-grave" options for the management of DOE MLLW. For the Systems Analysis, initial estimates are defined as rough approximations based upon simple calculations and minimal engineering, and are expected to be within ±40% of actual costs for known technologies.

The development and application of the cost estimation methodology is based on the following steps:

- Collection of historical cost and schedule data for DOE projects/facilities
- Development of individual cost modules for preparing initial estimates of each component of a "cradle-to-grave" MLLW management option (i.e., treatment, transportation, storage, disposal, etc.). Each module will contain a list of cost components for which cost data are needed in order to compile life cycle costs for that particular module
- Application of the cost estimation methodology and schedule data to estimate cost and schedule for alternative MLLW TSD options.

The historical cost data associated with treatment, storage, and disposal at various DOE sites is being collected and examined to determine the extent of cost growth encountered in these past projects. Cost growth refers to the almost universal tendency to underestimate capital costs during early stages of a project due to inadequate understanding of process complexity, especially where new or modified technologies are involved. The individual cost modules will include appropriate adjustments for cost growth based on the data obtained in the first step.

Once developed, the methodology will be applied to estimate initial costs and schedules for different MLLW TSD options. The developed methodology will adopt a generalized approach to cost estimation to the extent possible, and will have the ability to prepare estimates for any MLLW management options that fit within the overall definition of a MLLW TSD option.

Evaluation of Regulatory Compliance Impact

One of the components of MLLW Systems Analysis that could have a major impact on the implementation of a given TSD option is the acceptance and approval of the option by regulatory agencies. Examples of these regulatory impacts include potential state or local provisions that exclude the implementation of certain waste management options (e.g., siting a disposal facility near a sole source aquifer or cost growth and schedule delays that result from difficulties in meeting regulatory requirements). Therefore, an evaluation of the regulatory compliance impact on TSD options is also being performed as part of the Systems Analysis.

The evaluation of regulatory compliance impact is being based on the following information:

- Review and analysis of existing and impending regulations
- Compilation of historical data from the DOE sites on past regulatory experience.

The first of the above steps involves reviewing and analyzing current and impending federal/state/local regulations that may apply to the management of MLLW at each DOE site in the future, and examining the difficulty in implementing various TSD options at these sites in terms of permitting/documentation requirements. Concurrently, the DOE MLLW sites are also being contacted for compilation of information

related to past regulatory experience in the permitting, construction, and operation of existing site facilities. Once the review and analysis is completed, and the actual information has been obtained from the sites, these will be combined to formulate a qualitative scheme for evaluating the regulatory impact of each alternative TSD option.

Development of a Systemwide Risk Assessment

A systemwide risk assessment methodology is being developed to evaluate the health and safety risks associated with each TSD option. The components of a risk are scenarios, probabilities of the scenario leading to consequences, and an assessment of the consequences. A scenario is a particular chain of hypothetical circumstances that may, in principle, release radioactive and/or hazardous material from containment, or cause injuries or fatalities to occupational workers or the general public, during routine or accident conditions. The components of the risk are aggregated to arrive at a human health risk index, special risk factors for maximally exposed individuals and chemically sensitive population sub-groups, and an environmental risk index. Uncertainties in risk calculations and comparisons are analyzed by analytical methods and/or sampling methods. Risk scenarios are being developed, and data needed to assess the risks associated with the various TSD options are being compiled.

Integration of System Analysis Components

The various components of the systems analysis (effectiveness, cost and schedule, regulatory compliance and systemwide health and safety risks) will be integrated to allow quantitative comparison and ranking of the various TSD options. A number of multi-criteria decision techniques are being reviewed to select one or more techniques that will provide the best comparative analysis of the alternative TSD options.

CURRENT STATUS OF SYSTEMS ANALYSIS AND FUTURE ACTIVITIES

The different components of the Systems Analysis Methodology are under various stages of development. The critical issues and data needs that have an impact on the development of the methodology have been identified and are currently being refined. Various NRC-approved codes have been selected for simulating various processes in the Pathways Analysis Model, and the physical/chemical property data needs associated with these codes have been identified.

As of November 1992, work continues on defining a Reference Case TSD option and a group of TSD options based on the critical issues that have already been identified. The initial set of alternative TSD options (including the Reference Case TSD Option) is expected to be completely defined by December 1992 with input from the MLLW Steering Committee. Working groups in the DOE system associated with performance assessment of disposal facilities are being contacted to obtain data for input into the Pathways Analysis Model. Once these data are obtained, the Pathways Analysis Model will be used to perform preliminary evaluations of the effectiveness of the Reference Case TSD Option.

The other components of the Methodology continue to be developed at this time and are expected to be completed by Spring 1993. Once the development of the individual components have been completed, the Methodology will be used to evaluate the group of alterative TSD options in comparison with the Reference Case option and provide preliminary recommendation of DOE systemwide TSD options. These preliminary evaluations are scheduled to be completed in July 1993. Thereafter, the Methodology will be refined continuously as additional data are obtained and uncertainties in the Systems Analysis are reduced to acceptable levels, and it will be used to evaluate additional TSD options or modifications to the options already evaluated. The FY-93 Systems Analysis Methodology Report is scheduled to be published in December 1993.

Hazardous Waste Shipment Data Collection from DOE Sites

Lisa A. Page
Timothy D. Kirkpatrick
Idaho National Engineering Laboratory[a]
EG&G Idaho, Inc.
Idaho Falls, ID 83415

Lee Stevens
Department of Energy Headquarters
Washington, DC

ABSTRACT

Past practices at the U.S. Department of Energy sites for offsite release of hazardous waste are being reviewed to determine if radioactively contaminated hazardous wastes were released to commercial treatment, storage, and disposal facilities. Records indicating the presence of radioactivity in waste shipped to and treated at a commercial incineration facility led to a ban on offsite hazardous waste shipments and investigation of past practices for offsite release of hazardous waste from the DOE sites. A House of Representatives Interior and Insular Affairs Committee oversight hearing on potentially contaminated waste shipments to commercial facilities concluded that the main issue was the lack of a uniform national standard to govern disposal of mixed waste.

Hazardous waste shipment data collected from some DOE sites revealed contaminated waste shipments were sent to commercial treatment, storage, and disposal facilities during the 1980 through 1991 reporting period. These waste shipments were determined to be radioactive based on current standards. To follow up on past shipments of waste from all DOE facilities, a data request was sent to the DOE field sites. The data request required the sites to categorize the past waste shipments according to current standards as clean, likely clean, likely radioactive, or known radioactive.

Recent analyses of the radiological data gathered on past waste shipments conclude that the maximum dose to any individual was less then 0.1 millirem per year. Thus, the dose is 1000 times less than the regulatory standard of 100 millirem per year for radiation doses to the public.

INTRODUCTION

In May 1991, the Louisiana Department of Environmental Quality (DEQ) found evidence that hazardous waste received at the Baton Rouge Rollins Environmental Services (RES) incineration facility from a DOE site was contaminated with uranium. The DEQ inspections revealed that the facility had no regular procedures for testing the radioactivity of the waste it accepts. The DEQ stated that the data sheets accompanying shipments from DOE sites have always contained information on the components in the waste, but that perhaps RES employees did not recognize the uranium-235.[1]

On May 17, 1991, the U.S. Department of Energy Headquarters Environmental Restoration and Waste Management Office of Waste Operations (DOE-HQ, EM-30) directed the field to cease shipments of Resource Conservation and Recovery Act hazardous waste and Toxic Substances Control Act (TSCA) regulated waste. This decision to halt shipments was prompted by instances of sites using differing, and in some cases inappropriate, criteria for determining whether a waste is suitable for offsite release. The hold on shipments continues until the criteria and methods for offsite release are reviewed and approved by DOE-HQ. This moratorium applies to any hazardous wastes that have potential for contamination; that is, waste shall

---

a. Work sponsored by the U.S. Department of Energy, Office of Environmental Restoration and Waste Management, under DOE Idaho Field Office, Contract No. DE-AC07-76ID01570.

be considered to be potentially contaminated if it has been used or stored in radiation control areas that could contain unconfined radioactive material or where exposure to beams of particles capable of causing activation is possible.[2]

In addition to the moratorium on the offsite shipments of RCRA/TSCA wastes, DOE-HQ requested specific information from the DOE sites on past RCRA/TSCA waste shipments. A memorandum from Leo P. Duffy[b] (referred to as the data request in this paper) requested that the sites provide DOE-HQ with detailed information concerning 1984-1991 offsite hazardous waste shipments by September 30, 1991. The referenced memorandum including the data request is provided at the end of this paper.

In September 1991, the EG&G Idaho Inc., Radioactive Waste Technical Support Program (TSP) began supporting DOE-HQ Regulatory Compliance Division (EM-331) in the collection, quality review, electronic storage, and reporting of the shipment data received from the DOE sites.

DATA SUMMARY

Thirty-five sites were expected to respond to the data request, including the Uranium Mill Tailings Remedial Action and the Formerly Utilized Sites Remedial Action Project. Not all the sites were able to report their data by the September 30, 1991, deadline. Twenty-six of the 35 sites reported their data by December 31, 1991. As of October 1992, all sites except three have submitted data. The three exceptions are San Francisco Office sites, Lawrence Berkeley Laboratory, Energy Technology Engineering Center, and Stanford Linear Accelerator Center, which are currently preparing their submittals. Table 1 lists the sites that have responded to the data request.

Records show that 188 commercial treatment, storage, and disposal (TSD) facilities located in 35 states have received wastes from 32 DOE sites for final treatment or disposal. Table 2 lists these final TSD contractors along with the prime/broker contractors who provided management services for the hazardous wastes reported by the DOE sites. As of October 1992, 45,000 cubic meters and 89,000,000 kilograms of hazardous waste shipped to commercial TSD facilities have been reported by 32 DOE sites, as shown in Table 1.

The number of manifests reported by each of the sites ranged from seven to over 2000. Each manifest included anywhere from one to several hundred unique waste descriptions. Approximately 7,500 manifests summarizing over 16,000 waste descriptions have been reported by the 32 sites.

DATA REQUIREMENTS

The DOE-HQ data request instructed the sites to categorize the waste shipments as clean, likely clean, likely radioactive, or known radioactive. Guidance for assigning these categories is provided in the data request. This request asked the sites to complete two types of data forms: summary data forms and detailed data forms.

The summary forms are intended to summarize all the waste a site had shipped to each final commercial TSD contractor for treatment or disposal from 1984 through 1991. The detailed forms request information on specific waste shipments sent to each final TSD contractor on a manifest level. The detailed data form requests descriptions and quantities of each waste type shipped per manifest. The form also requests a list of isotopes that are, or could be, associated with each waste type. A complete submittal from each site includes one summary form for each final commercial TSD facility and all the detailed data forms for every manifest used to ship waste to that TSD facility.

---

b. Memorandum Leo P. Duffy to Distribution, "Data Requirements on Past Shipments of Hazardous/Toxic Wastes Potentially Contaminated With Radioactivity," August 26, 1991.

Bulk or volumetric and surface decision criteria are requested on the summary data form for years 1984 through 1991. The decision criteria are also requested on the detailed data form for each waste categorized as likely clean or likely radioactive. The summary data form also requests how naturally occurring radioactivity was accounted for in the decision criteria.

DATA QUALITY REVIEW PROCESS

The TSP developed guidance for the quality review of the data submittals to help determine whether each site's data submittal meets all the requirements set forth in the DOE-HQ data request. The review process steps through the two data forms, and a check is performed on each data entry field. In performing review of the data submittals, it is necessary to understand the intended use of the data. DOE-HQ intends to use the data for several evaluations, including the following:

- Determine quantities of clean, likely clean, likely radioactive, and known radioactive wastes shipped from DOE sites to commercial TSD facilities for final treatment and/or disposal
- Identify the decision criteria used by each DOE site to determine whether or not waste shipped in the past to commercial TSD facilities was acceptable for offsite release
- Estimate the potential radiological impacts at each TSD contractor from treatment or disposal of DOE wastes.

Each data submittal is examined against the review guidelines, and a preliminary memorandum is written to document the concerns identified during the review. This memorandum contains only comments to be resolved. The memorandum is sent to the respective site, and comment resolution is reached by phone or mail. Once the comments are resolved, a final memorandum is issued and distributed to DOE-HQ and all subcontractor or contractor personnel involved in the data submittal. The final memorandum summarizes the data submittal and documents any outstanding issues and concerns along with all comments and respective resolutions.

Some of the most common concerns identified in the review process include

- Final treatment or disposal facility was not identified for every waste shipment
- Final treatment or disposal facility information, when reported, was incomplete for some waste shipments (e.g., missing Environmental Protection Agency identification number, location, technology, etc.)
- Quantity discrepancy between summary TSD forms and detailed waste description forms
- Missing or incomplete identification of decision criteria in place during the time of shipment to determine offsite releasability of wastes
- Most sites defaulted to identifying DOE Order 5400.5 for surface contamination criteria and did not provide bulk decision criteria
- Missing or incomplete information on how naturally occurring background radiation was accounted for in determining offsite releasability of wastes
- Detailed waste descriptions not provided.

Once the quality review process is complete for a site's data submittal, the data is ready for electronic storage and subsequent reporting.

DATA SYSTEM DESIGN AND DEVELOPMENT

The Hazardous Waste Shipment Data System (HWSDS) was developed to function as a collection and reporting tool for the shipment data. The HWSDS contains shipment manifest information from the detailed data forms. The data system is modeled after this manifest information; that is, each manifest originates at a DOE site, is handled by a prime/broker TSD contractor, and ends at a final TSD facility. Each manifest includes shipment date, number of containers, and estimate of the quantity of waste. A manifest can include different kinds of waste that can go to different final TSD facilities for treatment or disposal. The data system also contains waste descriptions, waste quantities, waste categories (clean, likely clean, likely radioactive, and known radioactive), estimates of isotopes and activity levels, and decision criteria used in determining offsite releasability. This information is stored in dBase data files with standardized database structures. The HWSDS software programs are written in FoxPro and Clipper and are designed to run on PC-based hardware.

The HWSDS contains thousands of records of detailed information from shipping manifests. The data is entered into the HWSDS by manual input using the HWSDS data entry screens or translated into the file structures from various electronic file formats, if available. The sites submitted data using a variety of mass and volume units. Upon entry into the HWSDS, the units are converted to standardized units of cubic meters for volume and kilograms for mass. If bulk decision criteria are provided, they are converted to a standardized concentration of nanocuries per kilogram. When isotope concentrations are provided, they are converted to a standardized concentration of nanocuries per kilogram, and an activity in nanocuries is automatically calculated. A worst case activity estimate is automatically calculated based on standardized bulk decision criteria and waste quantity.

The HWSDS reporting capabilities are designed to allow the shipment data to be viewed from either the perspective of a TSD facility as a receiver of waste, or from the perspective of a DOE site as a sender of waste. The TSD facility is interested in how much waste it received, what types of waste it received, when it received waste, and from whom it received that waste. The site is interested in how much waste it shipped, what types of waste it shipped, when it shipped waste, and to whom it shipped that waste. The HWSDS reports are designed to answer these summary level questions from either perspective along with reporting the detailed level manifest data.

The HWSDS allows network access by multiple users and is designed for easy use with little training.

DATA SYSTEM APPLICATION

The data contained in the HWSDS have been used for multiple purposes and will continue to provide actual hazardous waste shipment quantities from DOE sites to commercial TSD facilities.

The House of Representatives Committee on Interior and Insular Affairs conducted a Congressional investigation of offsite disposal or treatment of solid waste containing radioactive materials from the DOE facilities. The investigation began with a letter to the Secretary of Energy dated December 13, 1991.[c] Oversight and investigation hearings conducted by the House Interior and Insular Affairs Committee began on February 20, 1992. HWSDS shipment data reports provided the basis for DOE's detailed analysis on past shipments of hazardous wastes from the sites to commercial TSD facilities.

To ensure that the public health has not been endangered by the shipment or TSD of the wastes, DOE performed worst case dose assessment for hazardous wastes sent from DOE sites to commercial TSD facilities. HWSDS shipment data reports were used as the basis for calculating the dose assessment.

---

c. Letter from U.S. House of Representatives Committee on Interior and Insular Affairs, George Miller, Chairman to Secretary of Energy, James D. Watkins, December 13, 1991.

The data from the HWSDS has not only provided the basis to calculate dose assessment on past shipments but has also been used by Battelle Pacific Northwest Laboratories to project future dose assessment at TSD facilities receiving wastes from DOE sites. The results of the dose assessment activities will assist in establishing uniform methodologies and criteria for determining offsite releasability of potentially radioactive hazardous wastes from DOE sites.

In addition to providing the HWSDS shipment data to ongoing efforts, the TSP provided copies of the HWSDS to DOE sites that did not have hazardous waste information systems. The DOE sites used the HWSDS to manually input and report their past shipment data for response to the DOE-HQ data request.

PLANNED ACTIVITIES

The hazardous waste data stored in the HWSDS provides a comprehensive collection of historical shipment data in an easily retrievable format. There are many potential uses for this information such as dose assessment activities and other analyses requiring actual quantities of hazardous wastes.

An independent review of the shipment data collected from various sites is planned. The principle objective of this independent review is to determine whether the shipments reported were properly categorized according to DOE-HQ definitions for waste categories (clean, likely clean, likely radioactive, and known radioactive). The process for categorizing shipment data is documented in Figure 1, "Decision Tree for Hazardous Waste Shipment Categorization." These categories were defined in the data request as follows:

Known Radioactive Waste For known radioactive waste, sampling and analysis data show radioactivity *above background* (background includes natural levels of radiation in materials) or surface contamination exceeds DOE Order 5400.5 guidelines.

Thus, this is waste for which sampling and analysis shows radioactivity was added to the volume or bulk of the waste as a result of DOE operations (i.e., radioactivity is present above background), or survey results show that surface contamination levels exceeding DOE Order 5400.5 guidelines.

Clean Waste Clean waste originates outside a radioactive materials management area (RMMA) or is waste that originates within an RMMA for which documented evidence of administrative controls, process knowledge, or sampling and analysis data show that no radioactivity was added to the waste bulk or volume by DOE operations and the surface contamination is less than DOE Order 5400.5 guidelines.

Likely Radioactive Waste Likely radioactive waste is waste that is not categorized as known radioactive or clean but is similar in form/type and originates from the same process/areas as known radioactive waste.

For these wastes, documented evidence of administrative controls, process knowledge, or analytical data are not available to show that no radioactivity was added to the waste bulk or volume by DOE operations.

Likely Clean Waste Likely clean waste is waste that originated in an RMMA but is not categorized as known radioactive, likely radioactive, or clean.

For these wastes, documented evidence of administrative controls, process knowledge, or analytical data are not available to show that no radioactivity was added to the waste bulk or volume by DOE operations, and the surface contamination is less than DOE Order 5400.5 guidelines.

An independent review of the shipment data reported by the Savannah River Site (SRS) is near completion. The overall hazardous waste management and offsite release process from 1987-1991 will be documented in the SRS Offsite Hazardous Waste Shipment Data Validation Report. This report will document sampling and analysis and surface surveying techniques and procedures used before offsite release at SRS along with the proper categorization of SRS hazardous waste shipments.

CONCLUSION

Among the issues that have surfaced since the RES incidence are the inconsistent, and sometimes incorrect, manner in which the sites determine whether a waste is suitable for offsite release. Inconsistent methodologies for testing potential radioactivity in hazardous wastes and inconsistent decision criteria for determining whether the waste is suitable for offsite release have been identified. The "Performance Objective for Certification of Non-Radioactive Hazardous Waste"[3] was written to provide requirements for determining whether a RCRA hazardous or TSCA regulated waste is radioactive. The requirements of this document and other DOE-HQ efforts for setting limits for levels of radioactivity that can be safely released for treatment or disposal are activities toward establishing some consistency in determining whether waste is suitable for offsite release.

Analyses of past waste shipments conclude that the maximum dose to any individual was less then 0.1 millirem per year. Thus, the dose is 1000 times less than the regulatory standard of 100 millirem per year for radiation doses to the public.

TABLE 1 10/18/92

OFFSITE HAZARDOUS WASTE SHIPMENT
SITE SUMMARY FOR ALL FINAL TREATMENT/STORAGE/DISPOSAL FACILITIES

Calendar Year: 1984-1991[a]

Site Name	Volume (m3)	Mass (kg)	Estimated Activity (mCi)
AMES Laboratory	27.95	-	0.000
Argonne National Laboratory - East	1776.46	66047.80	0.000
Brookhaven National Laboratory	681.18	-	0.000
Colonie Interim Storage Site	0.28	24927.41	0.000
Feed Materials Production Center	7.91	811.03	0.000
FERMI National Accelerator Laboratory	958.28	330876.33	0.000
Grand Junction Project Office	8.06	5090.73	0.000
Hanford Site	41.83	3749673.16	0.000
Idaho National Engineering Laboratory	719.82	1119416.39	0.000
Inhalation Toxicology Research Institute	92.80	-	0.000
Kansas City Plant	492.01	56582574.10	0.000
Lab for Energy-Related Health Research	22.04	5542.70	0.000
Lawrence Livermore National Laboratory	18862.92	4860295.59	0.000
Los Alamos National Laboratory	1934.04	2713422.52	0.000
Mound Plant	-	936896.04	0.000
Nevada Test Site	14043.41	383242.12	0.000
Niagra Falls Storage Site	-	340898.54	0.000
Oak Ridge Gaseous Diffusion Plant[a]	-	1519529.99	24.909
Oak Ridge National Laboratory[a]	-	1368570.86	0.000
Paducah Gaseous Diffusion Plant[a]	-	1659185.27	29.428
Pantex Plant	1097.59	-	0.000
Pinellas Plant	990.81	419366.80	0.000
Portsmouth Gaseous Diffusion Plant[a]	-	662731.00	6.093
Princeton Plasma Physics Laboratory	667.72	855273.90	0.000
Rocky Flats Plant	289.35	305865.52	0.000
Sandia National Laboratory - Albuquerque, NM	-	1673451.00	0.000
Sandia National Laboratory - Livermore, CA	2626.85	3658.73	0.000
Savannah River Site	-	825319.80	0.000
Uranium Mill Tailings Remedial Action	197.97	3538.08	0.000
West Valley Demonstration Project	-	41186.85	0.000
Weldon Spring Site Remedial Action Project	103.57	133808.37	0.000
Y12 Plant[a]	-	4282262.99	45.062
Shipment Quantity Totals	45642.85	84873463.62	105.492

a. Oak Ridge Sites include shipments from 1980-1991.

TABLE 2

COMMERCIAL HAZARDOUS WASTE TREATMENT, STORAGE, AND DISPOSAL FACILITIES

TSD Name	City, State	EPA ID Number
7-7 TRANSPORTATION	WADSWORTH, OH	OHD000772558
ADCOM EXPRESS	TINLEY PARK, IL	ILT180015273
ALLIED TECHNOLOGY GROUP	FREMONT, CA	CAD982462020
ALTAMONT SANITARY LANDFILL	LIVERMORE, CA	CAD981382732
ALTAMONT SANITARY LANDFILL	LIVERMORE, CA	CAX000084459
ALTERNATE ENERGY RESOURCES	AUGUSTA, GA	GAD033582461
AMERICAN CHEMICAL & REFINING CO.	WATERBURY, CT	CTD001184894
AMERICAN CHEMICAL & REFINING CO.	VILLA PARK, IL	ILD000675249
AMERICAN ENVIRONMENTAL MGMT CO.	RANCHO CORDOVA, CA	CAD980884183
AMERICAN RECOVERY	BALTIMORE, MD	MDD074923392
AMERICAN SMELTING AND REFINING	DUARTE, CA	-
AMERICAN WASTE	MAYWOOD, IL	ILD000716894
ANDERSON SOLID WASTE, INC.	ANDERSON, CA	CAD981388952
APPROPRIATE TECHNOLOGIES II	CHULA VISTA, CA	CAT080010101
APTUS	COFFEYVILLE, KS	KSD981506025
APTUS	LAKEVILLE, MN	MND980791321
APTUS	GRANTSVILLE, UT	UTD981552177
AQUA-TECH ENVIRONMENTAL	GREER, SC	SCD058754789
AQUA-TECH ENVIRONMENTAL	PORT WASHINGTON, WI	WID066888017
ASH GROVE CEMENT CO.	LOUISVILLE, NE	NED007260672
ASH GROVE CEMENT CO.	FOREMAN, AR	ARD981512270
ASH GROVE CEMENT CO.	CHANUTE, KS	KSD031203318
AVGANIC INDUSTRIES	COTTAGE GROVE, WI	WID000808824
B & J SANITARY LANDFILL	VACAVILLE, CA	CAD982042475
BARON-BLAKESLEE	NEWARK, CA	CAD074644659
BARON-BLAKESLEE	CICERO, IL	ILD051937068
BATTERY DISPOSAL TECHNOLOGY	CLARENCE, NY	NYD000632372
BEAVER OIL	HODGKINS, IL	ILD064418353
BEST ENVIRONMENTAL	CHANNAHON, IL	-
BETHLEHEM APPARATUS	HELLERTOWN, PA	PAD002390961
BKK CORPORATION	WEST COVINA, CA	CAD067786749
BOLIDEN METECH	GILROY, CA	CAD077182293
BRES-LUBE USA	EAST CHICAGO, IN	-
BROCO, INC.	RIALTO, CA	CAT080022148
BURLINGTON ENVIRONMENTAL	WASHOUGAL, WA	WAD092300250
C.P. CHEMICALS, INC.	SUMTER, SC	SCD070371885
C.P. INORGANICS	JOLIET, IL	ILD062480850
C.R. WARNER CO.	WOODSTOWN, NJ	NJD011881174
CALIFORNIA A.E.T.C.	RICHMOND, CA	CAT080014079
CALIFORNIA OIL RECYCLERS	NEWARK, CA	CAD980695761
CALIFORNIA SOLVENT RECYCLERS	EAST PALO ALTO, CA	CAT080031248
CAPITAL SILVER SERVICES INC.	GALLATIN, TN	TND078221249
CASMALIA RESOURCES	CASMALIA, CA	CAD020748125
CECOS	LIVINGSTON, LA	LAD000618298
CECOS	BRISTOL, CT	CTD000604488
CECOS	NIAGARA FALLS, NY	NYD080336241
CECOS	WILLIAMSBURG, OH	OHD087433744
CECOS	LAKE CHARLES, LA	LAD000618256
CHEM CLEAR	CHESTER, PA	PAD000731026
CHEM-MET SERVICES	WYANDOTTE, MI	MID096963194
CHEMICAL ANALYSIS	ROMULUS, MI	MID985568021
CHEMICAL CONSERVATION CORP.	UNKNOWN, NJ	NJD097407084
CHEMICAL PROCESSORS, INC.	SEATTLE, WA	WAD000812909
CHEMICAL PROCESSORS, INC.	KENT, WA	WAD991281767
CHEMICAL RECLAMATION SERVICES	AVALON, TX	TXD046844700

COMMERCIAL HAZARDOUS WASTE TREATMENT, STORAGE, AND DISPOSAL FACILITIES

TSD Name	City, State	EPA ID Number
CHEMICAL WASTE MANAGEMENT	FARMINGDALE, NY	NYD000691949
CHEMICAL WASTE MANAGEMENT	NEWARK, NJ	NJD089216790
CHEMICAL WASTE MANAGEMENT	WEST CARROLTON, OH	OHD093945293
CHEMICAL WASTE MANAGEMENT	EMELLE, AL	ALD000622464
CHEMICAL WASTE MANAGEMENT	PHOENIX, AZ	AZT050010180
CHEMICAL WASTE MANAGEMENT	FREMONT/COALINGA, CA	CAD003986718
CHEMICAL WASTE MANAGEMENT	KETTLEMAN CITY, CA	CAT000646117
CHEMICAL WASTE MANAGEMENT	POMPANO BEACH, FL	FLD000776708
CHEMICAL WASTE MANAGEMENT	MODEL CITY, NY	NYD049836679
CHEMICAL WASTE MANAGEMENT	CHICAGO, IL	ILD000672121
CHEMICAL WASTE MANAGEMENT	SAUGET, IL	ILD098642424
CHEMICAL WASTE MANAGEMENT	BRAINTREE, MA	MAD053452637
CHEMICAL WASTE MANAGEMENT	PORT ARTHUR, TX	TXD000838896
CHEMICAL WASTE MANAGEMENT	SULPHUR, LA	LAD000777201
CHEMICAL WASTE MANAGEMENT	MILLINGTON, IN	IND000772186
CHEMICAL WASTE MANAGEMENT	KANSAS CITY, MO	MOD300011194
CHEMICAL WASTE MANAGEMENT	FORT WAYNE, IN	IND078911146
CHEMICAL WASTE MANAGEMENT	FORT WAYNE, IN	IND099202681
CHEMICAL WASTE MANAGEMENT	GENEVA, IL	-
CHEMICAL WASTE MANAGEMENT	ALSIP, IL	ILD074411745
CHEMICAL WASTE MANAGEMENT (CID CORP)	CALUMET CITY, IL	ILD010284248
CHEMICAL WASTE MGMT. OF THE N.W.	ARLINGTON, OR	ORD089452353
CLEAN HARBORS	WOBURN, MA	MAD039322250
CLEAN HARBORS	NATICK, MA	MAD980523203
CLEAN HARBORS OF CHICAGO	CHICAGO, IL	ILD000608471
CLEAN HARBORS OF CLEVELAND	CLEVELAND, OH	OHD000724153
CLEMBOX DEBRIS AND RECYCLING	SAN FRANCISCO, CA	-
CONTINENTAL/RESOURCE RECOVERY	HANIBAL, MO	MOD054018288
CUSTOM ENVIRONMENTAL TRANSPORT	UNKNOWN, LA	LAD981059017
CUSTOM ENVIRONMENTAL TRANSPORT	UNKNOWN, DE	DED980918858
CYANOKEM	DETROIT, MI	MID098011992
CYLINDER RECON COMPANY	KEARNY, NJ	NJD000632240
CYPRUS MIAMI MINING CO	CLAYPOOL, AZ	AZD060624251
DAVID H. FELL & CO. INC.	LOS ANGELES, CA	CAD981384332
DEMCO	COALFIELD, TN	INACTIVE1986
DEMENNO/KERDOON	COMPTON, CA	CAT080013352
DESERT MOUNTAIN OIL	SPARKS, NV	NVD980892632
DETREX	VERNON, CA	CAD020161642
DIVERSIFIED SOURCES & SERVICES	KINGSTON, TN	TND982109142
DIVERSIFIED SYSTEMS, INC.	ATHENS, TN	TND034547141
DREW RESOURCES	BERKELEY, CA	CAD070148432
E.I. DUPONT & CO.	DEEPWATER, NJ	NJD002385730
EASTERN SMELTING	LYNN, MA	MAD001020775
EG&G IDAHO, INC., C\O US DEPARTMENT	SCOVILLE, ID	ID4890008952
ENGLEHARD INDUSTRIES WEST, INC.	ANAHEIM, CA	CAD000612150
ENSCO	WHITE BLUFF, TN	TND980729305
ENSCO	EL DORADO, AR	ARD069748192
ENSCO	DALTON, GA	GAD000222083
ENSR	PHILADELPHIA, PA	-
ENSR OPERATIONS	CANTON, OH	OHD981100969
ENVIROCHEM SERVICES	ZIONSVILLE, IN	-
ENVIRONMENTAL ENTERPRISES	CINCINNATI, OH	OHD083377010
ENVIRONMENTAL INT'L ELECTRICAL SERVICES	KANSAS CITY, MO	MOD980973556
ENVIRONMENTAL MANAGEMENT & CONTROLS	TURLOCK, CA	CAT080011828
ENVIRONMENTAL PACIFIC	AMITY, OR	ORD980977334
ENVIRONMENTAL SPECIALISTS, INC.	ALBUQUERQUE, NM	NMD986669216
ENVIRONMENTAL WASTE ENTERPRISES	ELOY, AZ	AZD980816102

COMMERCIAL HAZARDOUS WASTE TREATMENT, STORAGE, AND DISPOSAL FACILITIES

TSD Name	City, State	EPA ID Number
ENVIRONMENTAL WASTE RESOURCES	WATERBURY, CT	CTD072138969
ENVIROSAFE SERVICES OF IDAHO	GRANDVIEW, ID	IDD073114654
ENVIROTECH	MORRIS, IL	-
ERICKSON, INC.	RICHMOND, CA	CAD009466392
ETICAM	EAST FERNLEY, NV	NVD980895338
EVANS DRUM, CO.	RICHMOND, CA	CAD000415232
EVERGREEN LANDFILL	NORTHWOOD, OH	OHD068111327
EVERGREEN OIL	NEWARK, CA	CAD980887418
EWR	COAL CITY, IL	ILD087157251
EXCELTECH, INC.	FREMONT, CA	CAD980815054
EXCELTRANS, INC.	BENICIA, CA	CAD981982663
FONDESSY ENTERPRISES	OREGON, OH	OHD045243706
FORWARD INCORPORATED	STOCKTON, CA	CAD990794133
FOX VALLEY DISPOSAL	BATAVIA, IL	-
FRONTIER CHEMICAL	NIAGARA FALLS, NY	NYD043815703
G&L RECOVERY SYSTEMS	ASHTABULA, OH	OHD981093420
GENERAL BATTERY	READING, PA	PAD990753089
GENERAL ELECTRIC	CHICAGO, IL	ILD070015714
GENERAL ELECTRIC COMPANY	DENVER, CO	COD062753702
GENERAL ELECTRIC COMPANY	CINCINNATI, OH	OHD074713561
GIANT RESOURCE RECOVERY CO.	HARLEYVILLE, SC	SCD003351699
GIBRALTAR CHEMICAL RESOURCES	WINONA, TX	TXD000742304
GIBSON OIL AND REFINING COMPANY	BAKERSFIELD, CA	CAD980003177
GNB, INC.	VERNON, CA	CAD097854541
H&H SHIP SERVICE	SAN FRANCISCO, CA	CAD004771168
HALLMARK METALS, INC.	MT. VERNON, WA	WAD980976906
HAZ CONTROL INC.	GILROY, CA	CAD000628149
HAZCHEM ENVIRONMENTAL SERVICES	TUCSON, AZ	AZD982484578
HEAT ENERGY, INC.	DALLAS, TX	TXD980624035
HERITAGE ENVIRONMENTAL	INDIANAPOLIS, IN	IND093219012
HERITAGE ENVIRONMENTAL	ROMEOVILLE, IL	-
HIGH VOLTAGE MAINTENANCE	DAYTON, OH	OHD004483210
HRI/KDM	SAN ANTONIO, TX	TXD052649027
HUNT CHEMICAL CORP.	ROLLING MEADOWS, IL	ILT053218251
HUNTER/KECK	WEST CHICAGO, IL	-
HYDROCARBON RECYCLERS, INC.	TULSA, OK	OKD000632737
HYDROCARBON RECYCLERS, INC.	WICHITA, KS	KSD007246846
INDUSTRIAL ELEC. ENGINEERING & TESTING	ALBUQUERQUE, NM	-
INTERNATIONAL METALS RECLAMATION CO.	ELLWOOD CITY, PA	PAD087561015
IT CORP OIL REPROCESS FACILITY	MARTINEZ, CA	CAD000092619
IT CORPORATION	MARTINEZ, CA	CAD000094771
IT CORPORATION	BENICIA, CA	CAD000060012
IT CORPORATION	SAN JOSE, CA	CAD000633115
IT TRANSPORTATION	SAN JOSE, CA	CAD000063311
KEERS ENVIRONMENTAL	ALBUQUERQUE, NM	NMD147273528
KETTLEMAN HILLS LANDFILL	KETTLEMAN CITY, CA	CAT000646083
KINSBURSKY	ANAHEIM, CA	CAD088504881
LAIDLAW ENVIRONMENTAL SERVICES	REIDSVILLE, NC	NCD000648451
LAIDLAW ENVIRONMENTAL SERVICES	BESSEMER, OH	OHD980569438
LAIDLAW ENVIRONMENTAL SERVICES	PINEWOOD, SC	SCD070375985
LAIDLAW ENVIRONMENTAL SERVICES	MARTINEZ, CA	CAD982373664
LAIDLAW ENVIRONMENTAL SERVICES	ROEBUCK, SC	SCD981467616
LAIDLAW ENVIRONMENTAL SERVICES	GREENBRIER, TN	TND000645770
LAIDLAW ENVIRONMENTAL SERVICES	BARTOW, FL	FLD980729610
LAIDLAW ENVIRONMENTAL SERVICES	LAUREL, MD	MDD980554653
LAIDLAW ENVIRONMENTAL SERVICES	CLEARWATER, FL	FLD981474802

COMMERCIAL HAZARDOUS WASTE TREATMENT, STORAGE, AND DISPOSAL FACILITIES

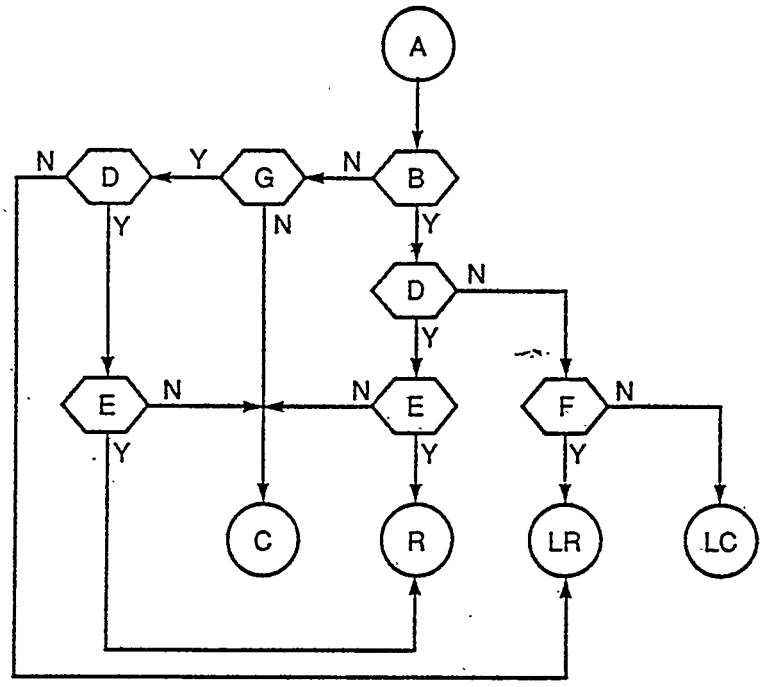
TSD Name	City, State	EPA ID Number
LAIDLAW ENVIRONMENTAL SERVICES	PECATONICA, IL	ILD980502744
LAIDLAW ENVIRONMENTAL SERVICES	CROWLEY, LA	LAD079464095
LILLYBLAD PETROLEUM, INC.	TACOMA, WA	WAD027543032
LLNL	LIVERMORE, CA	CA2890012584
LLNL SITE 300	TRACY, CA	CA2890090002
LWD	CALVERT CITY, KY	KYD088438817
M&M CHEMICAL AND EQUIPMENT	ATTALLA, AL	ALD070513767
MALONE SERVICE COMPANY	TEXAS CITY, TX	TXD027147115
MAR-COR INDUSTRIES	CHICAGO, IL	ILD984774695
MAR-COR INDUSTRIES	NORTHBROOK, IL	ILD032381550
MAR-COR INDUSTRIES	SKOKIE, IL	ILD982069601
MARBLEHEAD MNT. FACILITY	GRANTSVILLE, UT	UTD051294502
MARINE SHALE PROCESSORS	AMELIA, LA	LAD981057706
MERCURY REFINING, INC.	ALBANY, NY	NYD048148175
METCALF AND ASSOC.	ST. CHARLES, MO	-
MICHIGAN DISPOSAL	BELLEVILLE, MI	MID000724831
MICRO METALLICS CORP.	SAN JOSE, CA	CAD069124717
MID STATES RECYCLING	ROSEMONT, IL	ILD052350402
MONAHANS SANITARY LANDFILL	MONAHANS, TX	-
MR. FRANK	MATTESON, IL	ILD069506160
NATIONAL ENVIRONMENTAL CORP.	UNKNOWN, CA	CAD980674022
NOBLE OIL CO.	VINCETOWN, NJ	NJD980649024
NORRIS INDUSTRIES	LOS ANGELES, CA	CAD097030993
NORTH AMERICAN ENVIRONMENTAL	TACOMA, WA	WAD980978142
NORTH TEXAS CEMENT CO.	MIDLOTHIAN, TX	TXD007926496
NORTHWEST ENVIROSERVICE, INC.	SEATTLE, WA	WAD058367152
NSSI RECOVERY	HOUSTON, TX	TXD928560294
OHM RESOURCE RECOVERY	MORROW, GA	GAD096629282
OIL & SOLVENT PROCESS CO.	AZUSA, CA	CAD008302903
OIL & SOLVENT PROCESS CO.	HENDERSON, CO	COD980591184
OIL PROCESS CO.	LOS ANGELES, CA	CAD050806850
OKLAHOMA INDUSTRIAL SILVER	EDMOND, OK	OKD981057722
OLDOVER CORP.	GREEN COVE SPRINGS, FL	FLD000737312
OMEGA RECOVERY SERVICES	WHITTIER, CA	CAD042245001
PACIFIC ENERGY AND MINING	RENO, NV	-
PACIFIC TREATMENT	SAN DIEGO, CA	CAD095894556
PACIFIC WEST NUCLEAR ENVIRONMENTAL	SAN DIEGO, CA	CAR990019226
PATCHEM/RIVER CEMENT	FESTUS, MO	MOD050232560
PCB INC	KANSAS CITY, KS	KSD980963565
PCB INC OF MISSOURI	KANSAS CITY, MO	MOD980633044
PEN-ROB CORPORATION LANDFILL	JOSEPH CITY, AZ	AZ0000000150
PETRO-CHEM PROCESSING INC.	DETROIT, MI	MID980615291
PETROCHEM	LEMONT, IL	ILD085349264
PETROLEUM RECYCLER CORP.	PATTERSON, CA	CAD083166728
PETROLEUM-RECYCLING, INC.	SIGNAL HILL, CA	CAT080011059
PGP INDUSTRIES	SANTA FE SPRINGS, CA	CAD060398229
POLLUTION CONTROL	EAST CHICAGO, IN	IND000646943
PPM INC.	KANSAS CITY, MO	MOD069277549
PPM INC.	PHILADELPHIA, PA	PAD981113749
QUADREX	GAINESVILLE, FL	FLD980711071
QUICKSILVER	BRISBANE, CA	CAD981424732
R&D FABRICATING AND MANUFACTURING	COLFAX, LA	LAD981055791
RADIAC RESEARCH	BROOKLYN, NY	NYD049178296
RAMOS ENVIRONMENTAL SERVICES	WEST SACRAMENTO, CA	CAD044003556

COMMERCIAL HAZARDOUS WASTE TREATMENT, STORAGE, AND DISPOSAL FACILITIES

TSD Name	City, State	EPA ID Number
RAMSEY CHEMICALS	VALDOSTA, GA	GAD093380814
RAY TECH TRANSPORT	TINLEY PARK, IL	ILD98093403
RECYCLING RESOURCES	PHOENIX, AZ	AZD049318009
RESOURCE SERVICES	SPRINGFIELD, MO	MOD980688840
REZULTZ	VINELAND, NJ	NJD045995693
RHO-CHEM	INGLEWOOD, CA	CAD008364432
RINCHEM COMPANY, INC.	ALBUQUERQUE, NM	NMD002208627
ROLLINS ENVIRONMENTAL SERVICES	BRIDGEPORT, NJ	NJD053288239
ROLLINS ENVIRONMENTAL SERVICES	BATON ROUGE, LA	LAD010395127
ROLLINS ENVIRONMENTAL SERVICES	DEER PARK, TX	TXD055141378
ROLLINS ENVIRONMENTAL SERVICES	BENSENVILLE, IL	-
ROMIC CHEMICAL CORP.	CHANDLER, AZ	AZD009015389
ROMIC CHEMICAL CORP.	EAST PALO ALTO, CA	CAD009452657
ROSS ELECTRIC OF WASHINGTON, INC.	CHEHALIS, CA	CAD980835268
ROSS INCINERATION SERVICES	GRAFTON, OH	OHD048415665
S&W WASTE	SOUTH KEARNY, NJ	NJD991291105
S.D. MEYERS	TALLMADGE, OH	OHD053576294
SAFETY KLEEN	PASCO, WA	WAD980978746
SAFETY KLEEN	ALBUQUERQUE, NM	NMD000804294
SAFETY KLEEN	AMARILLO, TX	TXD000747410
SAFETY KLEEN	WICHITA FALLS, TX	TXD000747428
SAFETY KLEEN	DENTON, TX	TXD077603371
SAFETY KLEEN	NEW CASTLE, KY	KYD053348108
SAFETY KLEEN	ELGIN, IL	ILD000805911
SAFETY KLEEN	SCHAUMBURG, IL	ILD079749073
SAFETY KLEEN	OAKLAND, CA	CAD053044053
SAFETY KLEEN	SALIDA, CA	CAT000613968
SAFETY KLEEN	RANCHO CORDOVA, CA	CAT000613950
SAFETY KLEEN	TIPP CITY, OH	OHD980683155
SAFETY SPECIALIST, INC.	SANTA CLARA, CA	CAD010917805
SANITARY SYSTEMS SERVICE	PITTSBURGH, PA	-
SEABOARD CHEMICAL	JAMESTOWN, NC	NCD071574164
SETTLERS HILL	BATAVIA, IL	-
SILVER RECOVERY ASSOCIATES	LONGMONT, CO	COD789008967
SOL-PRO	TACOMA, WA	WAD981769110
SOLOMON ELECTRIC SUPPLY	KANSAS CITY, MO	KSD054757646
SOLVENT SERVICES, INC.	SAN JOSE, CA	CAD059494310
SOLVENTS RECOVERY SERVICES OF NEW JERSEY	LINDEN, NJ	NJD002182897
SOUTH WINDSOR METALLURGICAL	SOUTH WINDSOR, CT	CTD981205271
SOUTHDOWN ENVIRONMENTAL SYSTEMS	CINCINNATI, OH	OHD000816629
SOUTHERN CALIFORNIA CHEMICAL	SANTA FE SPRINGS, CA	CAD008488025
SOUTHERN CALIFORNIA CHEMICAL	GARLAND, TX	TXD047823265
SOUTHWEST HAZARD CONTROL	TUCSON, AZ	AZD980887434
SPECTRON	ELKTON, MD	MDD000218008
STAMCO	SAN MARTIN, CA	CAD063547996
SYSTECH ENVIRONMENTAL	LEBEC, CA	CAT080031628
SYSTECH ENVIRONMENTAL	FREDONIA, KS	KSD980633259
SYSTECH ENVIRONMENTAL	PAULDING, OH	OHD005048947
TCD SERVICES	MORRIS, IL	ILD087153995
TECHNICAL ENVIRONMENTAL SERVICES	LAPORTE, TX	TXD982290140
TEXAS INDUSTRIES	MIDLOTHIAN, TX	TXD007349327
THE NDL ORGANIZATION	PEEKSKILL, NY	NYD045662921
THERMALKEM	ROCK HILL, SC	SCD044442333
TIPTON ENVIRONMENTAL TECHNOLOGY	TIPTON, MO	MOD981506611
TRANSTEC ENVIRONMENTAL	CANTON, OH	OHD981954571
TREATMENT TX-1	HOUSTON, TX	TXD055135388
TRICIL	MEMPHIS, TN	TND000772277

COMMERCIAL HAZARDOUS WASTE TREATMENT, STORAGE, AND DISPOSAL FACILITIES

TSD Name	City, State	EPA ID Number
TECHNICAL TRANSPORT INC.	UNKNOWN, TX	TXD987986106
TRINITY CHEMICAL	MOUND VALLEY, KS	KSD980687065
U.S. ECOLOGY	BEATTY, NV	NVT330010000
U.S. ECOLOGY	RICHLAND, WA	WAD000000025
U.S. ECOLOGY	PLEASANTON, CA	-
UNISON TRANSFORMER SERVICES	CLEARFIELD, UT	UTD982589145
UNISON TRANSFORMER SERVICES, INC.	YERINGTON, NV	NVD980894588
UNITED INDUSTRIAL SERVICES	MERIDEN, CT	CTD021816889
USPCI	WAYNOKA, OK	OKD065438376
USPCI	CLIVE, UT	UTD991301748
USPCI	OKLAHOMA CITY, OK	OKT410010474
VAN WATERS & ROGERS	LOS ANGELES, CA	CAD080029671
WASTE CONVERSION	HATFIELD, PA	PAD085690592
WASTE OIL REPROCESS FACILITY	OAKLAND, CA	CAD000626515
WASTE RESEARCH AND RECLAMATION	EAU CLAIRE, WI	WID990829475
WAYNE DISPOSAL	DEARBORN, MI	MID048090633
WEST CONTRA COSTA SANITARY LANDFILL	RICHMOND, CA	CAD041844002
WESTERN DRUMS, INC.	HAYWARD, CA	CAD087210399
WESTINGHOUSE	GLENDALE, IL	-
WORLD RESOURCES CO	PHOENIX, AZ	AZD980735500
YENTER ENVIRONMENTAL SERVICES	LONGMONT, CO	COD982586968



A Hazardous waste (HW) that has been shipped to a commercial TSD

B Was the waste generated in an area that meets radioactive materials management area (RMMA) definition?

D Does analysis and/or surface survey data exist for this HW?

E Does analytical data indicate radioactivity was added to waste bulk or volume or that surface contamination exceeds DOE 5400.5 limits?

F Is the HW similar in form/type as known radioactive waste?

G Is there any reason to believe that the HW could have been radioactively contaminated by DOE operations?

C Clean
LC Likely clean
R Known radioactive
LR Likely radioactive

T92 0795

Figure 1. Decision tree for hazardous waste shipment categorization.

United States Government

Department of Energy

memorandum

Idaho Field Office

DATE: August 26, 1991

SUBJECT: Data Requirements on Past Shipments of Hazardous/Toxic Wastes Potentially Contaminated with Radioactivity

TO: EM-331 (Stevens, 3-7133)
Distribution

Attached is a data requirements document for the referenced waste shipments. This consolidates and supersedes all previous requests contained in memoranda from Jill Lytle dated May 17, June 7, and June 28, 1991.

In view of the Department's need to protect public health and the environment through responsible management of our operations involving radioactive materials and in view of the public concern we anticipate as a result of imminent announcements on past shipments of potentially contaminated wastes, a full response is required by September 30, 1991. If you are unable to make a firm commitment to meeting this deadline, notify me immediately. This situation is among the highest priorities faced by the Department.

To facilitate our followup on past shipments of wastes, you are encouraged to make partial submittals of significant quantities or types of wastes, rather than hold up this information until all your past shipments have been reviewed. If partial submittals are made, indicate this clearly and state that more data are expected to follow. In any case, complete submittals are required by the deadline.

Your are to use the format specified in the attachment. The data will be entered into an electronic database using DBase-4. It will be most helpful if you can submit the data on computer disks in the DBase-4 format, or in some other readily translatable format. The EM-331 staff will be working with you to investigate the feasibility of submittals on electronic media.

The data is to be submitted to Lee Stevens, EM-331, of my staff. Also direct all questions and requests for instructions or assistance to him.

Leo P. Duffy
Director
Office of Environmental Restoration
and Waste Management

3 Attachments

Attachment 1

Standard Format for Summary Data
on Off Site Shipment of RCRA/TSCA Waste

1. Final TSD Contractor:(1) _____
2. Type(s) of service:(2) _____
3. Field Office: _____
4. DOE Site: _____
5. Contractor:(3) _____
6. Prime Contractor:(4) _____

_____

_____

Calendar Year	Radioactive Waste	Clean Waste	Suspect Waste	
			Highly Suspect	Questionable
1991[5]	(6)[7]			
1990				
1989				
1988				
1987				
1986				
1985				
1984				

(5)(7)

Standard Format for Detailed Data
for Off Site Shipments
of RCRA/TSCA Radioactive and Suspect Waste

Field Office:

DOE Site: _____

Contractor:(3) _____

1. Prime Contractor:(4) _____
2. Date of Shipment: _____
3. Manifest Number: _____
4. Number of Containers: Waste Volume:

Radioactive Waste:	_____	_____
Suspect Waste:	_____	_____
Clean Waste:	_____	_____
Total:	_____	

FOR RADIOACTIVE WASTE

5. Waste Description:(8) Volume:(9)

a.	_____	_____
b.	_____	_____
c.	_____	_____

6. Isotopic Concentration:(8)

a.	_____	_____	_____	_____	_____
b.	_____	_____	_____	_____	_____
c.	_____	_____	_____	_____	_____

7. TSD Facility where Final Treatment or Disposal Occurred: (1)(8)

a. _____
b. _____
c. _____

FOR SUSPECT WASTE

8. Decision Criteria: Bulk- _____
   Surface- _____

9. Highly Suspect Waste Description:(8) Volume:(10)
   a. _____ _____
   b. _____ _____
   c. _____ _____

10. Potential Isotopes:(8)(11)
    a. _____ _____ _____ _____ _____
    b. _____ _____ _____ _____ _____
    c. _____ _____ _____ _____ _____

11. TSD Facility where Final Treatment or Disposal Occurred:(8)
    a. _____
    b. _____
    c. _____

12. Undocumented Waste Description:(8) Volume:(10)
    a. _____ _____
    b. _____ _____
    c. _____ _____

13. Potential Isotopes:(8)(11)
    a. _____ _____ _____ _____ _____
    b. _____ _____ _____ _____ _____
    c. _____ _____ _____ _____ _____

14. TSD Facility where Final Treatment or Disposal Occurred:(1)(8)
    a. _____
    b. _____
    c. _____

Instructions for Completing Standard Formate Data Forms

Following are definitions, explanations and directions for submitting data in response to the attached request.

1. Definitions

Radioactive waste is any waste (that should be) managed for its radioactive content, which is not otherwise regulated for that radioactive content (e.g., regulated by the Clean Air Act, Clean Water Act, etc.). If a material was received as nonradioactive, any resulting waste is not a radioactive waste if it meets the following conditions:

1) it contains no added radioactivity in volume or bulk resulting from DOE operations; and

2) it contains no surface radioactivity above limits established in DOE Orders or guidance [e.g., surface contamination limits and requirements of DOE Order 5400.5, II.5.c.(1)].

For purposes of this historical data, radioactive waste is waste for which sampling and analysis data indicate radioactivity above background (background includes natural levels of radiation in materials) or for which surface contamination exceeds the DOE Order 5400.5 guidelines.

Clean waste is waste originating outside a radioactive materials management area (RMMA) or waste originating within an RMMA for which documented evidence of administrative controls, process knowledge, survey or sampling and analysis indicates no radioactivity was added to the waste volume by DOE operations and for which the surface contamination is less than the guidelines in DOE Order 5400.5.

Suspect waste is waste that is not categorized as radioactive waste or clean waste as defined above.

Highly suspect waste is waste similar in form and process/area of origin as a waste known to be a radioactive waste.

Questionable waste is suspect waste, other than highly suspect waste, originating in an RMMA for which process knowledge, survey or sampling and analysis documentation is not available.

2. Directions for Standard Format for Summary Data

(1) Provide the name, EPA identification number, city and state of the treatment, storage or disposal contractor that provided treatment or disposal for your waste. For example, provide information for the TSD facility that incinerated your waste, or directly land disposed of your waste.

(2) Indicate the process(es) or services that the final TSD contractor in (1) provides: landfill, incineration, distillation, or other (indicate what the other technology is if it was applied to DOE waste).

(3) Provide the DOE contractor or other organization that held the contract with the prime contractor [see (4)].

(4) Provide the name, EPA identification number, city and state of the contractor with whom the DOE contractor contracted to receive RCRA or TSCA waste (e.g., a broker or TSD facility). If more than one contractor has been used, include the effective time period that each was used (e.g., 9/87 to 2/88).

(5) Using a footnote that corresponds to the year(s), indicate the criteria for determining that waste was not radioactive that were in effect at the time the determination was made. For bulk waste, report this in curies per mass or volume (e.g., 2 nCi/g, 50 pCi/ml, etc). For surface contamination, if the DOE Order 5400.5 limits were used, enter "5400.5," otherwise, enter the specific limits. In reporting these, address how naturally occurring radioactivity/background was accounted for.

(6) By the waste categories defined herein, provide the volume of waste treated or disposed of by the contractor listed in (1) for each year. If a waste was not sent to the contractor in the year, indicate "NA" (not applicable). For a prime contractor (3), include only the amount of waste that the contractor treated or disposed of themselves. Report quantities sent to subcontractors on separate sheets corresponding to the individual contractors.

(7) If all efforts to determine whether a subcontractor received a waste shipment are not successful, indicate in a footnote the volume of waste that is in question and the other possible recipients. For example in 1989 you sent 10,000 gallons of waste that you now identify as questionable to your prime contractor A who in turn sent waste to sub-contractors B, C, and D. After examining contractor A's records and manifests you cannot determine how much waste went to each of the contractors B, C, and D. When filling out the summary data form for contractor B, the entry for 1989 in the column "Questionable" would: 1) contain the volume of questionable waste, if any, known to have been sent to contractor B, and 2) a reference a footnote. The footnote would indicate that "all or part of 10,000 gallons of waste went to contractor B or C or D." The same footnote should appear on the data sheets for contractors C and D. For "Clean Waste" the information on which subcontractor it was sent to can be estimated.

(8) Remembering that this data is going to be used to evaluate the radiological impact of the treatment or disposal of the waste, divide the waste into categories based on type of treatment applied, radionuclides present or potentially present, and/or TSD where the treatment or disposal occurred. Data entered on line 5.a must correspond to data entered on lines 6.a and 7.a. Similarly lines a. under 9, 10, and 11 must all represent a consistent set of data as must those from lines 12, 13, and 14. For example, if regulated waste oils were sent to a company that composited it and sent it to subcontracter X and Y for incineration, lines a. and b. under numbers 5, 6, and 7 would be used for reporting waste treated by subcontractor X and subcontractor Y, respectively. Add additional lines as necessary.

(9) Provide volumes of waste in units compatible with the denominator of the isotopic concentrations reported in 6 (e.g., for isotopic concentrations reported in nCi/ml, volumes should be in liters or cubic meters).

(10) Provide volumes of waste in units compatible with the denominator of the bulk contamination criterion reported in 8 (e.g., for isotopic concentrations reported in nCi/ml, volumes should be in liters or cubic meters.).

(11) List the isotopes that were possibly in this waste based on knowledge of the source of the waste.

REFERENCES

1. *Nuclear Waste News*, July 18, 1991, p. 286.

2. U.S. Department of Energy, "Radiation Protection of the Environment and Public," DOE Order 5400.5, February 8, 1990.

3. Office of Environmental Restoration and Waste Management Office of Waste Operations, "Performance Objective for Certification of Non-Radioactive Hazardous Waste," November 15, 1991.

Solutions for Dioctyl Phthalate-Tested High-Energy Particulate Air Filters Destined for Disposal at Hanford, Washington[a]

Kenneth A. Gablin
Argonne National Laboratory
Argonne, IL 60439

INTRODUCTION

In January 1992, Argonne National Laboratory East, Environmental and Waste Management Program, learned that a chemical material used for testing of all high-energy particulate air (HEPA) filters at the primary source, Flanders Filter, Inc., in Washington, North Carolina, was considered a hazardous chemical by Washington State Dangerous Waste Regulations. These regulations are under the jurisdiction of the Washington Administration Code, Chapter 173-303, and therefore directly under impact the *Hanford Site Solid Waste Acceptance Criteria*. Dioctyl phthalate, "DOP" as it is referred to in chemical abbreviation form, is added in small test quantities at the factory, at three Department of Energy-operated HEPA filter test facilities, and in the installed duct work at various operating laboratories or production facilities. When small amounts of radioactivity are added to the filter media in operation, the result is a mixed waste. This definition would normally only develop in the State of Washington since their acceptance criteria is ten times more stringent then the U.S. Environmental Protection Agency's. Methods of processing will be discussed, which will include detoxification, physical separation, heat and vacuum separation, and compaction. The economic impact of a mixed waste definition in the State of Washington, and a low-level radioactive waste definition in other locations, may lend this product to be a prime candidate for commercial disposal in the future, or a possible delisting by the State of Washington.

WHAT IS A HEPA FILTER?

A HEPA filter is a throwaway, extended media, dry type filter with a rigid casing enclosing the full depth of the pleats. The filter is extremely efficient in its ability to stop 99.97% of a testing or challenge aerosol that is 0.3 microns diameter when mono dispersed. The filter that is on display is 24 in. square, representing the filter area for a tested flow rate of 1000 cfm. The filter media is about 1 ft deep, enclosed in a 3/4-in. plywood frame or rigid metal casing.

WASTE MANAGEMENT PROBLEMS WITH HEPA FILTERS

The HEPA filter is a constant irritating problem in our Waste Management Operations because of its size and the difficulty of compaction within the normal rules of radiation and air borne particulate management. The filter itself varies in size, but the majority of filters that Argonne National Laboratory-East (ANL-E) has in the HEPA filter category are 24 in. square, but many filters, including pre-filters, are thinner and smaller. Some filters used in other locations have metal frames, making compaction and disposal far more difficult.

The HEPA filter is somewhat difficult to break down and compact because of the structural integrity and makeup of the wood frame. The fact is, the frame does not fit into a compactor designed for fifty-five gallon drums without a great deal of reconstruction labor. This includes (a) radiation exposure that is not as low as reasonably achievable (ALARA), and (b) dust exposure that is caused by cutting the filter media away from the plywood frame before compacting.

---

a. Work supported by the U.S. Department of Energy, Environment and Waste Management Program, Waste Management Technical Support Group, under Contract W-31-109-Eng-38.

GLASS FIBERS MAKE UP THE FILTER MEDIA

Some descriptions of the HEPA filter mention that it is a paper media. This is in total error. It is really made of glass fibers. The glass fibers may resemble paper due to its white color and appearance. The glass fibers are produced by passing molten glass through fine holes and drawing it into the desired diameter by steam. In this case the small glass fibers are approximately the diameter of the aerosols they are designed to catch. Because the filter is made out of glass fibers, it has the right composition and tolerance for handling corrosive air, as well as having the normal fireproof capabilities of glass, in the same way glass fiber insulation in the home is capable of operating in the environment of a fire. The glass is manufactured by heating it to about 2750°F and removing it from a continuous open-hearth furnace in a plastic condition. This feature is very important for future disposal choices.

DOP AND LABORATORY DOP TESTING

The material used to test the HEPA filter is called DOP (dioctyl phthalate). The DOP material is used for initial testing at the Flanders Filters, Inc. Factory located in Washington, North Carolina. HEPA filters are DOP tested by Industrial Hygiene at Argonne National Laboratory while the filters are in place in the duct work. Before coming to the ANL-E, HEPA filters are again tested at a DOE-operated testing facility located in Oak Ridge Tennessee, which then supplies the filters to our laboratory. There are two additional filter testing facilities within the DOE complex, namely Rocky Flats, CO, and the other in Hanford, Washington, which is operated by the Hanford Environmental Health Foundation.

DOP is manufactured by Eastman Chemical Products, Inc., which is part of the Eastman-Kodak Company, and is a plasticizer that rivals another plasticizer, Disononyl Phthalate (DINP). Both are used in the manufacture of flexible polyvinyl chloride (PVC) and in other commercial applications. The flexible PVC is then used for the manufacture of storage bags used by blood banks for storing whole blood, an application that has Food and Drug Administration (FDA) approval, and in many household and industrial items such as garden hose and garbage can liners. The material information that is supplied here comes from the Material Safety Data Sheet (MSDS), and from the medical officer of Eastman Chemical Products in Kingsport, Tennessee.

During a routine trip to Westinghouse Hanford Company in January of 1992, I learned through discussions with their personnel that DOP was considered a suspected carcinogen by the State of Washington. The State of Washington, along with the Hanford Site Solid Waste Acceptance Criteria 0063-3 issued by Westinghouse Hanford Company, produces rules for disposing our waste in their disposal facility, or store it in their mixed waste facility. With the addition of DOP to the filters, plus any HEPA filter with a small amount of radioactivity on it, is classified as mixed waste. The economic significance of the addition of DOP is its redefinition from low-level waste to mixed waste. It in our estimation, this is a purely economic decision. The price increases from a rough estimate of $\$75–80/ft^3$ for disposal of LLW, to approximately $\$330–340/ft^3$ for mixed waste storage. We looked at this extensively, and decided we need to find superior ways of handling HEPA filters both in volume reduction and in characterization of the material, and review our thoughts with other waste generators at other national labs as well as Westinghouse Hanford, Inc.

Since Westinghouse Hanford Company is under the dictates of Washington Administrative Code, 173-303, which in reality is a law, not a Waste Acceptance Criteria, they have very little choice but to obey the law as they interpret it. Currently, there are several ways we are working with Westinghouse Hanford Company and other Laboratories to solve the problems listed below.

Under Colorado Hazardous Waste Regulations, ". . .if DOP has been used for its intended purpose the resultant used commercial product (liquid) *is not* controlled as a RCRA-regulated hazardous waste. As long as the DOP was used for its intended purpose, the object receiving the DOP (filters wipes, machine parts) are not rendered hazardous waste when discarded."

DE-LISTING OF DOP

A solution to the DOP problem would be a straightforward negotiation leading to delisting of this product by the state of Washington. A meeting held in mid-October 1992, between DOE-Richland Operations, Westinghouse Hanford Company personnel and the writer, indicated that Westinghouse Hanford Company was going forward with the delisting. How this fits within the general timeframe is not well understood, the four calls that have been placed to get current information for this paper have not been returned as of this writing, so I have little more to report. At least there is a position to review delisting and have coordination with the commercial site at Hanford operated by the US Ecology Company. It appears that US Ecology is getting some of the problems generated by the DOP information being disseminated, and they may not accept HEPA filters from the commercial industry.

DETOXIFICATION OF HEPA FILTERS

A second method for removing the DOP from the HEPA filters uses a combination of high heat and high vacuum. Referring to the specifications of DOP, there is a boiling temperature of 723°F at atmospheric pressure, lending itself to very low vapor pressure at normal conditions. Considering the high temperature and the plywood frame, any temperature that approached the boiling point of DOP would also cause auto-ignition of the plywood frame and off-gassing of various adhesives that hold the HEPA filter media to the frame.

To reduce the temperature, Argonne National Laboratory has proposed a test where a HEPA filter and HEPA filter media be put into an oven evacuated to 5 mm of Mercury absolute. At that reduced pressure, the DOP would boil off at approximately 450°F. This would reduce the risk of fire problems, since the process would introduce helium through the HEPA filter and act as a transfer medium device to purge the material towards an exit point, where it could be analyzed and measured very easily.

VOLUME REDUCTION FOR SEPARATION AND COMPACTION

Westinghouse Hanford Company, would allow us to put the filter media into a compactor with anti-snap-back disks inside, then compact each HEPA filter media sequentially. When the filter media has completely filled the compacted drum, the anti-snap back discs, which would have a testing hole in the center, could provide a convenient composite sample of all the compacted HEPA filter media. A Toxicity Characteristic Leaching Procedure (TCLP) of the entire drum using a circle saw or "cookie cutter" type device could draw the sample. Obviously, this still produces a mixed waste with accompanying additional costs of a mixed waste. It also has the very complicated problems of ALARA, the cost of labor, and associated dust and inhalation problems, which are significant in our waste operation.

Besides the problems mentioned above, we still would have the large quantity of plywood, which represents four sheets of 3/4-in. plywood, each 2 ft long and 1 ft wide. The material is extremely difficult to compact, and the only possible advantage is that it could be surveyed under health physics requirements and possibly considered a waste that could go into the sanitary landfill. This is still questionable.

COMMERCIAL INCINERATION

Another method would require the use of commercial facilities, and would take the material offsite. There it could be commercially incinerated, with the understanding that we would receive the slag back from the molten glass fibers. The majority of other material, i.e., the plywood and the plastic mastic that glues them together, would be incinerated, as well as the PVC bag that covers the filter.

REMEDIAL TECHNOLOGY—WROUGHT IRON

The final method of HEPA filter disposal would require the use of a commercial facility that has metal-melting capabilities. Argonne has a sufficient amount of contaminated steel that could be reclaimed in the shielding blocks. If ANL-E could access a system where HEPA filters could be added to the top of molten steel or iron while the metal is being processed, this would produce a drastically reduced volume of the HEPA

filter, resulting in only a very small amount of slag produced from the molten form of glass fibers in the HEPA filters. The glass fiber contribution would probably represent the volume of a glass marble. This molten glass could either be incorporated in the steel melt, or skimmed off as slag, depending on how the process operates. In this way, a large number of HEPA filters could be incorporated in one melt of steel. The steel could either be taken back to ANL-E for disposal or be available for other options, depending on how the system would operate in practice. I have no idea as of this writing how we would have a TCLP performed in this case, but I feel that because glass and steel have approximately the same melting points, this may easily be a solution if the standards were set up, the procedures approved, and it was allowed to take place. If the slag representing the glass fibers were incorporated in the steel melt, this would result in wrought iron, which is the oldest iron known to man. I would consider this the best in remedial technology.

SHALLOW LAND DISPOSAL

An additional alternative to disposal of the HEPA filters would include shallow land burial, and disposal in states having a process for dealing with extremely low-level mixed waste. It is my understanding that Envirocare of Utah is opening up a site for mixed waste under DOE authority in the very near future. The DOE contract will be for the permanent disposal of mixed Resource Conservation and Recovery Act (RCRA) Hazardous/Toxic Substance Control (TSCA) and Radioactive Contaminated Waste.

REPLACEMENT FOR DOP FOR TESTING OF HEPA FILTERS

Another method that could solve the problem of newly generated HEPA filter waste would be the substitution of the DOP material by other aerosol testing devices that have been reviewed. One that has some use in industry is corn oil, which has been used by the laboratory. It has the problem of smelling like food and of going downhill with bacteria action creating an offensive odor.

The other replacement being reviewed by the Hanford Environmental Health Foundation is Emery 3004 synthetic hydrocarbon 4 CST fluid. Another material that is used in some locations is called DOS. What the future of these materials will be is still questionable, but the problem that remains at Argonne National Lab is our historic waste that has been stored since 1988 when we were refused access to the Idaho Falls disposal. We have a significant backlog of filters, and consequently a very expensive problem to review and solve, with little process knowledge available for documentation.

It should be noted that our problem is not unique within the organization of National Laboratories operated by the Department of Energy.

INSTITUTIONAL TRACK

The Texas Concurrent Characterization, Licensing, and Development Process

Robert V. Avant, Jr., P.E.
Deputy General Manager
Texas Low-Level Radioactive Waste Disposal Authority
7701 N. Lamar Blvd.
Austin, TX 78752

INTRODUCTION

The 72nd Texas Legislature specifically delineated a 400-square-mile area in southeast Hudspeth County where siting activities would be limited. The Authority was given unprecedented powers of property access and eminent domain and expanded budget authority to conduct site selection, characterization, and licensing. In the summer of 1991, the Authority identified five general siting areas in the prescribed region, and in the fall of 1991, the Authority narrowed the siting area to one large ranch composed of about 16,000 acres—called the Faskin Ranch.

Site characterization began in 1991 and will be complete by September 1993. In September 1991, Authority staff began preparing the license application and included all available information on the Faskin Ranch. At its February meeting, the Authority's board directed staff to submit the license application to the Texas Water Commission (the new Texas radiation control agency). The license application was submitted on March 2, 1992, and on April 15, 1992, the Commission determined that the application was sufficiently complete to begin review. Discrete technical packages such as groundwater hydrology, surface water hydrology, design, etc., will be submitted to the agency for review on the completion of each package. A schedule has been developed to allow the regulators the maximum time possible to review critical technical areas while minimizing the total review period.

SITE SELECTION AND DESCRIPTION

Figure 1 shows the location of Hudspeth County and Figure 2 shows the siting area delineated by the legislature. In the summer of 1991, the Authority identified five general siting areas in the prescribed region, and in the fall of 1991, the Authority narrowed the siting area to one large ranch composed of about 16,000 acres—called the Faskin Ranch. The ranch is about 5 miles east of Sierra Blanca and south of Interstate 10. Figure 3 shows the Faskin Ranch.

SITE CHARACTERIZATION

Some surface evaluations, drilling, and well sampling activities began as early as the summer of 1991. All characterization work was underway by the fall of 1992 and completion is expected by September 1993. Since the new siting region is within about 30 miles of the abandoned Fort Hancock site, a significant amount of regional geology, geophysical, meteorological, flora and fauna, demographics, and archaeology information is available. Site specific data will be collected to augment the regional data obtained during the characterization of the Fort Hancock site where necessary to support the performance assessment, facility design, and licensing.

Geology

Geology investigations include surfical evalutions of lineaments and fissures, a shallow and deep drilling program, and fault investigations. Shallow, drainage related fissures have been noted in alluvial deposits associated with the major drainage crossing the ranch. The fissures are drainage related and do not appear to have tensional cracks. Numerous shallow borings have been completed to determine the type and extent of fill, and four deep borings to the water table have been completed to establish the depth of fill and the

depth to the water table. Fill material ranges from about 150 to 600 feet thick and is composed of sand, silt, clay, and gravel layers characteristic of desert alluvial fill.

No active faults have been identified in close proximity to the Faskin Ranch, but older, Cenozoic faults have been mapped associated with the mountains that ring the Eagle Flat Basin. The trans-Pecos region of Texas is relatively more tectonicly active than other parts of the state, but is still not classed as a high frequency area.

Hydrogeology

In addition to the four wells mentioned previously, 52 area wells have been sampled to define the characteristics and extent of the aquifer. Chemical analysis and dating of the water samples are being conducted. The water table is between 600 and 700 feet below the surface in the siting area. To date, one of the most significant findings is that the aquifer recharges from the mountains ringing the siting area, and little if any recharge comes from the basin fill. The deep boreholes were also located to function as monitoring wells when the facility becomes operational.

Surface Hydrology

Floodplain maps have been prepared for the siting area and the Faskin Ranch. Blanca Draw cuts through the area and at places, has a floodplain approaching 3,000 feet wide. Other small drainages have floodplains associated with them primarily from sheetflow. However, the actual disposal facility is well ouside the boundaries of the 100-year floodplain. Additional mapping work will also define the probable maximum flood.

Geophysical

Geophysical techniques are being used to address current seismicity and the character of the geologic materials that underlie the site vicinity. Current seismicity in the site vicinity will be monitored and surveys will be conducted to provide additional data on the distribution of geologic strata beneath the site and in the site vicinity. A network of seismic stations has been installed to monitor current seismic activity in the site vicinity.

Geotechnical

A geotechnical analysis of materials from the borings has been conducted to define the engineering properties in the siting area. Laboratory reports indicate that the disposal site is underlain by low permeability clays. In-situ soil properties, borrow material characteristics, and compaction and strength properties of the granular materials are being evaluated to support facility design. Construction materials indigenous to the area are being evaluated for supply and availability.

Soils

Soils will be mapped in high detail such that each soil series is defined. Available information on agricultural and engineering properties will be provided based on procedures used by the USDA Soil Conservation Service.

Flora and Fauna

Detailed flora evaluations are identifying each plant community on the site. All species are being collected and preserved as specimens, or in the case of cacti, as pictorial vouchers. Special attention is being given to endangered, rare, threatened, or peripheral plant species which mitigative measures might be required

A descriptive account of fauna on the site is being based on both collections and observations. The evaluation is documenting and quantifying those species that occupy the site as well as the migratory species that are seasonally in the area. Also, special attention is being given to endangered, rare, threatened, or peripheral animal species.

Since the Sierra Blanca area gets more rainfall than Ft. Hancock, a more productive habitat exists on the Faskin Ranch. The physiographic classification of the area is the desert grassland vegetation region. Although plant and animal species are more diverse, no endangered species are listed by the U.S. Fish and Wildlife Service for Hudspeth County. However, certain endangered species are listed and documented in adjacent counties, but the habitats for these species are not found on the siting area. The Texas Horned Lizard is a threatened species and does exist in the Eagle Flat area. However, the presence of a threatened species will not affect the siting or design of the Authority's facility.

Cultural Resources

Cultural features such as the schools, churches, and cemeteries at Sierra Blanca are located within about 5 miles of the Faskin Ranch. Other historic features such as the Old Spanish Trail, Fort Quitman, and Indian Hot Springs are located in the general region of the ranch. Archaeological and cultural sites in the siting area is being classified and quantified. A 100 percent reconnaissance of the immediate vicinity of the site will be conducted in the spring of 1993. In addition, specific area reconnaissance will be conducted for areas where other investigations are anticipated so that significant archaeological sites are not disturbed.

Environmental Monitoring

Radiological data from flora, fauna, soil, and water samples and TLDs is being compiled to define background radiation levels at the site. A continuous record of environmental monitoring data for the site is required to support licensing and site operation.

Socioeconomics and Demography

Socioeconomic and demographic information has been reviewed and updated to reflect the 1990 census and revised growth projections.

Meteorology

Recorded meteorological data from Ft. Hancock and Sierra Blanca have been compared, and about 12.5 inches of rainfall can be expected annually at Sierra Blanca—about 2 inches more that Ft. Hancock. The meteorological station has been moved to the Faskin Ranch from Ft. Hancock, and data is being retrieved, processed, and archived.

Performance Assessment

Performance assessment modeling will use site characterization data to assess compliance with performance objectives. Doses to the public and workers will be predicted, and long-term release scenarios will be evaluated to determine the impact to the public for at least 1,000 years after site closure. Selected scenarios will be modeled using computer codes that will be selected for their applicability to the site. Because of the arid environment and high evapotranspiration, performance modeling indicates virtually no potential for downward movement of groundwater. Consequently, worst case infiltration scenarios will be evaluated to demonstrate compliance at levels at least one order of magnitude below the performance objectives. Because of the depth to the water table and the low permeablity clays below the site, preliminary radiological dose assessments for the groundwater flow pathway indicate that the site would have exposure levels at least one order of magnitude below the regulatory limits.

Infrastructure

The Faskin Ranch fronts Interstate Highway 10. One railroad parallels the interstate and another parallels the southern boundary of the siting area. Water from a local water district, electricity from two suppliers, and telephone service are available on the site.

FACILITY DESIGN

The Fort Hancock facility layout and drainage system was changed by Rogers and Associates to match topography on the new site. Radian Corporation and Morris Knudsen are preparing the construction plans and specifications and bid documents. Distinctive components of the plans include:

- Administration Building
- Operations Building
- Maintenance Building
- Waste Storage Building
- Pump House
- Gate House
- Class A Disposal Units
- Class B/C Disposal Units
- Drainage System
- Roads
- Security Fencing

LICENSE APPLICATION

Because a substantial amount of information was already available from reconnaissance level information, previous characterization activities at Ft. Hancock, previous design activities, and previous license preparation activities, the Authority was able to submit the license application on March 2, 1992. Additional site specific detail will be submitted, in phases, as it becomes available from the characterization activities. The Texas Water Commission intends to review complete data packages as they are submitted rather than to wait until all characterization has been submitted. This will expedite the review and response time and will reduce the possibility that additional field characterization data will be required during or after regulatory review.

Table 1 lists the major sections of the license application.

DEVELOPMENT SCHEDULE

Table 2 shows the development schedule through construction.

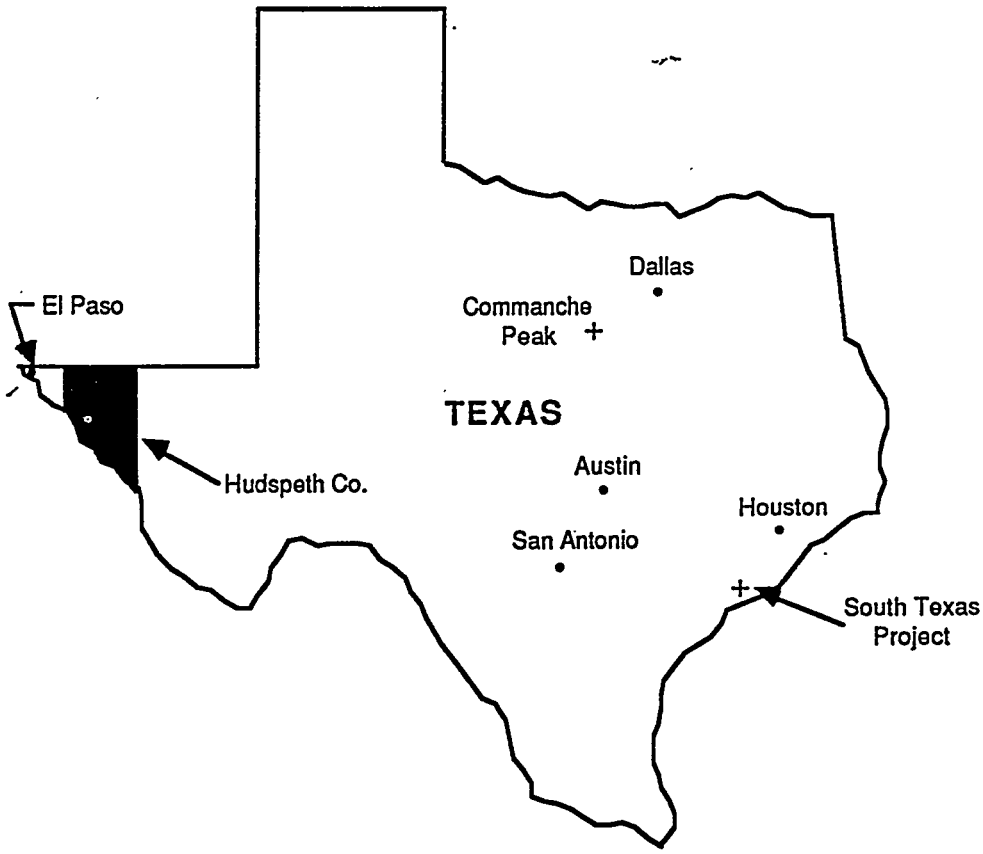


Figure 1. Hudspeth County Location.

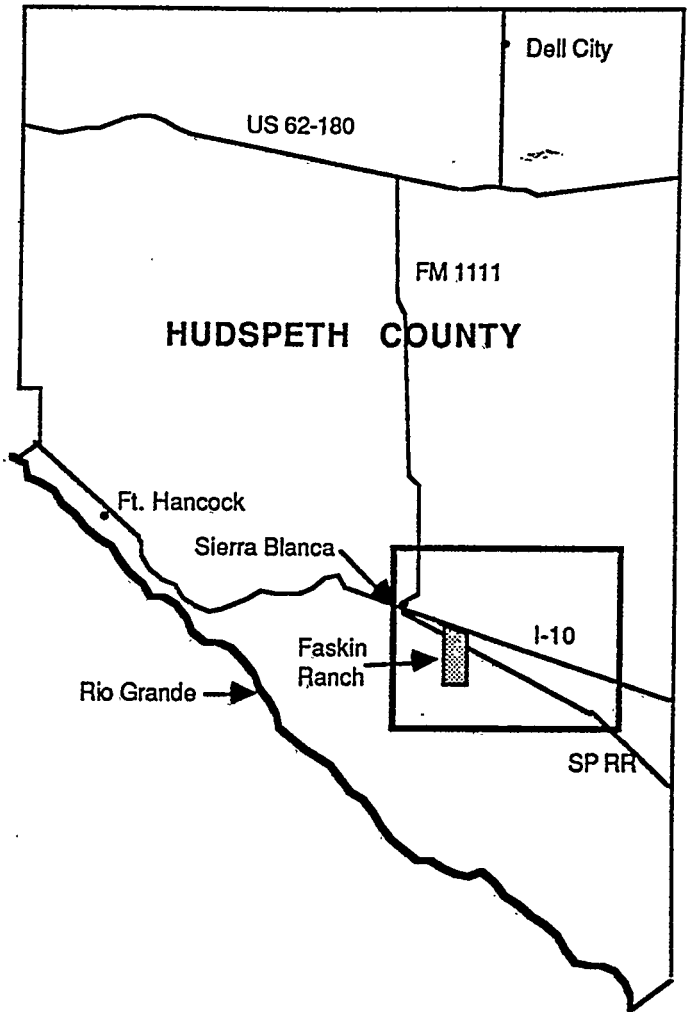


Figure 2. Siting area.

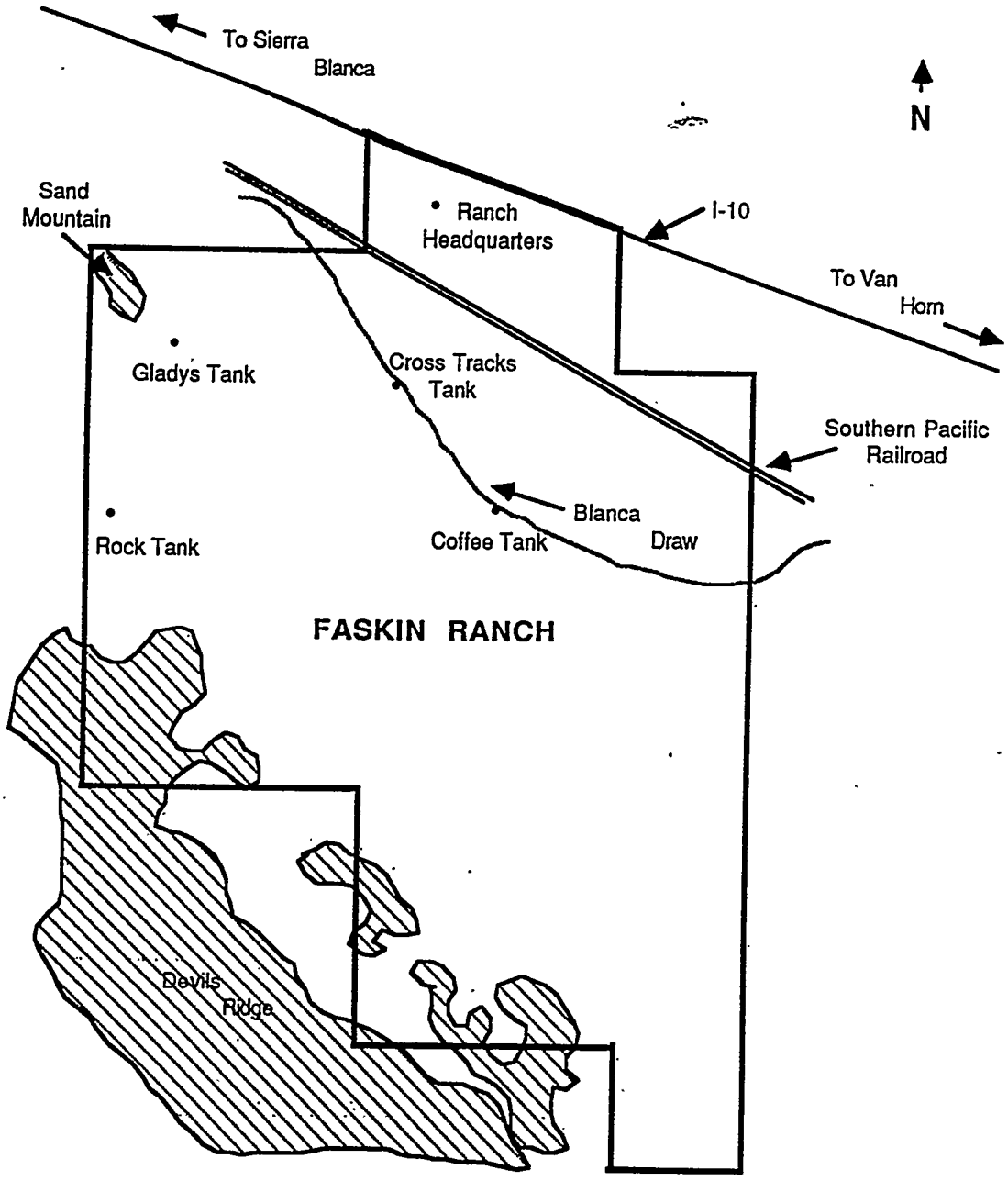


Figure 3. Faskin Ranch.

Table 1. License application sections and submittal dates.

	Licensing item	First Submission March 1992	Second Submission December 1992	Third Submission June 1993	Final Update December 1993
1.	GENERAL INFORMATION				
1.1	Identity of Applicant	Complete			
1.2	Qualifications of Applicant	Complete			Update
1.3	Description of Site and Proposed Facility	Complete	Update		
1.4	Schedules	Complete			
1.5	Material Incorporated by Reference	Complete			Update
1.6	Summary of Principal Review Matters	Complete			
2.	SPECIFIC TECHNICAL INFORMATION				
2.1	Design Criteria	Complete			
2.2	Natural Events and Phenomena	Complete	Update		
2.3	Codes and Standards	Complete			
2.4	Design Features	Complete			
2.5	Construction and Operations	Complete			
2.6	Source Term	Complete			Update
2.7	Quality Assurance	Complete	Update		
2.8	Radiation Safety Program	Complete			
2.9	Operating and Emergency Procedures	Initial		Complete	
3.	ENVIRONMENTAL INFORMATION				
3.1	Statement of Need	Complete			
3.2	Schedule	See 1.4			
3.3	Area and Site Characteristics	Initial	Update	Update	Update
3.4	Natural Resources	Complete		Update	
3.5	Flow Diagram	Complete			
3.6	Site Selection	Complete			
3.7	Project Alternatives	Complete			
3.8	Radiological and Nonradiological Impacts	Complete			Update
3.9	Environmental Effects	Complete			Update
3.10	Environmental Monitoring Program	Pre-Op Complete		Ops/Closure Complete	

Table 1. (continued).

	Licensing item	First Submission March 1992	Second Submission December 1992	Third Submission June 1993	Final Update December 1993
3.11	Decommissioning and Site Closure	Complete			Update
3.12	List of Permits	Complete			
4.0	TECHNICAL AND ENVIRONMENTAL PATHWAYS				
4.1	Migratory Pathways Analyzed	Initial		Complete	Update
4.2	Protection of Inadvertent Intruders	Initial		Complete	Update
4.3	Worker Dose Assessment	Complete			Update
4.4	Site Stability	Complete			Update
4.5	Nonradiological Impacts	Complete			Update
5.0	INSTITUTIONAL INFORMATION				
5.1	Certification of Post-Closure Agency Acceptance	Complete			
5.2	Ownership of Site	Complete			
5.3	Legal Description	Complete			
5.4	Detailed Management Plan	Complete			
6.0	FINANCIAL PLAN				
6.1	Application Qualifications and Assurances	Complete			
6.2	Funding for Disposal Site Closure, Stabilization, and Institutional Controls	Complete			

Table 2. Development schedule.

Item	Schedule
Site Characterization	September 91–September 93
License Application Submittals	March 92–December 93
License Application Review	December 92–May 94
License Hearing Process	June 94–May 95
License Issued	September 95
Construction	September 95–May 96
Operation	June 96

Developing a Low-Level Radioactive Waste Disposal Facility in Connecticut: Update on Progress and New Directions

Ronald E. Gingerich
Low-Level Radioactive Waste Program
Connecticut Hazardous Waste Management Service
Hartford, CT 06105-1904

INTRODUCTION

Connecticut is a member of the Northeast Interstate Low-Level Radioactive Waste Management Compact (Northeast LLRW Compact). The other member of the Northeast LLRW Compact is New Jersey. The Northeast Interstate Low-Level Radioactive Waste Commission (Northeast Compact Commission), the Northeast LLRW Compact's governing body, has designated both Connecticut and New Jersey as host states for disposal facilities. The Northeast Compact Commission has recommended that, for purposes of planning for each state's facility, the siting agency for the state should use projected volumes and characteristics of the LLW generated in its own state.

In 1987 Connecticut enacted legislation that assigns major responsibilities for developing a LLW disposal facility in Connecticut to the Connecticut Hazardous Waste Management Service (CHWMS). The CHWMS is required to:

- Prepare and revise, as necessary, a LLW Management Plan for the state
- Select a site for a LLW disposal facility
- Select a disposal technology to be used at the site
- Select a firm to obtain the necessary approvals for the facility and to develop and operate it
- Serve as the custodial agency for the facility.

The CHWMS is a nonregulatory, quasi-public agency established by state law 1983. When originally established, the CHWMS was responsible for planning for and promoting the appropriate management of hazardous waste (i.e., waste covered under the federal Resource Conservation and Recovery Act) generated in Connecticut. The CHWMS' LLW responsibilities are in addition to its hazardous waste responsibilities.

The CHWMS is directed by a 10-member Board of Directors, six of whom are currently voting members. Each of the voting directors is appointed by the Governor for a staggered four-year term. One director must be appointed from each of Connecticut's six Congressional districts. Two of the directors must represent the public, two the business community and two the scientific community. The Governor, with the consent of both houses of the General Assembly, appoints one of the directors as the Chairperson of the Board. The Chairperson also serves as the Executive Officer of the CHWMS. The four nonvoting directors, representing various state agencies, will become voting members when a preferred site is selected for a LLW disposal facility.

PROGRESS IN CONNECTICUT

After Connecticut was designated as a host state in 1987, the CHWMS began to implement its LLW responsibilities.

LLW Management Plan

In 1988, the CHWMS completed its first LLW Management Plan for the state. The Management Plan contains the following information:

- An inventory of the LLW generators in the state and a description of the LLW they generate and how they manage it
- Projections of future LLW generation
- An analysis of LLW disposal technologies
- A general analysis of LLW transportation.

The CHWMS has updated the section on LLW generators and management practices annually.

Between 30 and 40 entities in Connecticut ship LLW to disposal facilities each year. The volume of waste shipped to disposal facilities averages about 40,000 cubic feet. The radioactivity in the waste varies widely from year to year, ranging from a low of 3,600 curies in 1991 to a high of 255,200 curies in 1990. Approximately two thirds of the volume and over 99% of the radioactivity in the waste come from the four nuclear power plants in Connecticut. The remainder of the waste comes from universities, hospitals, private research firms, industrial firms and the U.S. Navy.

Technology Selection

The CHWMS' goal in technology selection is to have the technology used at a site enhance the natural capabilities of the site. With that goal, a technology cannot be selected until sites have been identified and some data collected.

The CHWMS has eliminated shallow land burial as a potential technology in Connecticut.

Developer/Operator Selection

In 1990, the CHWMS issued a request for proposals for a facility developer/operator and in 1991 Chem-Nuclear Systems Inc. was selected as the preferred firm with which to negotiate a contract. Considerable progress has been made on negotiating a contract, but legislation enacted in May 1992 has led the CHWMS to suspend negotiations.

Site Selection

After completion of the LLW Management Plan, the CHWMS prepared a Site Selection Plan, which was adopted in 1990. The minimum size for a site was set at 160 acres, of which approximately 70 acres would be used for disposal units. This site size would accommodate a facility that would operate for 50 years, which includes the scheduled decommissioning and dismantling of the four nuclear power plants in the state.

The Plan called for a stepwise screening of the state using published data to identify three candidate sites. A preferred site would be selected from among the candidate sites based on the results of onsite testing. The site selection criteria closely followed state and federal statutory and regulatory requirements. The Plan specified that the results of intermediate steps in the site screening process would not be made public until after the candidate sites had been identified. Before adopting the Plan, the CHWMS entered into a contract with Battelle Memorial Institute for assistance with site screening, selection and characterization.

The CHWMS Board of Directors (Board) had decided that it wanted to be closely involved in the selection of the three candidate sites and to do it in a way that precluded the political and parochial pressures that are inevitably associated with a siting process. To meet these two goals, a geographically neutral approach

was developed for candidate site selection. Thus far, Connecticut is the only state developing a LLW disposal facility that has undertaken such an approach.

In June 1991 the CHWMS, with assistance from Battelle, conducted a three-day workshop, open to the public, in which eight sites were presented to the Board. Data on the sites were presented in a way that did not disclose the geographic locations of the sites. Three candidate sites were selected by the Board, after which the locations of the sites were revealed to the Board, local elected officials, and the public. This is perhaps the purest example of the decide/announce/defend siting approach.

The three sites were approximately 15 miles northeast of Hartford and they were all within approximately 2 miles of each other. While each of the sites had few houses on them, there were some suburban developments and rural community centers close to them.

While reviewing preliminary drafts of the report on the site screening process, the CHWMS discovered two errors made in the screening process. Both errors were corrected and neither affected the selection of the eight sites that were presented to the Board or the Board's selection of the three candidate sites, but both could have done so. These discoveries raised serious concerns for the CHWMS and the public. To address the concerns, the CHWMS decided to undertake an independent quality review of the site screening process and to postpone any onsite studies until the review was complete. The CHWMS entered into a contract with TRC Environmental Consultants, Inc., to conduct the independent quality review.

NEW DIRECTIONS

In the midst of the independent quality review of the site screening process, the Connecticut General Assembly enacted legislation (Public Act 92-45) directing the CHWMS to terminate its site selection activities under the 1990 Site Selection Plan and, among other things, to prepare a new plan for a new site selection effort.

Specifically, the new legislation requires the CHWMS to undertake the following:

1. Prepare a new LLW Management Plan
2. Prepare a plan for developing a centralized, temporary LLW storage facility
3. Prepare a plan for a new siting process for a LLW disposal facility
4. Rebid the contract for assistance in site screening.

The legislation requires the CHWMS to submit all three plans to the General Assembly by February 1, 1993. The General Assembly has allotted itself 60 days to review the plan and to approve, reject or modify the plan. Failure by the General Assembly to take any action on the plan constitutes approval.

The CHWMS anticipates having all three plans ready for submission to the legislature on February 1, 1993.

New LLW Management Plan

The draft new LLW Management Plan should be ready for distribution to the public early in December 1992. Particular emphasis is being placed on preparing new LLW projections for the next 50 years, the planned operating life for a LLW disposal facility in Connecticut. The CHWMS has entered into a contract with Rogers and Associates Engineering Corporation (RAE) to develop these projections. As part of the contract, RAE will subcontract with Vance and Associates to project iodine-129 and technetium-99 quantities in the waste from the four nuclear power plants in the state using the latest projection methodologies.

Centralized, Temporary Storage Facility Development Plan

The draft "Plan for Developing a Centralized, Temporary LLW Storage Facility in Connecticut" was released for public review and comment early in November 1992. As required in the new state law, the CHWMS first analyzed the need for such a facility. Based on comments from the regulatory agencies and LLW generators, the CHWMS has determined that, at present, there is not a need for the State to develop a centralized, temporary LLW storage facility. Therefore, the CHWMS has not addressed in detail the other subjects to be covered in the plan.

The CHWMS proposes reassessing the need for a centralized, temporary LLW storage facility in two years or if there is a significant change in the LLW management situation, whichever occurs first.

Rebid the Siting Contract

The CHWMS, as directed by the new law, has terminated its contract with Battelle Memorial Institute for assistance with site screening, selection and characterization. As progress is made with development of the new plan for siting a disposal facility, a Request for Proposals reflecting the process in the new siting plan will be developed and published.

New Plan for Siting a LLW Disposal Facility

The draft plan for a new process for siting a LLW disposal facility in Connecticut was released for public review and comment in mid-November 1992. The new plan will have to operate in a social/political environment that has been affected by the first attempt at siting a facility. While Connecticut is not the first state to go through the siting process more than once, it is a small state in which major media outlets practically have statewide coverage. Therefore, there is wider knowledge throughout the state about the initial process than one would have found in other states that have had to repeat site selection.

Given the current situation, the CHWMS is convinced that the most appropriate way to develop a disposal facility in Connecticut in a timely manner is to site and develop the facility with the cooperation of a community, rather than with the opposition of a community. A volunteer approach to site selection, in which the CHWMS will only consider sites offered by local government units with jurisdiction over the site, presents such an opportunity.

Under the volunteer approach proposed in the draft Siting Plan, the Service will only consider a site that has been approved by the electorate of a town[a] in a town-wide referendum. The proposed approach is entirely voluntary. Only towns that want to participate in the process will be considered.

The CHWMS will develop and undertake a site screening approach, that is an imposed decision approach, if, and only if, the volunteer approach does not produce a site that protects public health and safety. The CHWMS would follow the same legislative approval process for a plan for a site screening approach that applies to the plan for the volunteer approach.

The CHWMS will begin the volunteer approach with an intensive and extensive public information effort designed to inform people and local officials about the volunteer approach.

At some point during the public information effort, the CHWMS will formally invite towns to participate in the process and will set a date by which a town must notify the CHWMS that it wants to participate. The CHWMS has not specified in the draft Plan what form of local approval is necessary for a town to become

---

a. In Connecticut, a "town" is the primary unit of local government. There is no county government in Connecticut. All of the land in the state is incorporated into towns. There is no unincorporated land in Connecticut. There are 169 towns, some of which include cities and some of which existed as political entities before the state existed as such. There is a very strong tradition of local home rule.

a participant. We have left that decision up to each town to make on its own, taking into account its own requirements and traditions.

"Participation in the process" means that a town will:

1. Identify a site, in consultation with and with the assistance of the CHWMS

2. Negotiate a facility development agreement with the CHWMS

3. Hold a town-wide referendum on the site and the facility development agreement.

The CHWMS will only consider a site that has been approved in referendum along with its accompanying facility development agreement.

A town can withdraw from the volunteer process at any time it wants until the approval in a referendum of the facility development agreement. After that, the town would follow the procedures that it has negotiated in the facility development agreement that was approved in the referendum.

The draft Plan proposes a series of incentives for towns to participate in the volunteer process.

1. A town that participates in the volunteer process through the holding of a referendum, regardless of the outcome of the referendum, will be exempt from a subsequent stepwise, criteria-based site screening process. Such a process will be undertaken if the volunteer approach does not result in a safe site.

2. The CHWMS will compensate towns for becoming participants. The CHWMS has proposed that a town that decides to participate will be paid $250,000. If it is the first town to so notify the CHWMS, it would be compensated an additional $100,000. If the town identifies a site and negotiates is good faith with the CHWMS, at the end of six months the town would be compensated an additional $250,000. A town that approves a site and facility development agreement at referendum will be compensated an additional $1 million. This compensation would carry no restrictions or obligations.

3. The CHWMS will cover all the town's costs to participate in the process, including grants to help identify sites, for assistance in negotiations, for holding a referendum and for public participation efforts.

4. Perhaps most importantly, the CHWMS is prepared in a volunteer approach to share control over the development and operation of a facility with the volunteer town. The mechanism for sharing control is the facility development agreement.

The facility development agreement will be a contract between the town and the CHWMS. This will bring contract law in addition to state and federal law to bear on facility development and operation. It provides more guarantees to a town than might otherwise be available. The CHWMS intends to require the facility developer/operator to negotiate and enter into a separate facility development agreement with the town.

The facility development agreement will cover at least four primary areas.

1. It will cover provisions and mechanisms for local control over the development and operation of the facility, which may address health and safety concerns as well as other issues.

2. The agreement will cover programs to address the potential social and economic impacts of the facility. This would include existing programs, such as payment-in-lieu-of-taxes and the property value guarantee program, as well as new programs.

3. It will cover the amount and the form of the compensation to be paid to the town for hosting the facility. In the draft Plan, the CHWMS has proposed a floor for negotiations of $2 million before operations and $1 million a year for each year of operation with an inflation adjuster. This would be in addition to the existing assessment on facility gross receipts, which is projected to provide between $500,000 and $750,000 per year.

4. The agreement would address other programs and measures identified by the town to assist it and its region in meeting other needs.

The facility development agreement will always include a provision, negotiated and approved by the town, establishing procedures and conditions under which a town can withdraw its site or shutdown the facility.

The draft Plan recognizes the benefits of, and encourages towns to form, regional groups to participate in the volunteer approach. This is reflected in the compensation provisions for participating. In each instance, a town with a site would be paid more if it participated in the process in cooperation with it neighbors rather than by itself In addition, each neighboring town that participates would be compensated.

Status of the North Carolina/Southeast Compact Low-level Radioactive Waste Disposal Project

Constance Kalbach Walker
N.C. Low-Level Radioactive Waste Management Authority

INTRODUCTION

The Southeast Compact is a sited region for low-level radioactive waste because of the current facility at Barnwell, South Carolina. North Carolina has been designated as the next host state for the compact, and the North Carolina Low-Level Radioactive Waste Management Authority is the agency charged with developing the new facility. Chem-Nuclear Systems, Inc., has been selected by the Authority as its primary site development and operations contractor.

This paper will describe the progress currently being made toward the successful opening of the facility in January 1996. The areas to be addressed include site characterization, performance assessment, facility design, public outreach, litigation, finances, and the continued operation of the Barnwell facility.

SITE CHARACTERIZATION

Following a statewide site screening effort and preliminary field studies on four candidate site areas, Chem-Nuclear recommended to the Authority that two potentially suitable sites be selected for full-scale characterization. This recommendation was accepted by the Authority in April 1990. The locations of the two sites are shown in Figure 1. One is in Richmond County, about 3 miles north of the South Carolina border. The other is on the Wake/Chatham County line, near Carolina Power and Light's Shearon Harris nuclear power plant. The two sites are in very different geological settings, presenting different challenges to the site characterization teams.

The Wake/Chatham Site

Characterization of the Wake/Chatham site was begun in August 1991, following the approval by the state regulatory agencies of the Site Characterization Plans. The site is in the Durham triassic basin and consists of partially fractured sedimentary rock with intrusive features known as diabase dikes. These dikes are nearly vertical sheets of igneous rock of varying thicknesses. The principal concerns with this site are the nature and extent of the fracturing, and the hydrogeological role played by the dikes. These must be studied to see if the site can be successfully modeled for performance assessment calculations.

Accordingly, characterization work has focused heavily on investigating these areas of concern. An early step was the delineation of the dikes using magnetometers. This revealed a significant dike-free area in the northeast portion of the site, and most of the subsequent characterization work has focused on this area. A major ongoing effort is to study the hydrogeology of both the dikes and the country rock. Work conducted to date supports the appropriateness of using the equivalent porous medium method for the computer modeling.

The Richmond Site

Characterization of the Richmond County site was begun somewhat later than for Wake/Chatham because of some legal obstacles. It started in January 1992. This site is in the Sand Hills region of the state and generally has more porous, sandy soil interspersed with horizontal clay layers or lenses. The principal areas of concern with this site are the possibility for rapid groundwater flow through the sandy material, the extent and hydrological role of the clay lenses, and the potential for liquefaction of the soils in a seismic event.

Early characterization work involved the concurrent use of geologic drilling and ground penetrating radar to study the clay lenses. Current hydrogeological studies are partially aimed at determining the amount of interconnection between different sandy layers.

Regulatory Interface

The site characterization process is being carefully monitored by various state regulatory agencies, their consultants, and consultants hired by the three counties involved. The regulators hold Comprehensive Review meetings on each site about every 90 days to discuss recent results and their significance, as well as any need for changes to the Site Characterization Plans. In addition, more specialized and informal meetings for some of the disciplines are carried out at more frequent intervals.

PERFORMANCE ASSESSMENT AND LICENSING

The characterization data will eventually feed into the facility performance assessment calculations. In preparation for this step, Chem-Nuclear has submitted to the lead regulatory agency its proposed Performance Assessment Plan. Discussions of this plan are ongoing. Work is also nearing completion on the anticipated Facility Waste Inventory, the first step in the performance assessment. This will soon be followed by the development of the Source Term, which will describe the leaching of waste out of the disposal modules after the end of the institutional control period.

Site characterization and performance assessment results will be only one part of the facility License Application. In order for preparation and review of the application to be completed on time, Chem-Nuclear and the regulators have agreed to a process of early submittals of standalone sections of the license application. This has several advantages. First, Chem-Nuclear will get early feedback on the completeness and adequacy of these sections. Second, the regulators' final review should be expedited because they will be familiar with the material. Third, the public will be afforded additional time to review the material.

While the regulatory agencies intend to provide a full review of these early submittals, no approvals will be made until after a complete license application has been formally filed and reviewed in its entirety.

It is also worth noting that Chem-Nuclear is planning on preparing two essentially complete license applications, one for each site. Some sections will be the same in both applications, but others will be site specific. This will permit filing as soon as the Authority has selected the preferred site. Obviously, however, this assumes that site characterization and performance assessment continue to point to the licensability of both sites.

FACILITY DESIGN

Another important aspect of the license application will be the facility design. The North Carolina facility is required to incorporate engineered barriers, and in March of 1991 the Authority accepted Chem-Nuclear's recommendation that we use the integrated vault technology. This is shown schematically in Figure 2. The waste packages will all be placed in concrete overpacks that will, in turn, be grouted shut and loaded into modular concrete vaults. Class B and C waste will be placed in the bottom center of the vaults, surrounded and shielded by Class A waste. As currently envisioned, the modules will be built in parallel pairs of rows and loaded from a movable building that will provide protection from the elements. After loading, the spaces between the overpacks will be filled with granular material, and a concrete roof will be poured. Finally, the finished rows of modules will be covered with an earthen mound and a multi-layer cap.

Based on the results of the first phase of site characterization, Chem-Nuclear identified in September of this year the likely locations of the disposal cells on each of the potential sites. This paved the way for the start of the geotechnical studies that will feed into the detailed facility design. These studies are investigating factors such as the load bearing potential of the soils.

Work on the design basis specification is nearing completion and the design of the concrete overpacks is under way. Other design work will be gearing up soon.

PUBLIC OUTREACH

The site selection and development activities are continuously tracked by our public information and involvement program. During the early site screening, public outreach activities spanned the entire state. They were aimed at providing general information about low-level radioactive waste, about the project, and about community benefits. With the identification of the two potentially suitable sites, however, the public outreach effort has naturally become focused on the areas around these two sites. Further, the subject of this focused effort has changed with time to reflect the changing characterization and facility development activities.

One of our primary interfaces with the citizens of the affected counties is through the Site Designation Review Committees established under North Carolina statute. These committees are appointed by the Boards of County Commissioners in the three counties and are funded by the General Assembly. They receive copies of all of the site characterization data as well as other documents produced by the project. They review the ongoing work of the Authority and its contractors and make recommendations to the county commissioners.

In addition, both the Authority and Chem-Nuclear produce newsletters, direct mail pieces, and advertisements intended for citizens living near the candidate sites. Meetings with local landowners and residents are also important for information exchange. Trips to the current facility at Barnwell, South Carolina, are another effective way of conveying information about the project. Finally, Chem-Nuclear operates a Mobile Resources Center that is displayed at such places as schools, shopping malls, and county fairs. At the state fair this fall it had roughly three thousand visitors.

Public input to the project is received through public comment at Authority meetings, through reports from the Site Designation Review Committees and county commissioners, and through formal open record periods for the receipt of public input at major decision points such as the technology selection.

Unfortunately, there is still significant opposition to the project from some of the residents near the potential sites who anticipate a negative impact on their community or who do not want to lose their homes. We are sensitive to their concerns but remain hopeful that continuing dialogue and the presence of substantial community benefits will help to moderate their opposition.

North Carolina Statute currently provides for a proposed package of benefits to be available to the host community that is finally selected. The Authority has recommended modifications to that package, and these recommendations are currently in the hands of a legislative oversight committee.

LITIGATION

In spite of our best efforts at public information and involvement, litigation seems to be an unavoidable part of this kind of project. The Authority is currently involved in significant litigation on two separate matters.

Shortly after the two potentially suitable sites were selected for characterization, Richmond and Chatham Counties each filed suit against the Authority and Chem-Nuclear. Wake County later joined with Chatham County as a co-plaintiff. These very similar suits made various allegations of inadequacies in the site selection and contractor selection processes. Most of the allegations were dismissed for "lack of ripeness," although the same issues could be raised again once the final site selection has been made. The dismissal is under appeal. The counties also failed in their efforts to have the Authority and Chem-Nuclear enjoined from beginning site characterization.

In a totally separate matter, the North Carolina Press Association and several local newspapers sued the Authority claiming that all contractor records are public documents, whether or not they have been received by the Authority. The Authority contends that this is contrary to the clear definition of public documents in

North Carolina law, and this suit generally seems to be an effort to expand the scope of the state's public records law. The ruling in the case appeared to uphold the Authority's basic position but contained internal inconsistencies and has been appealed by both sides.

FINANCES

All the work of the Authority and Chem-Nuclear, including litigation expenses, has been funded by two principal sources—State Appropriations and funds raised by the Southeast Compact Commission. All funds advanced by the state will, however, be repaid with interest out of operating revenues from the facility once it opens. The current estimate for Phase I of the project (up to the issuance of a facility license) is about $83 million. This represents an $8 million increase from the estimates of a year ago, with the increase due largely to increased characterization costs and to the cost of site security.

Authority operations have been funded by appropriations from the state's operating budget and by Host State Assistance Grants of $200,000 per year from the compact commission. The work of Chem-Nuclear and its subcontractors has been funded out of a $16 million capital appropriation from the state and by fees that the compact commission has assessed against southeast generators using the Barnwell facility. Those fees (a volume-based surcharge and a facility access fee) are scheduled to terminate at the end of this year.

Without additional funding, the Authority would face a shortfall for the preconstruction phase of the project of about $30 million. With the vote by the South Carolina General Assembly to keep the Barnwell facility open, the Southeast Compact Commission is currently discussing mechanisms to raise the additional project funds needed.

An additional $5 million will be raised from southeast generators and will be held in a special account. It would be paid to South Carolina if North Carolina fails to meet one of two project milestones established by the compact commission.

CONTINUED OPERATION OF THE BARNWELL FACILITY

The meeting of project milestones by North Carolina was only one of the conditions set by the South Carolina legislature for the continued operation of the low-level waste disposal facility at Barnwell. The Barnwell facility was scheduled to close at the end of 1992, but this past summer the South Carolina General Assembly voted to keep it open to waste from the southeast compact region until the end of 1995 and to waste from outside the region until mid-1994. Such operation would be terminated (though not always immediately) by any of the following events:

- North Carolina sites a solid or hazardous waste facility within one mile of the North Carolina state border
- North Carolina selects a low-level waste site within ten miles of the state border (i.e., the Richmond site)
- North Carolina does not exclude all low-level waste sites within 10 miles of the state border by the end of 1993
- North Carolina fails to have a complete license application for a low-level waste facility filed by the end of 1993.

Under the terms of the South Carolina legislation, either the 31 December 1993 deadline for a license application or (if the first milestone is met) an additional milestone of having a license issued by 15 March 1995 would, if missed, trigger a $5 million payment to South Carolina. Similar milestones were adopted by the Southeast Compact Commission prior to actions by the South Carolina General Assembly but with 60-day grace periods, which are missing in the legislation.

While North Carolina is certainly aware of the conditions established by South Carolina for the continued operation of Barnwell, the Low-Level Radioactive Waste Management Authority is bound by North Carolina, not South Carolina, law. We are thus continuing with the orderly development of the North Carolina facility with a targeted opening date of 1 January 1996.

A simplified timeline of significant events leading to a January 1996 opening is shown in Figure 3. It also shows how we intend to meet the milestones established by the Southeast Compact Commission. Key features of this timeline are the preparation of dual license applications and the early submittals of sections of these applications.

SUMMARY

The state of North Carolina is making steady progress in the development of the second low-level radioactive waste disposal facility for the Southeast Compact. In spite of substantial litigation, the site characterization work is continuing as planned on both the Wake/Chatham and Richmond County sites. So far there has been no evidence to prove that either site is unlicensable.

The Authority has chosen to adopt Chem-Nuclear's proposal of an integrated vault technology, which incorporates concrete overpacks, modular concrete vaults, and a multi-layer cap. With the selection of the likely disposal cell locations at the two potential sites, geotechnical studies have begun and detailed design work is gearing up.

We continue to try to work cooperatively with local citizens around the potential sites, for many of whom this project is stressful and unwelcome.

Much of the financing for the project has come from charges imposed by the Southeast Compact Commission on regional generators using the Barnwell facility. With the recent decision by South Carolina to delay closure of this facility, we are hopeful of a continuing cash flow to fund the North Carolina project.

The Authority is committed to meeting its responsibility under North Carolina Law to develop and open an environmentally sound and economically viable low-level radioactive waste disposal facility to serve the Southeast Compact region. We are also committed to making every possible effort to meet the compact milestones.

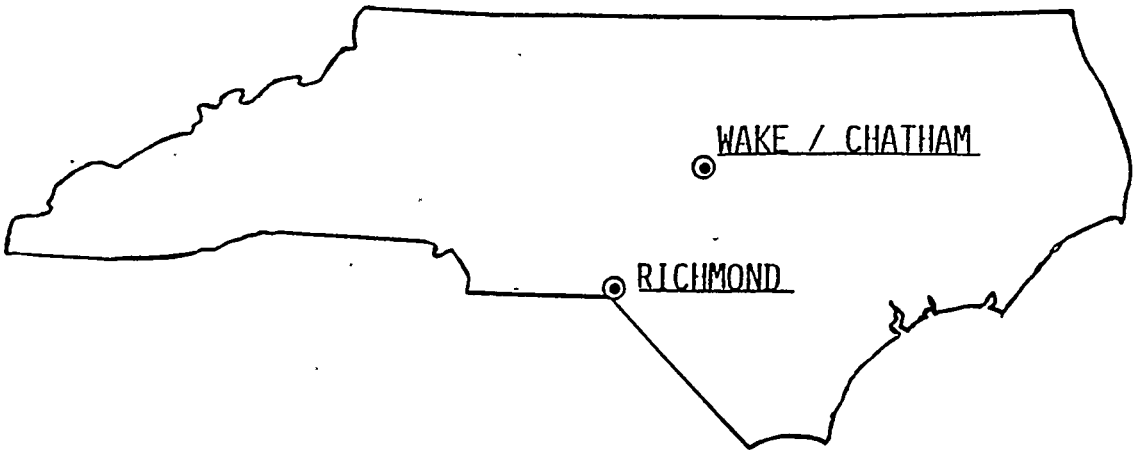


Figure 1. Location of the two proposed sites in North Carolina.

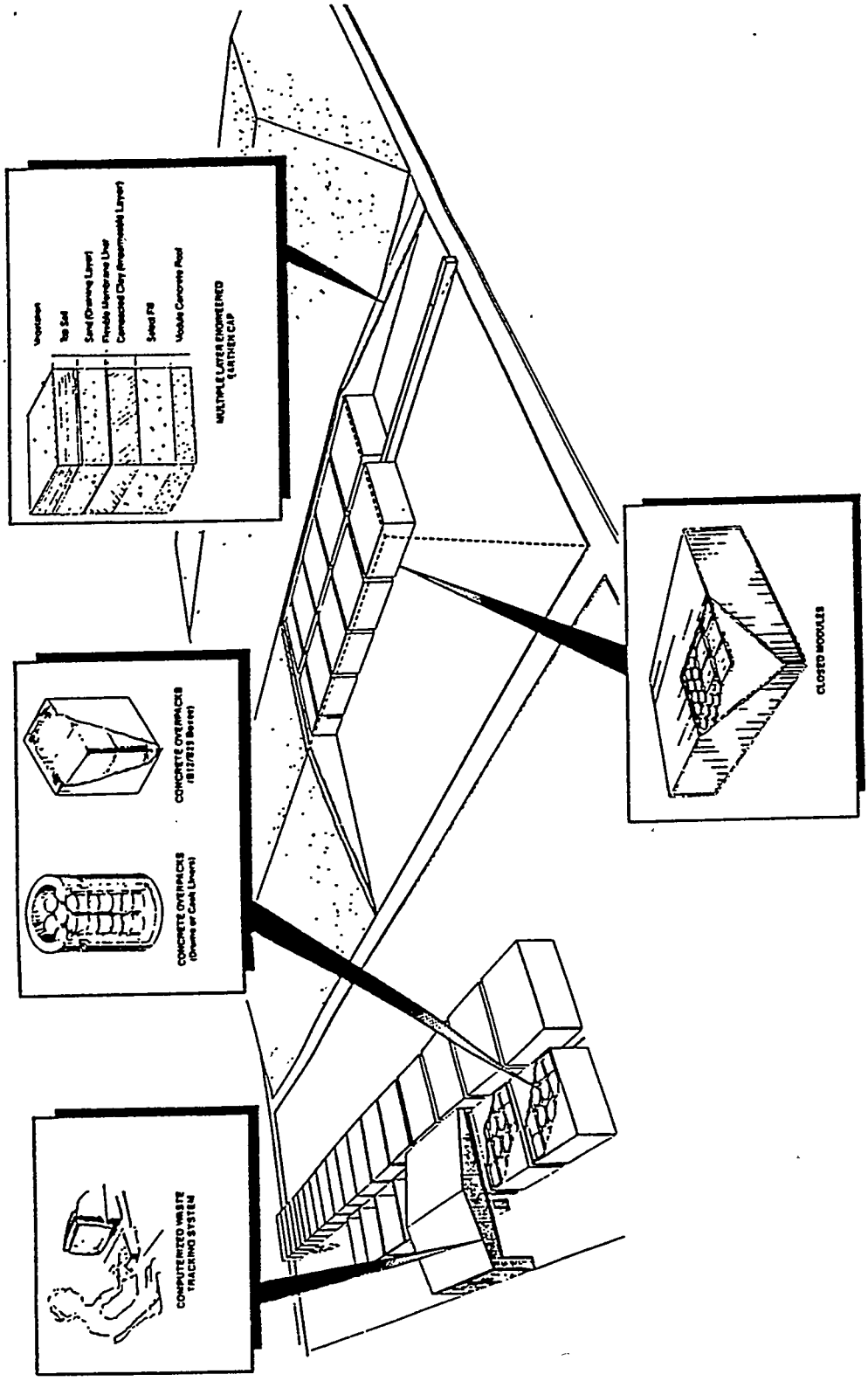


Figure 2. Integrated vault technology.

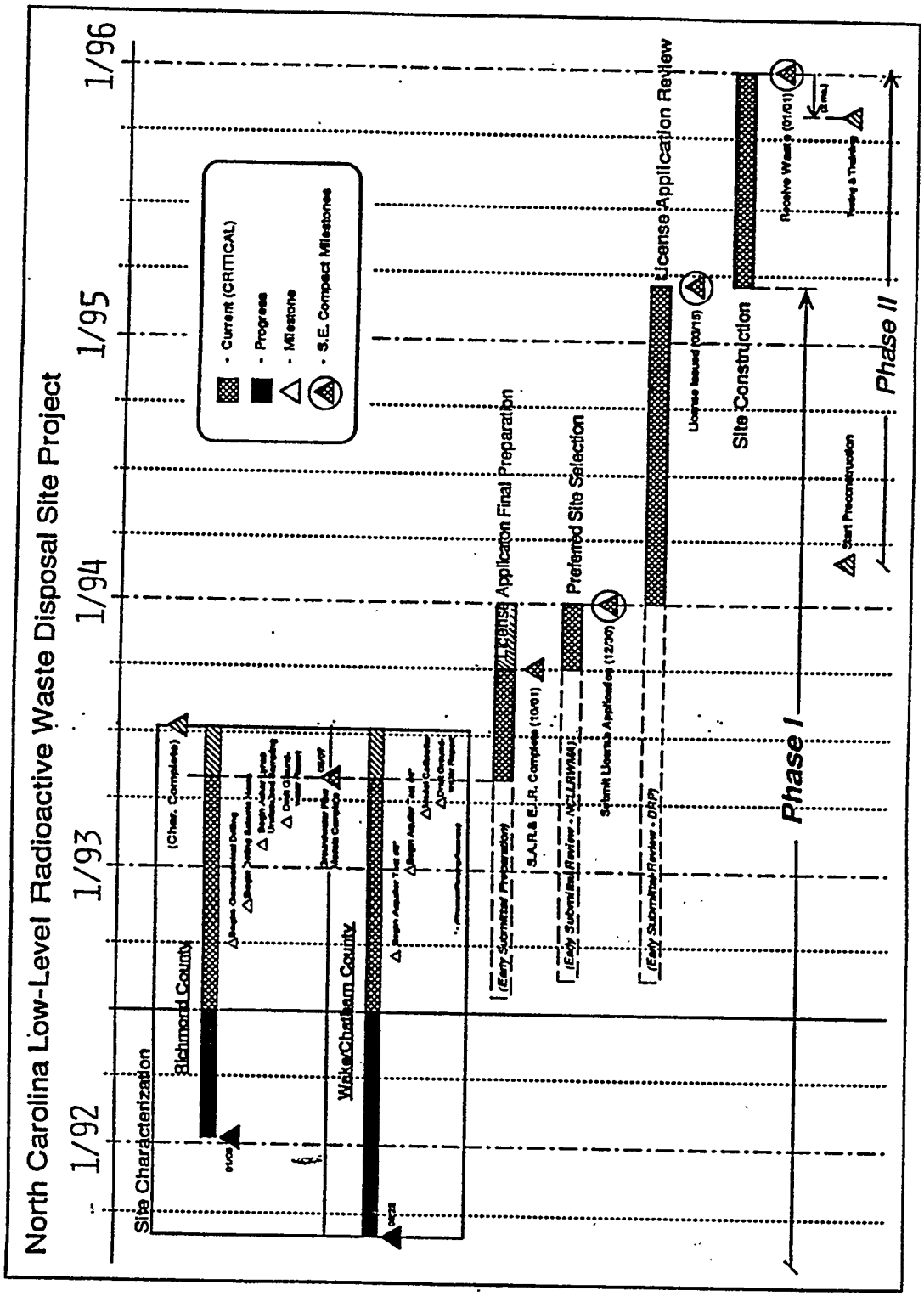


Figure 3. Timeline of significant events leading to a January 1996 opening of the North Carolina facility.

Requirements and Impacts of the Federal Facility Compliance Act on the Department of Energy

Lydia Chang
Susan C. Tripp
U.S. Department of Energy
Regulatory Compliance Division,
Office of Environmental Restoration and Waste Management

SUMMARY OF THE FEDERAL FACILITIES COMPLIANCE ACT

The Federal Facilities Compliance Act (FFCA, the Act) was signed into law on October 6, 1992, primarily as a means of waiving sovereign immunity for federal facilities with respect to requirements under the Resource Conservation and Recovery Act. The FFCA specifically addresses mixed waste management problems at federal facilities and was a result of administration considerations over the previous year. Both Houses agreed to the provisions of H. R. 2194 in late September of 1992. A previous Senate version, S. 596, had given the Department of Energy storage authority for mixed waste; however, the final Act does not.

DOE's implementation of the FFCA will have significant effects on current and future DOE waste management operations. DOE will need to rethink its strategy in the area of future compliance agreements to ensure commitments and deliverables are made consistent throughout the different DOE facilities. Several types of agreements that address mixed waste land disposal restrction (LDR) compliance have already been signed by both DOE and the regulators. These agreements are in place at the Hanford Reservation, the Savannah River Site, the Oak Ridge Reservation (Oak Ridge National Laboratory, K-25, Y-12), and the Paducah Gaseous Diffusion Plant. The Rocky Flats Agreement is now being renegotiated. Los Alamos National Laboratory, Sandia/Albuquerque National Laboratory, Lawrence Livermore National Laboratory, and Idaho National Engineering Laboratory agreements are in progress.

Major components of the FFCA include provisions on:

- Sovereign immunity waiver
- Cost reimbursements
- Mixed waste requirements
  - Inventory reports
    - mixed waste
    - treatment capacity and technologies
  - Plans for the development of treatment capacities and technologies

Each of these components is discussed in turn below.

Sovereign Immunity Waiver

Under the FFCA, sovereign immunity has been waived effective October 6, 1992, for all of DOE's requirements under RCRA except for those mixed waste activities covered under RCRA Section 3004(j), which refers to the storage prohibition on hazardous waste restricted from land disposal. As of October 6, 1992, penalties under 3004(j) have been delayed for three years for facilities that are subject to an LDR administrative or judicial Consent Order or Agreement, as long as they remain in compliance with the Agreement or Order. EPA, the State, and local agencies can undertake administrative enforcement actions under RCRA Section 6001.

If an Agreement is currently under negotiation, it is not clear how the sovereign immunity waiver will apply to the mixed waste storage prohibition during the three-year period following execution of the

Agreement. It is most likely that the facilities involved will be subject to fines and penalties for noncompliance with the Agreement.

For facilities not subject to an LDR Order, Agreement, or permit, fines and penalties are delayed for three years as long as mixed waste is managed in compliance with all other requirements (e.g., labeling, inspections, etc.). After three years (by October 1995) the facility must be in compliance with an approved Plan and an Order requiring compliance with the Plan issued by the applicable State or EPA, or fines and penalties will apply. States with LDR authority under State law and mixed waste authority from EPA can issue Orders or sign Agreements regardless of whether or not they have EPA RCRA LDR authorization. Otherwise, EPA will review and approve DOE's Plan and issue the Order for compliance with the Plan. New Jersey, Missouri, Virginia, and Iowa are the only States that lack both mixed waste authority and host DOE facilities. For example, for the Princeton Plasma Physics Laboratory in New Jersey, EPA will review the Plan and issue the Order.

Liability Issues

Federal employees are not liable (see Table I) for civil penalties with respect to an act within the scope of official duties but are subject to criminal sanctions. In contrast, federal agencies are subject to civil penalties, but not criminal sanctions. Contractor employees and their companies are liable for civil penalties and are subject to criminal sanctions. Liabilities are unchanged from before the signing of the FFCA. The Act does not clarify when violations are attributable to DOE or to contractors; therefore, often the same notice of violation (NOV) may be sent to either or both by regulators. NOVs should be addressed on a case-by-case basis during settlement, if necessary.

Cost Reimbursements

DOE facilities are now subject to reasonable Federal, State, local or interstate entity service charges connected with a hazardous waste program including:

- Permit fees
- Inspection fees (e.g., cost reimbursement to EPA to do annual inspections)
- Fees for reviews of plans, studies and other documents.

State fees and service charges must be nondiscriminatory, meaning the same types of charges must be presented to private firms. The FFCA does not define the term "reasonable," which leaves this area open for interpretation. Currently, DOE funds the States through grants or agreements in principle (AIP) for their services. These may be used or expanded upon as a payment mechanism for compliance with the Act.

Table 1. Liability issues.

EMPLOYEE/EMPLOYER	CIVIL PENALTIES	CRIMINAL SANCTIONS
Federal employees	Not liable	Yes subject
Federal agencies	Yes liable	Not subject
Contractor employees[a]	Yes liable	Yes subject
Contracting companies[a]	Yes liable	Yes subject

a. Contractor liabilities are unchanged from before the FFCA.

National Mixed Waste Inventory

DOE must complete two inventories by April 1993 and report them to EPA and affected States:

- National inventory of all mixed waste
- National inventory of treatment capacity and technologies.

These inventories will use existing data in DOE's Waste Management Information System (WMIS) and Integrated Database (IDB). The WMIS database was initially developed to prepare a national report on the status of mixed waste as of 1989. DOE continues to use WMIS to collect and compile updated information on mixed wastes for internal information management purposes and for the preparation of reports and documents such as the IDB. For each type of mixed waste, the following is required under the Act:

- Description of the waste, including its name
- Amount of waste, separated by its LDR prohibited or nonprohibited status
- Estimated generation rates for the next five years
- Description of waste minimization actions implemented
- EPA hazardous waste code, if characterized
- Basis for determination of the hazardous waste code (sampling and analysis or process knowledge)
- Process (source) that generated the waste
- LDR technology specified for treating the hazardous component
- Radionuclide effects on the selection of the specified LDR technology.

For the inventory of treatment capacity and technologies report the following is required:

- Estimate of available treatment capacity for each waste described in the waste inventory report for which technology exists
- Description of treatment unit capacity, number and location used for the above estimate
- Description of treatment units not used in determining the capacity reported above, their capacity, number and location, and a statement of why their capacity wasn't included
- Proposed capacity, number, location, and estimated date of availability of each proposed treatment unit
- Information to support the decision that no treatment technology exists and description of technological approaches DOE will need to be developed to treat the waste.

Development of Treatment Capacities and Technologies Plans for Mixed Waste

In addition to inventory requirements, the Act stipulates that DOE facilities that generate or store mixed waste must develop site-specific plans for the development of treatment capacities and technologies - "Treatment Plans." By April 6, 1993, DOE is to publish a schedule in the Federal Register for submitting the Plans to the applicable States or EPA. Progress reports on the submission and approval status of the Plans are due to Senate and House Committees in October of 1993, 1994, and 1995. By October 1995, DOE must have submitted Plans to all affected States and obtained their approval.

For mixed wastes for which treatment technologies exist, a schedule for submitting all applicable permit applications, entering contracts, initiating construction, commencing operations, and processing backlogged and currently generated mixed waste is to be included in the Plan. For mixed wastes for which no technologies exist, a schedule for identifying and developing technologies, funding requirements, submitting treatability study exemptions, and research and development applications is to be included in the Plan.

For those cases where DOE proposes the radionuclide separation of mixed waste or material derived from mixed waste, DOE is to provide an estimate of the volume of waste generated by each case of radionuclide separation, the volume of waste that would exist or be generated without radionuclide separation, the estimated cost of radionuclide separation compared to estimates of cost if not used, and assumptions

underlying the waste volume and cost estimates in the Plan. The Plan may provide for centralized, regional, or onsite treatment of mixed waste or any combination.

The Plans are not required for facilities subject to Orders or Agreements to which the State is a party governing compliance with the mixed waste storage prohibition, or subject to State-issued permits that establish a schedule for compliance with the mixed waste storage prohibition.

As a point of clarification, Federal Facility Agreements (FFAs) are typically CERCLA-based agreements between DOE and EPA, whereas Federal Facility Compliance Agreements (FFC Agreements) are typically RCRA-based agreements between DOE and EPA. Once a third party, the State, is added to the agreement it is termed a tri-party agreement (TPA), and may include RCRA, CERCLA, or both issues. The Act refers to RCRA-based agreements between DOE and the State if the State has mixed waste authority; otherwise the agreements are between DOE and the regional EPA office.

The Hanford Site appears to be the only facility subject to an Agreement with the host State that was executed before the FFCA enactment and which addressed the mixed waste storage prohibition compliance issue. All other DOE facilities that generate or store mixed waste must prepare a facility-specific Treatment Plan, unless the facility enters into an Agreement addressing LDR compliance with the State, and the State waives the Plan requirement by issuing an Order requiring compliance, before the October 1995 deadline.

The FFCA has no threshold limits for Treatment Plan submittal requirements, thereby placing a burden on DOE facilities that generate small quantities of mixed waste to develop a Plan and negotiate an Agreement.

The Treatment Plans are to contain specific schedules for achieving compliance, and the schedules are dependent upon whether treatment technologies exist. The Treatment Plans may provide for centralized, regional, or onsite treatment of mixed waste.

Review and approval of the Treatment Plans is by either the applicable State or EPA. States with LDR and mixed waste authority under State law and mixed waste authority from the EPA are to review and approve or disapprove of the Treatment Plan within six months of receipt. EPA RCRA authorization for LDR waste is irrelevant. For facilities located in States without such authority, EPA approves or disapproves of the Treatment Plan within six months of receipt and the affected State receives a copy. The reviewer must consider the need for regional treatment facilities, and comments from the public and all parties affected by the Plan. Following approval of the Plan, the State (or EPA) issues an Order for compliance with the Plan.

DOE'S APPROACH TO COMPLIANCE WITH THE FFCA

DOE is preparing an implementation plan (IP) to ensure its compliance with the FFCA. The IP addresses:

- Anticipated difficulties and their solutions
- Required changes to resources or facilities
- Funding constraints or needs
- Proposed language for authorization and appropriate bills to permit execution of new legislation
- Integration of the FFCA requirements with national programs.

It is DOE's goal to accomplish the requirements spelled out in the FFCA through its integration with other national programs, such as the National Compliance Plan for Mixed Waste (NCP) and DOE's Environmental Restoration and Waste Management Programmatic Environmental Impact Statement (EM PEIS). DOE developed the concept of the NCP to provide an integrated, complex-wide approach to waste management. The NCP effort is now being integrated with the FFCA requirements. It is DOE's intent to get EPA, State, governors, Indian tribes, and the public involved in the development of the NCP. The EM PEIS is still in its early stages and will be "dovetailed" with the NCP and the IP to ensure National Environmental Policy Act guidelines are followed.

FFCA FUNDING IMPLICATIONS FOR DOE

In addition to more work, the FFCA has some serious funding implications. If the FFCA requires DOE to meet new deliverables that have not been budgeted for in either FY 1993 or 1994, a funding supplement or budget amendment may be necessary to comply with FFCA requirements. Future requirements will be factored in during the development of the FY 95 budget. DOE Order 2020.1A describes how the above IP is to be developed and details the actions DOE is required to take under the new legislation. The Order refers specifically to funding constraints posed by the legislation and the consequent preparation of appropriation bills.

CONCLUSION

The FFCA contains short deadlines:

- National inventories are due in six months
- A schedule for completing the Plans is due to Congress in six months
- All Plans are to have been approved by the affected States by October 1995.

The FFCA has financial implications for DOE:

- Sovereign immunity waived - fines and penalties may result
- Cost reimbursements to EPA and States are involved.

DOE's approach will be to:

- Draft guidance and policy for the field
- Prepare an FFCA Implementation Plan that addresses:
- Required changes to resources or facilities
- Proposed language for authorization and appropriation bills if feasible
- Integrate the FFCA requirements with all applicable national programs.

Planned Revision to DOE Order 5820.2A, "Radioactive Waste Management"

Gregory J. Duggan
U.S. Department of Energy Headquarters, EM-35

R. Eric Williams
Don E. Kudera
Idaho National Engineering Laboratory[a]
EG&G Idaho, Inc.
Radioactive Waste Technical Support Program
Idaho Falls, ID 83415

David E. Bailey
NJG, Inc.

ABSTRACT

U.S. Department of Energy Headquarters initiated efforts to revise DOE Order 5820.2A, "Radioactive Waste Management." The purpose of the revision is to enhance DOE waste management requirements, reflect new DOE organizational responsibilities, and consolidate requirements for management of all waste, under the responsibility of Environmental Restoration and Waste Management, into a single order. This paper discusses the revision philosophy, objectives of the revision, and strategy for the revision. Issues being considered for inclusion in the revision and recommended methods of resolving each issue are also discussed.

INTRODUCTION

The current DOE Order 5820.2A, "Radioactive Waste Management," establishes policies, guidelines, and minimum requirements by which DOE manages its radioactive and mixed waste and contaminated facilities. Since DOE Order 5820.2A was issued in September 1988, the DOE waste management system has changed significantly. Many of the changes are the result of an evolving regulatory environment. Changes in DOE policies have increased emphasis on environmental, safety, and health issues, some of which have been communicated in Secretary of Energy Notices and Admiral Watkins' 10-point plan. Other changes stem from modifications in mission and programs and in organizational responsibilities, involving the Office of Defense Programs and the Office of Environmental Restoration and Waste Management (EM).

REVISION PHILOSOPHY

The revision of DOE Order 5820.2A will be based on the following principles:

- Build credibility and public confidence in DOE's waste management system
- When appropriate, make requirements and guidelines agree with those of the Nuclear Regulatory Commission and Environmental Protection Agency
- Provide coverage for waste management responsibilities of EM-30 (i.e., radioactive, hazardous, mixed, and sanitary wastes)
- Promote a feeling of ownership throughout the DOE system by broad participation in the revision.

---

a. Work supported by the U.S. Department of Energy, Office of Environmental Restoration and Waste Management, under DOE Contract No. DE-AC07-76ID01570.

OBJECTIVES OF THE REVISION

DOE Order 5820.2A needs to be revised to reflect current DOE waste management organizational responsibilities, policies, and practices. As with other orders, it is anticipated that over time subsequent updates will be required. However, this revision should include those changes that are currently known to be needed and can be adequately changed without extensive development work. Some of the goals of the revision of DOE Order 5820.2A are to

- Ensure protection of the public, environment, and workers; this will be done in concert with other DOE orders
- Include new requirements since last issuance and incorporate evolving requirements, as appropriate
- Consolidate requirements for management of all waste, under the responsibility of EM, into a single order
- Define waste management requirements and make them more prescriptive
- Issue order as soon as practicable for use in program implementation.

ISSUES CONSIDERED FOR THE REVISION

A Steering Committee, consisting of Department of Energy Headquarters personnel, reviews and approves a course of action on issues under consideration for inclusion in the order revision. The issues considered for the revision are separated into six categories. Issues in each category are considered for addition, expansion, or clarification. These issues and recommendations have not necessarily been finalized at this time. The categories of issues being considered for the revision are

- Organization and content of the order
- Waste classification and characterization
- Performance objective/performance assessment-based waste management system
- Waste management operations
- Documentation of waste management operations
- Miscellaneous issues.

Issue: What should be the organization and content of the revised order?

Recommendation: It is expected that the revised order will include policies, guidelines, and requirements for managing all waste that is the responsibility of EM. Therefore, hazardous and sanitary waste management should be included with radioactive waste management. Waste management from contaminated sites and facilities should also be included in the revised order; however, management of the physical contaminated sites and facilities should be excluded and covered in a separate order. Organizational responsibilities in DOE Order 5820.2A should be updated and a standard structure should be used, as practical, for each chapter on waste types.

Issue: What should the revised order include on waste classification and characterization?

Recommendation: The current classification system allows some waste to fall into more than one category (e.g., high-level waste and transuranic waste) and causes disposal of other wastes to be unacceptable (e.g., low-level waste whose radionuclide content prevents it from being disposed as LLW). A source-based system,

similar to the present system, will be used. However, the system will be developed to cover all DOE waste and material-not-classified-as-waste (e.g., spent fuel and excess nuclear material) and will be structured so that no waste can be classified into more than one category, and each waste classification will have a strategy for disposal. Figure 1 shows the waste classification logic diagram. This diagram will be subjected to further reviews before it is finalized.

A section in the order will present the requirements for characterizing, segregating, certifying, and manifesting of waste. The requirements will incorporate, as appropriate, EPA and NRC regulations. Some characteristics of waste, such as large sizes, can cause management problems. These wastes will be treated as special cases, and guidance on their management will be given separately.

Issue: Should the performance objective/performance assessment (PO/PA) based waste management system be expanded?

Recommendation: Consideration is being given to expanding the current PO/PA based system, which is required for disposal of LLW, to mixed LLW and possibly other waste types. This may be too involved to incorporate all waste management at this time. However, the concept will be considered further in subsequent revisions.

Related to this PO/PA system is a specification for some minimum treatment to be required for long-term storage and disposal of all wastes. Treatment would be required to ensure that the performance objectives will be met. Consideration is being given to include a section reflecting DOE's minimum requirements for treatment of the wastes before long-term storage or disposal.

Issue: Should the order include policies, guidelines, and requirements on selection, operation, and closure of a disposal site?

Recommendation: This issue should be covered in a section of the revised order. The content should mirror applicable and appropriate NRC requirements. Proper selection, operation, and closure of a disposal site are key elements to the safe management of waste. It is important that the revision provides prescriptive information on how these three phases will be accomplished.

Issue: Should the order include policies, guidelines, and requirements on physical security?

Recommendation: There should be a general policy statement with reference to the safeguards and security 5600 series of orders.

Issue: Should the order include policies, guidelines, and requirements on emergency management?

Recommendation: A general statement will be provided addressing emergency management planning. Reference should be made to the emergency management 5500 series of orders.

Issue: Should the order include policies, guidelines, and requirements on transportation?

Recommendation: Transportation requirements for onsite and offsite shipments should be provided in the revision.

Issue: What should the order include on records management?

Recommendation: Existing records management guidelines applicable to the order shall be required. EPA cradle-to-grave requirements should be referenced as applicable.

Issue: What should the order include on reporting requirements (e.g., annual waste management plan, site-specific plan, road maps, and five-year plan are not consolidated or consistent with other DOE orders such as 1332.1A, "Uniform Reporting System.")

Recommendation: A chapter of the order should identify the type, content, and frequency of required reports.

Issue: What should the order include on accountability?

Recommendation: There should be a general policy statement with reference to the safeguards and security 5600 series of orders.

Issue: What should the order include on implementation of a compliance review system?

Recommendation: The order should have the requirement for field type audits to evaluate compliance with the requirements of the order. To accomplish the goal of protecting the public, environment, and workers, it is important to ensure that the managers of the waste are complying with the requirements of the order. Therefore, a thorough, documented compliance review system that reflects the recent cultural changes in the DOE way of doing business is essential.

Issue: What should the order include on quality assurance?

Recommendation: Provide minimum detailed quality assurance requirements for each waste classification.

The following issues do not seem to fall into any of the above categories. Some of these items need to be expanded, some need more details for clarification, and some need both expansion and clarification. It is expected that more of these issues will be apparent the revision continues.

Issue: What should the order include on waste minimization?

Recommendation: A general statement or paragraph should be included that discusses requirements for all DOE installations to implement a waste minimization program. Reference should be made to a separate order that will be prepared on waste minimization.

Issue: What should the order include on recycling of materials?

Recommendation: A general paragraph or section should be included that provides guidance for recycling materials. Reference should be made to the planned waste minimization order, which will cover recycling of commercial-type products such as paper, cans, etc.

Issue: What should the order include on recovery of valuable materials?

Recommendation: Include a general statement on the recovery of valuable materials.

Issue: What should the order include on "Systems Performance Assessments" [Chapter III 3.b.(2) of the existing order]?

Recommendation: The systems performance assessment should be renamed and guidance provided on how to perform the assessment.

Issue: What should the order include on a radioactive/clean determination?

Recommendation: This is considered to be an important subject; however, it can not be incorporated in the revision until a policy is developed.

Issue: What should the order include on conflicts that may involve DOE, NRC, EPA, States, or local governmental agencies?

Recommendation: The order should establish a time limit and system for resolution of conflicts. Initial attempts to resolve the conflicts should be at the field office level.

Issue: What should the order include on waste containing naturally occurring radioactive materials (NORM)?

Recommendation: Guidance should be provided on the exemption of NORM, fallout, and consumer product radioactivity from DOE radioactive waste.

Issue: What should the order include on criticality safety?

Recommendation: The revision should briefly discuss criticality safety as it applies to waste management. The discussion should reference other documents on criticality safety.

Issue: What should the order include on classified waste?

Recommendation: DOE policy on management of classified waste should be discussed.

Issue: What should the order include on inadvertent intruder protection?

Recommendation: The Performance Assessment Task Team should assess this and other performance assessment subjects. Any requirements that are included in the revision should be comparable to NRC intruder protection requirements.

Issue: What should the order include on concentration averaging?

Recommendation: Guidelines for permissible concentration averaging should be discussed as a general topic in the revised order.

Issue: What should the order include on technology development?

Recommendation: A policy statement should be included on the need for technology development, and a process should be defined to identify waste management technology development needs.

Issue: What should the order include on radioactive mixed waste coverage?

Recommendation: References to EPA requirements should be included. DOE guidelines should be included on how to manage mixed waste when there is a conflict between EPA and as low as reasonably achievable requirements.

Issue: What should the order include on DOE equivalent Greater-than-Class C (GTCC) waste?

Recommendation: The management of DOE-owned GTCC waste should still be covered in the LLW chapter. The revision should provide suggested disposal methods that may be acceptable if a site-specific performance assessment is done on the GTCC type waste. Another name should be used to differentiate DOE owned waste that is equivalent to NRC GTCC waste from NRC GTCC waste.

The Steering Committee will review these and other issues to determine if they should be incorporated into the order revision.

REVISION STRATEGY

DOE-HQ formed a Steering Committee to revise the order. The writing of the revised order will be performed by a Technical Working Group (TWG) with DOE Field Office personnel as team leaders and DOE contractor personnel as members of each team. Chapters discussing the following areas will be included in the revised order: Material-Not-Classified-as-Waste, High-Level Waste, Transuranic Waste, Low-Level Waste,

Mixed Waste, Performance Assessment, Hazardous Waste, Sanitary Waste, and Mill Tailings. The revision of the order will include

- Preparing an initial draft of the revised order
- DOE system-wide review, evaluation, and resolution of the comments
- Preparing a final draft
- Second DOE system-wide review, evaluation, and resolution of the second set of comments
- Preparing the concurrence copy of the revised order and final approval by DOE-HQ.

It is envisioned that the revision will take approximately two years to complete.

SUMMARY

Preparations are being made to revise DOE Order 5820.2A. It is expected that the revised order will include guidelines for managing all DOE waste. The draft revisions will be prepared by DOE and their contractor personnel. Reviews of the revised order will be completed by personnel throughout the DOE system. It is expected that the revision process will take approximately two years to complete. The current target date for issuance of an approved revision of the order is by the end of 1994.

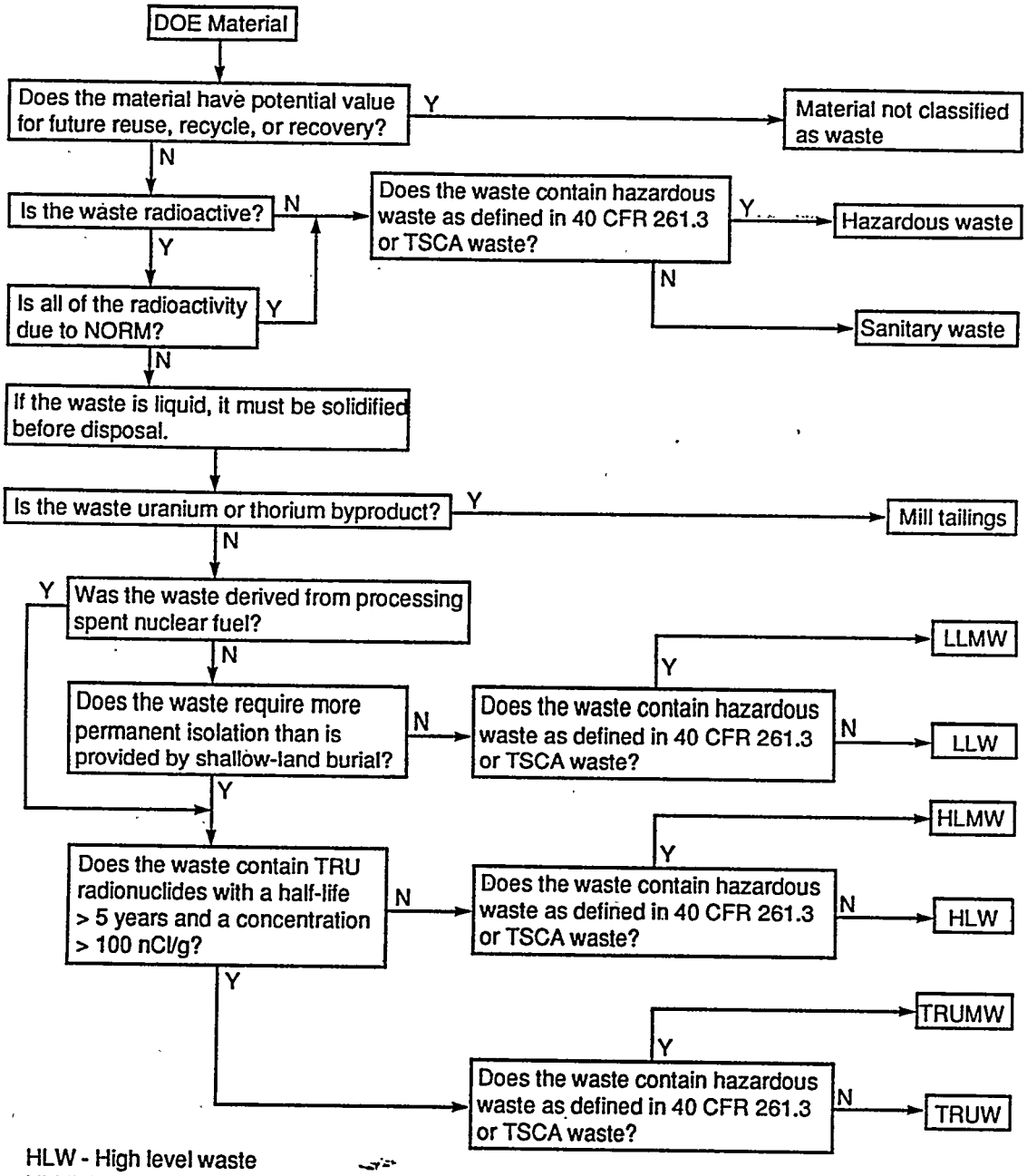


Figure 1. DOE waste classification logic diagram.

Integrating Total Quality Management Principles with the Requirements of DOE Order 5700.6C

Dale Hedges
Director, Quality Assurance
Scientific Ecology Group, Inc.

INTRODUCTION

The Department of Energy has recently required its field offices, contractors, and subcontractors to implement DOE Order 5700.6C, "Quality Assurance," for all work on waste management contracts. The order restructures the 18 criteria of NQA-1 and focuses on the role of management in achieving and assuring quality, performance of activities to achieve and assure quality, and management's assessment of its performance for the purpose of identifying improvements to be made. The DOE order also introduces elements of the total quality management (TQM) philosophy, which were not present in DOE Order 5700.6B.

The research community within DOE has recently issued a document entitled *DOE Order 5700.6C Implementation Guide*, which is more explicit about the integration of TQM principles with the implementation of DOE Order 5700.6C in research facilities.

The Environmental Protection Agency is sponsoring a quality assurance standard (ANSI/ASQC E-4) to replace EPA's QAMS 005/80. The new standard is consistent with DOE Order 5700.6C, and it also stresses the integration of TQM principles within the quality assurance process.

This paper will discuss the intent and philosophy of the 10 criteria of the new DOE order, the status of ANSI/ASQC E-4, and how to effectively integrate TQM principles into the quality assurance process as the conversion is made from NQA-1 to DOE Order 5700.6C. The purpose and value of *DOE Order 5700.6C Implementation Guide* for research will also be discussed.

WHY REVISE THE DOE ORDER ON QUALITY ASSURANCE

For the past few years the Department of Energy has been placing greater emphasis on "doing the right job right the first time." The authors of DOE Order 5700.6C have attempted to carry that message one step further by focusing upon where in the organization the responsibility lies for end-product quality and the importance of effective planning before starting work. The DOE has also introduced total quality management principles, rather subtly, in DOE Order 5700.6C in an effort to cause managers to better use their human resources. A draft document authored by the DOE research community to interpret 5700.6C for research has been more explicit about implementation of TQM principles in the performance of research. The TQM principles that the DOE is focusing upon include:

- Clear definition of the work to be done and the expected quality of end products
- Recognition that quality of work is the responsibility of each person in the process chain
- Empowerment of people to perform their work and to be responsible for the end-product quality—no micro-managing
- Effective planning to ensure proper training and tools are provided, and to ensure that the quality requirements of the customer are understood
- Measurements of the work process performance to identify the need for work process improvements

- Recognition of each person for their contribution to the overall performance of meeting the customer's expectations.

You may react to the above by saying, "There is nothing new in these principles." There isn't; there also isn't anything new in DOE Order 5700.6C. There is a re-focus on the customer's needs and the great potential resource of the people assigned to a program to ensure quality and bring about significant process improvements. We are trying to leave behind us the mindset, nurtured during the nuclear power plant construction days, that project managers could not be trusted and the quality assurance organization must ensure compliance. Today, the focus is upon the project or program manager being responsible and accountable for quality—and his or her ability to plan for quality and motivate people to accept responsibilities for meeting customer expectations. Identifying who the customer is and what the customer expects is new in the sense that we haven't done it well before. Some managers and supervisors still find it difficult to share their responsibilities with the work force and to take the time to discuss the customer's expectations and the importance of customer quality requirements. Sometimes just understanding how a product is to be used can greatly influence how an employee will feel about making certain the product is "right."

WHERE DOES QUALITY ASSURANCE START?

We traditionally think of quality planning at the time we receive a contract. In reality, careful consideration of end-product quality requirements must start when the request for proposal (RFP) is conceived and carried through the proposal and contract award process, if there is to be any chance for an effectively planned and initiated project or program. There are still RFPs issued with a requirement for the application of a consensus standard such as ASME NQA-1 or ANSI N45-2 and a statement requesting the bidder to supply a QA Manual to prove they meet the requirements of the standard. Such a request will elicit a manual that lists the eighteen criteria and commits to implement each. The proposal review team too often merely determines that the manual exists and awards the contract. DOE is striving to break these old habits, but there remains much to be done in the proposal process to cause effective implementation of DOE Order 5700.6C and the TQM principles embodied within it. It is necessary for the writers of RFPs, the evaluators of responses to RFPs, and the contract-negotiating team to thoroughly understand the intent of DOE Order 5700 6C, the quality requirements of the proposed work, and how to integrate quality assurance, TQM, and technical work processes. No longer can we assemble whoever is available and simply assign them to an RFP review and contract negotiating team. Many of us have experienced the agony of being positioned on a new contract—either as the performer or the receiver of the end product—only to find the contract was poorly written and difficult to administer and work to. Too often the lawyers get to sort out these misunderstandings before a judge.

In the haste to get work started, a very important step is too often bypassed—a line-by-line review of the contract, technical requirements, and quality requirements between performer and customer. Those attending the meeting must be the managers who are to be responsible for performing the work and for accepting completed products and services. Any ambiguities must be formally corrected during that review.

STRUCTURE OF DOE ORDER 5700.6C

The quality assurance requirements in DOE Order 5700.6C are grouped under three headings—Management, Performance, and Assessment. Ten criteria are listed under these three headings.

Management - The four criteria listed under management are intended to cause the user to structure an organization to accomplish project or program objectives, provide needed resources, provide procedures for work processes, provide training, and determine documentation to be preserved to provide evidence that objectives were met.

Performance - The four criteria listed under performance are intended to cause management to consider how they will control the work processes that are necessary to perform activities or produce products to meet predetermined objectives.

Assessment - There are two criteria listed under assessment. The first is a management assessment and the second an independent assessment. The focus of these assessments is to achieve objectives and identify needed improvements.

One can compare the 18 criteria of ASME NQA-1 to the 10 of DOE Order 5700.6C and find similarities. The real difference is the focus upon management's responsibilities to plan effectively, motivate people to accept responsibility, and to periodically assess the work process for improvement needs.

A question often raised by contractors who already have a quality assurance program in place to meet the 18 criteria is whether they must revise it to 10 criteria. The answer is no. It will be necessary to review the current program to ensure that it results in a focus on management responsibilities as described earlier in this paper. One can have 10 or 20 criteria to describe the program. How the contractor breaks down the 10 criteria is not important. What is important is that the intent of DOE Order 5700.6C is understood and integrated into the everyday work processes.

The DOE would like the user to understand the intent of the 10 criteria and then develop a program consistent with the nature of the work to be performed. The risks and consequences of failure must be considered and appropriate management controls applied to ensure that requisite quality is attained.

The key points to remember are as follows:

- It is management's responsibility to establish and cultivate principles that integrate quality requirements into the daily work routine
- Performers of the work must receive appropriate training information, tools, support, and encouragement
- Management must demonstrate commitment and leadership through active involvement in the implementation of the quality assurance process
- Quality assurance is everyone's responsibility, and its principles must be threaded through each person's daily work routine
- Management must encourage and foster a continuous work process improvement attitude
- Empower people to do their jobs and to improve the work processes
- Establish innovative measurements of the work process performance and focus corrective measures on the process—not on people.

A NEW QUALITY ASSURANCE STANDARD IS ABOUT TO BE ISSUED

ANSI/ASQC E4, "Quality Systems Requirements for Environmental Programs," is in final peer review and will soon be issued. It is expected that the Environmental Protection Agency will adopt the standard as a requirement and suspend use of QAMS 005/80, which is EPA's guidance for quality control of data. Therefore, contractors working on waste management projects for the DOE that come under the purview of the EPA will find two standards they must meet--DOE Order 5700.6C and ANSI/ASQC E4. The good news is the authors of ANSI/ASQC E4 have closely followed the development of the DOE order and have structured E4 to be consistent with the DOE order's intent. You will find a stronger reference to inclusion of TQM principles in the quality assurance programs; otherwise, the documents are similar in what they are trying to attain.

The authors of E4 did not write the document merely as a replacement for QAMS 005/80, but rather to fill a void that had existed for some time. The EPA did not have a standard for quality assurance, and often contractors ended up using ASME-NQA-1 in an effort to satisfy EPA requirements. NQA-1 does not

adequately address sampling, analysis, or data collection activities. The EPA management decided it was necessary to either write, or sponsor the writing of, a standard to address their needs; thus, with the EPA active support such a standard is about to be distributed.

The authors of ANSI/ASQC E4 intend to make the document a living document. Additions to be made soon after its issue will be to address analytical laboratories and some research and development activities.

The efforts of the DOE research community to provide guidance in the use of 5700.6C—represented in a letter dated May 11, 1992, from William Hipper, Director Office of Energy Research to distribution—provide the basic framework to be used in the next addition to E4. The DOE research community is to be applauded for the time and effort and the insight and clarification offered in their guidance document.

CONCLUSIONS

The DOE has made a great improvement in the guidance offered to the waste management industry by the approval and distribution of DOE Order 5700.6C. Its value to the user is dependent upon how the user reads and interprets the contents. It is DOE's intent that the user will use the guidance of 5700.6C to develop a total-quality-based program that will start with clearly stated performance objectives, clearly articulated responsibilities and authorities, management controls based upon risk management and the importance of end products, and empowerment of individuals to attain and improve quality. The user should refer to 5700.6C as guidance and not as a prescriptive set of rules.

It is important that the guidance of 5700.6C be considered from the time an RFP is conceptualized through the final delivery of products and services.

The DOE research community has provided a great service to the industry by preparing a document to interpret the use of 5700.6C for research projects. Any scientist involved in DOE research can benefit from the use of the research guidance document.

A Process for Ensuring Regulatory Compliance at the INEL's Buried Waste Integrated Demonstrations[a]

Patricia G. Cannon
Larry R. Watson
Paul B. Blacker
Idaho National Engineering Laboratory
EG&G Idaho, Inc.
P.O. Box 1625
Idaho Falls, ID 83415

INTRODUCTION

The Buried Waste Integrated Demonstration Program is funded by the Department of Energy Office of Technology Development. The mission of this Integrated Demonstration is to identify, evaluate, and demonstrate a suite of innovative technologies for the remediation of radioactive and hazardous waste buried throughout the DOE complex between 1950 and 1970. The Buried Waste Integrated Demonstration is coordinated for the DOE by the Environmental Restoration Technology Development Programs Unit of EG&G Idaho, Inc., at the Idaho National Engineering Laboratory. This is very appropriate, since approximately 30% of the DOE complex buried transuranic waste is located at the Idaho National Engineering Laboratory, making this site an ideal test bed for selected demonstrations. The majority of this waste is stored or buried at the Radioactive Waste Management Complex, located on approximately 144 acres in the southwest corner of the Idaho National Engineering Laboratory. Radioactive waste from the Idaho National Engineering Laboratory and the Rocky Flats Plant in Colorado was disposed of in pits and trenches at the Subsurface Disposal Area of the complex (see Figure 1).

The make-up of this waste includes construction and demolition materials (lumber, concrete blocks, steel plates, etc.), laboratory equipment (hoods, tubing, glassware, etc.), maintenance equipment (hand tools, cranes, etc.), process equipment (heat exchangers, valves, High-efficiency particulate air filters, etc.), and decontamination materials (paper, rags, plastic bags, etc.). Records indicate that a variety of containers were used to ship the waste, including steel drums, cardboard cartons, and wooden boxes. Degradation of the waste containers has resulted in contamination of the immediately surrounding soil, and this is the target of some of the remediation efforts at the Idaho National Engineering Laboratory. The types of waste include both hazardous and radioactive wastes, such as transuranic waste, low-level radioactive waste, Greater-Than-Class C low-level waste, hazardous waste regulated by 40 CFR 261, mixed (hazardous and radioactive) transuranic waste, and mixed low-level radioactive waste.

The program approach to development of a long-range strategy for improving buried waste remediation capabilities is to combine systems analysis with already identified remediation needs for DOE complex buried waste. The systems analysis effort has produced several configuration options (a top-level block diagram of a cradle-to-grave remediation system) capable of remediating the transuranic-contaminated waste pits and trenches at the Idaho National Engineering Laboratory (see Figure 2). Technologies for demonstration are selected using three criteria: (a) the ability to satisfy a specific buried waste need, (b) the ability to satisfy functional and operational requirements defined for functional sub-elements in a configuration option, and (c) performance against Comprehensive Environmental Restoration and Compensation Liability Act selection criteria, such as effectiveness, implementability, and cost.

Early demonstrations experienced problems with missed requirements, prompting the Buried Waste Integrated Demonstration Program Office to organize a Corrective Action Team to identify the cause and recommend corrective actions. The result of this team effort is the focus of this paper.

---

a. Work supported by the U.S. Department of Energy, Office of Environmental Restoration and Waste Management, under DOE Idaho Field Office Contract DE-AC07-76ID01570.

REQUIREMENTS IMPACTING DEMONSTRATIONS

Over the years, a large number of requirements (regulations, laws, DOE orders, etc.) have been developed to ensure hazardous and radioactive activities are evaluated and performed in a manner that protects the public and the environment. A summary of these requirements is provided in Table 1.

Before a technology can be considered "ready" for demonstration, there must be some objective means of ensuring that all requirements have been met. These requirements can be redundant, conflicting, and vague, and many hours and dollars have been spent at the Idaho National Engineering Laboratory and other government facilities reviewing, evaluating, and interpreting these requirements. DOE Headquarters requirements documents, laws, regulations, and orders are interpreted by the field offices, resulting in the publication of field office requirements. In turn, field office requirements are interpreted by the contractors, resulting in contractor requirements documents. From contractor requirements documents, policies and procedures are developed to ensure consistent implementation throughout the company (see Table 2). At the Idaho National Engineering Laboratory, Buried Waste Integrated Demonstration Program staff has evaluated the flowdown of requirements from the customer requirements to the operating procedures to identify specific requirements that may affect demonstrations.

Along with a myriad of environmental, safety, health, and quality requirements, the demonstrations vary in technical complexity and maturity, demonstration sites, times, and duration. The complexity is a result not only of the technical nature of the processing and engineering but because of the many unknowns inherent in any research application. Since very few requirements regulated radioactive and hazardous waste processing and disposal between 1950 and 1970, varying methods were used. Documentation is sketchy; some documents contain insufficient information, and some shipping documents have been destroyed.

Based on the above information, successfully demonstrating innovative technologies can be a complicated task. The principal investigators, scientists, engineers and technicians are experts at identifying technical requirements, and they understand what is needed to make the technology perform well theoretically or in the laboratory. But very few know what is required logistically and what is required to meet all the regulatory requirements. The Buried Waste Integrated Demonstration Program Integrated Demonstration coordinator and project manager are responsible for ensuring that the mission of the program is met. They also have had experience with missed requirements for technology demonstrations; for example, it was discovered that the helicopter had arrived at the site for the aerial surveillance demonstration, but a permit had not been obtained and security had not been notified. With much last-minute scrambling, frustrated calls, finger pointing, and anticipation, requirements were finally met, but there was still a feeling of "what else did we forget?" A Corrective Action Team was formed to evaluate the incident and recommend a corrective action. The corrective action was the use of a Preparedness Checklist and Action Plan based on regulatory requirements. The term "regulatory" in this paper encompasses all environmental, safety, health and quality requirements.

TECHNOLOGY DEPLOYMENT PROCESS—REGULATORY COMPLIANCE FOCUS

As the Corrective Action Team was evaluating these problems, the Buried Waste Integrated Demonstration Program Office put together a Technology Deployment Team to support deployment of the technologies. The interdisciplinary team was formed to provide support to principal investigators planning field demonstrations of their technologies at the Idaho National Engineering Laboratory. The team consisted of representatives with backgrounds in facilities and maintenance, operations and environmental issues, safety, health, and quality (some of these representatives were also participating in the Corrective Action Team). As a first step, a flow diagram was prepared of the entire Buried Waste Integrated Demonstration process, from identification of needs to completion of the demonstration and a technology evaluation report. The technology deployment portion of this flow diagram magnified the interrelationship of operations, facilities and environmental, safety, health, and quality disciplines. Modifications were made to streamline the process, resulting in the Technology Deployment Process. The goal was to develop a process to ensure that all regulatory requirements were considered in the early planning stages of a technology demonstration. The Technology Deployment Team implemented the recommendations of the Corrective Action Team and applied the Operational/Occupancy Readiness Review process used when bringing a facility or large system on line.

This brief explanation of Operational/Occupancy Readiness Review is provided for those who may not be familiar with this process. An Operational/Occupancy Readiness Review process is a systematic approach to evaluating the readiness of an interrelated set of activities to function as required to yield the intended results. This process uses a two-dimensional matrix or readiness tree as the primary tool for planning the review. The components of the tree are management, personnel, and hardware. Each of these components is expanded based on the requirements (see Figure 3).

Because of each team member's experience with Operational/Occupancy Readiness Reviews, the initial approach was to prepare separate checklists to be completed by the principal investigator. But as the team communicated, reviewed documents, and brainstormed, it became obvious that a simpler, more powerful tool was being created. There was redundancy in the three documents because the driver for each document was the requirements. The three checklists were eventually merged, and the Preparedness Checklist now being used is the result of the Operational/Occupancy Readiness Review tree for a technology demonstration (see Figures 4 and 5).

IMPLEMENTATION STRATEGY

Of course, a checklist is no good if no one uses it. Fortunately, the Buried Waste Integrated Demonstration Technology Deployment (BWID) Team had the support of some very visionary managers. Having recognized the benefits of identification of requirements early in the planning stages of a project, BWID management developed a strategy to ensure that the checklist was used. The checklist was added as an appendix to the Technology Status Report, which is required 30 days after a technology receives funding. DOE-HQ had also recognized the need for an early planning tool and was in the process of having a similar document prepared. The *Buried Waste Integrated Demonstration Technology Preparedness and Status Report Guidance* was shared with DOE-HQ sponsor, who agreed to support the following requirement: The *Buried Waste Integrated Demonstration Technology Preparedness and Status Report* is due 30 days after funding is approved. If the document is not received, funding will be put on hold until the document is received by the BWID Program Office. It is recognized that it is easy to talk about the benefits of good planning but that not many take the time to plan well. This process is designed to force good planning in the early stages of the project.

Initially, the Preparedness Checklist is used to identify demonstration requirements. It also gives the Buried Waste Integrated Demonstration Technology Deployment Team a tool to track the status of activities. When all requirements have been fulfilled, a letter authorizing the demonstration to begin will be issued by the Integrated Demonstration Coordinator.

Another feature of this process is that the deployment function is centralized. Rather than having each Principal Investigator fund the deployment effort separately and work with the site operations personnel; Environmental, Safety, Health, and Quality Unit; and Facilities Unit; Buried Waste Integrated Demonstration coordinates all of this work for each Principal Investigator. Centralization of these activities ensures that use of environmental, safety, health, and quality documentation is maximized. The Buried Waste Integrated Demonstration Program Office is aware of National Environmental Policy Act documentation, which may cover a large number of demonstrations. For example, a Site Characterization Categorical Exclusion will cover all the nonintrusive characterization technology demonstrations. Hazard classification documentation prepared for a nonintrusive sensing device provides basic information about the concept and provides the foundation for hazard classification reports for other technologies of this type. Representatives from the Buried Waste Integrated Demonstration Program Office take on this responsibility, allowing the principal investigators to concentrate on the technical aspects of the demonstration without overlooking other administrative requirements.

The checklist was used before deploying two technologies in June 1992, and both were completed without any surprises or regulatory delays.

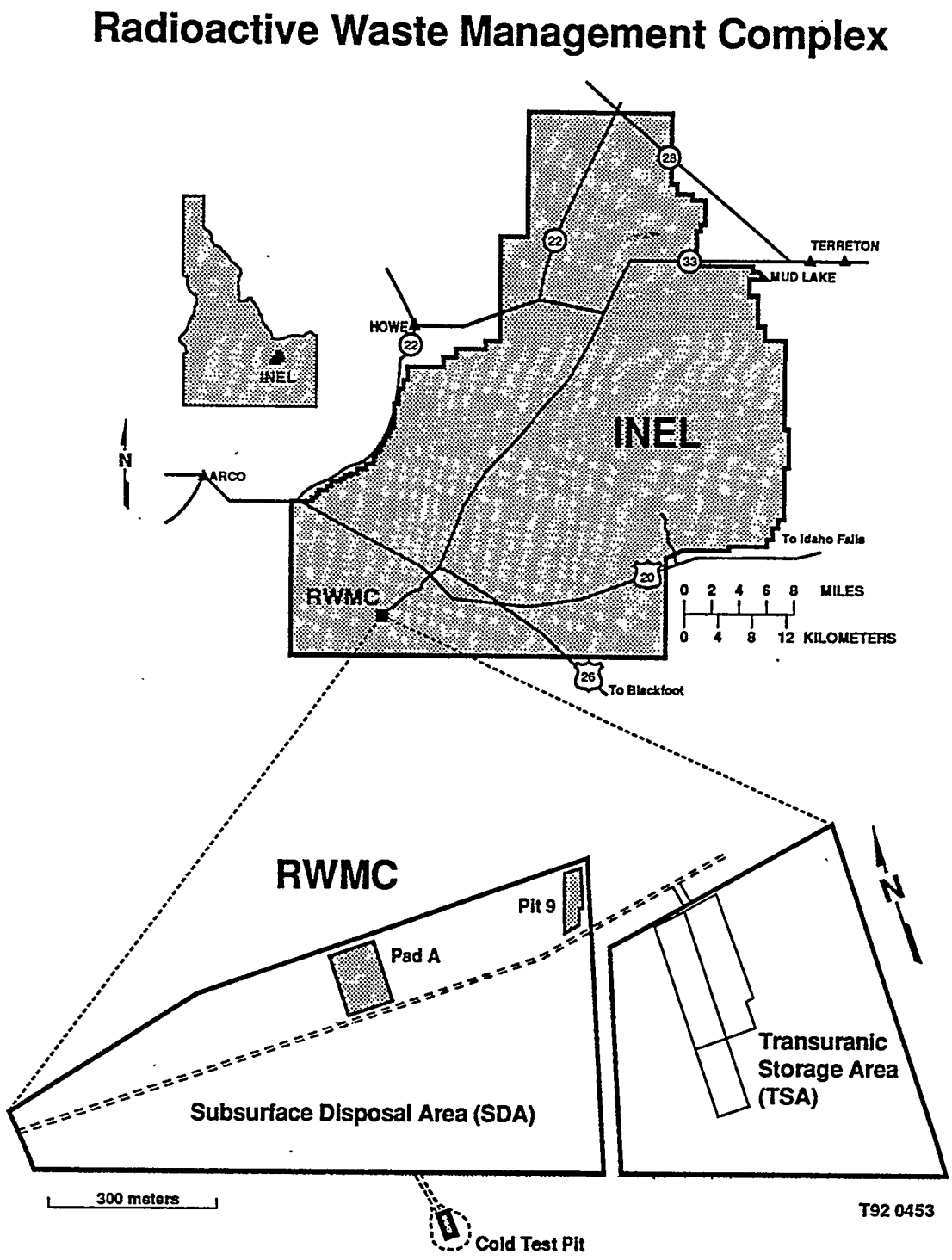
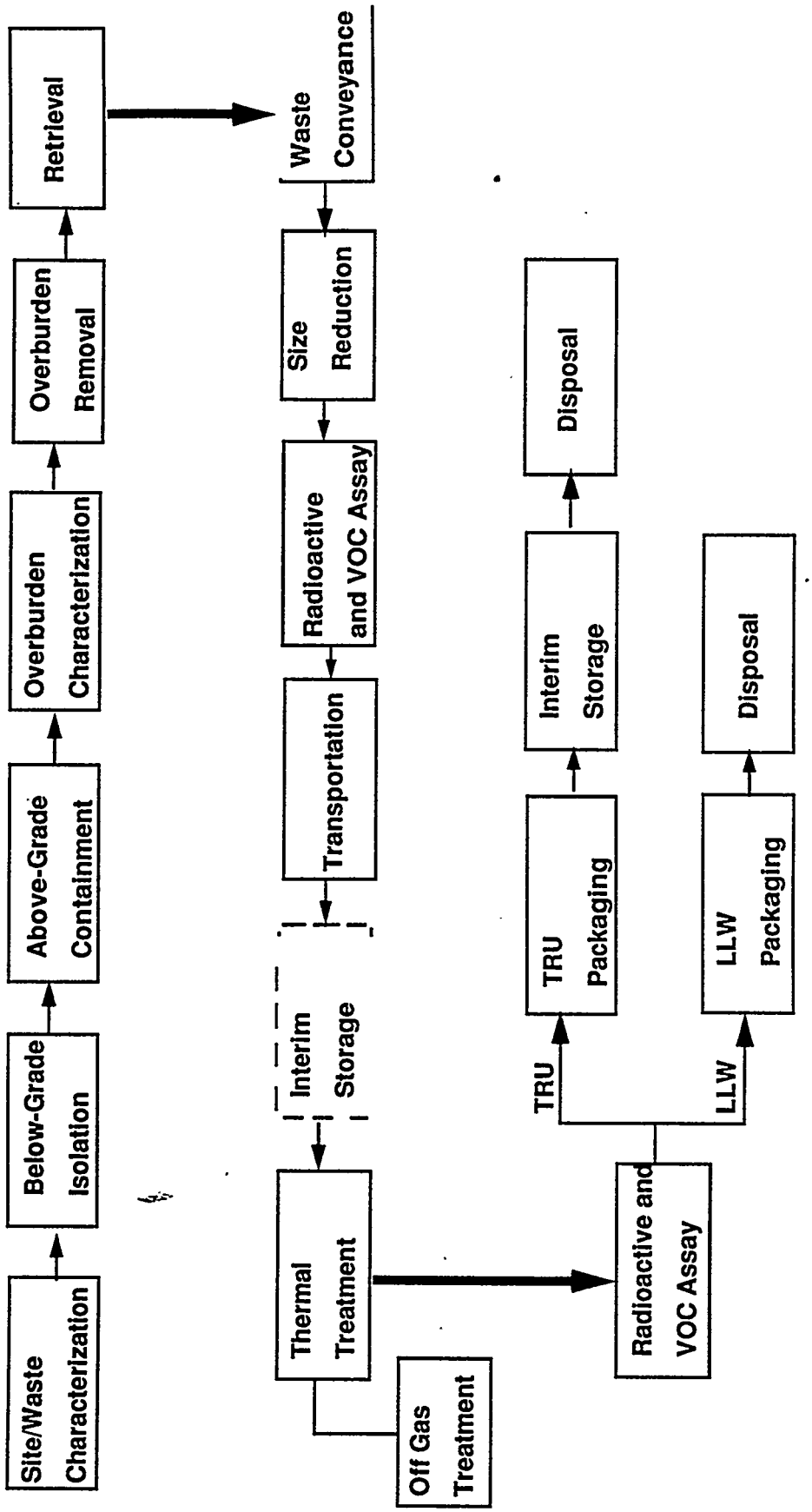


Figure 1. Radioactive Waste Management Complex at the Idaho National Engineering Laboratory.

Figure 2. Block diagram of cradle-to-grave remediation system



KM8/10-5

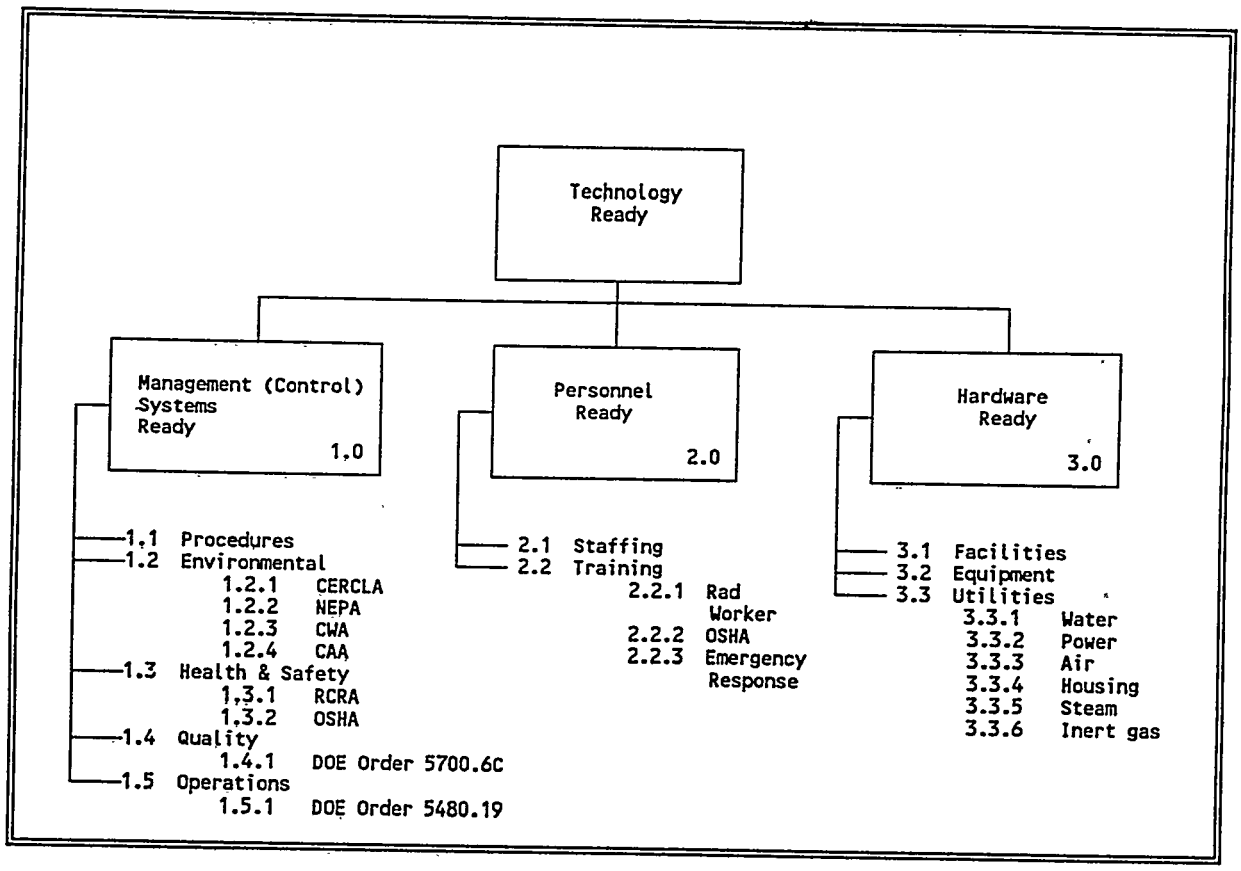


FIGURE 3. Expanded Buried Waste Integrated Demonstration Readiness Tree

Table 1. Requirement documents.

Category	Requirements (Regulations, Laws, DOE Orders, etc.)
Environmental	• Comprehensive Environmental Response and Compensation Liability Act (CERCLA) • National Environmental Policy Act (NEPA) • Clean Air Act (CAA) • Clean Water Act (CWA) • Resource Conservation and Recovery Act (RCRA) • Endangered Species Act • Fish and Wildlife Coordination Act • Marine Protection, Research, and Sanctuaries Act • Marine Mammal Protection Act • American Indian Religious Freedom Act • Coastal Zone Management • Federal Insecticide, Fungicide, and Rodenticide
Health and Safety	• Toxic Substance Control Act (TSCA) • Emergency Planning and Community Right to Know Act • Operational Safety and Health Act (OSHA) • Superfund Amendments and Reauthorization Act (SARA) • Hazardous Materials Transportation Act • Federal Health and Safety Act • Federal Food, Drug, and Cosmetics Act • Consumer Product Safety Act • DOE Order 5480.19
Quality	• DOE Order 5700.6C

Table 2. INEL Document hierarchy.

Level 1	Customer Requirements Federal Laws, Regulations, DOE-HQ Orders, etc.
Level 1A	Customer Requirements State, and local laws, DOE-ID Orders
Level 2	Company Requirements
Level 3	Company Procedures
Level 4	Department Directives
Level 5	Plans, Instructions, Operating Procedures

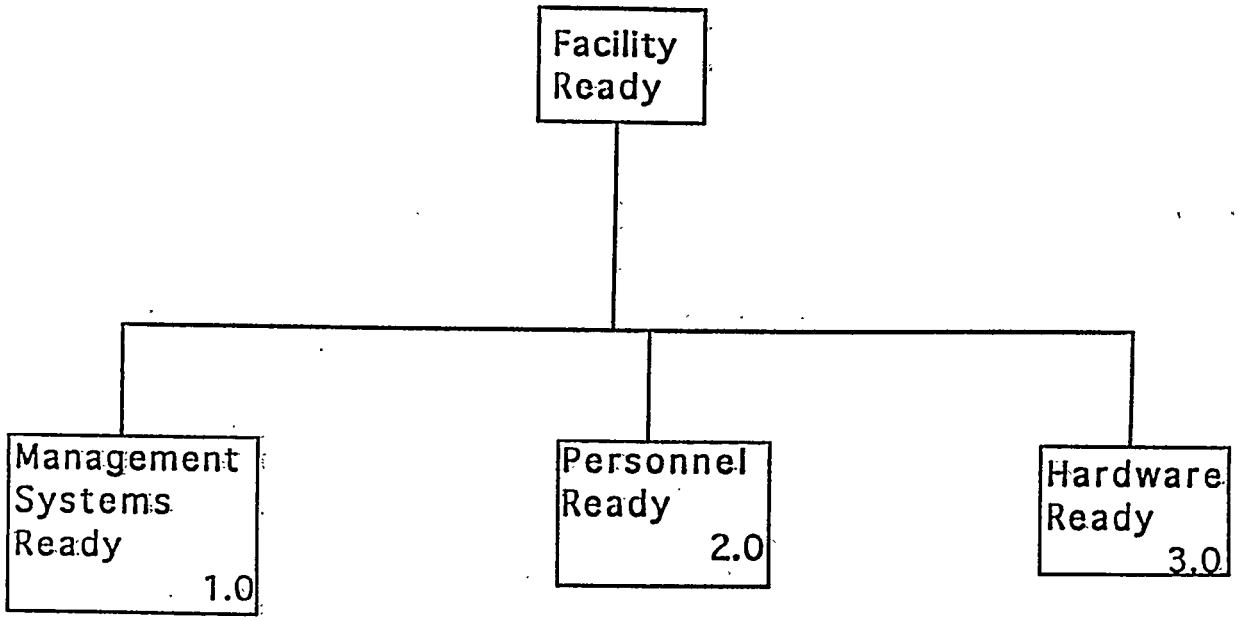


Figure 4

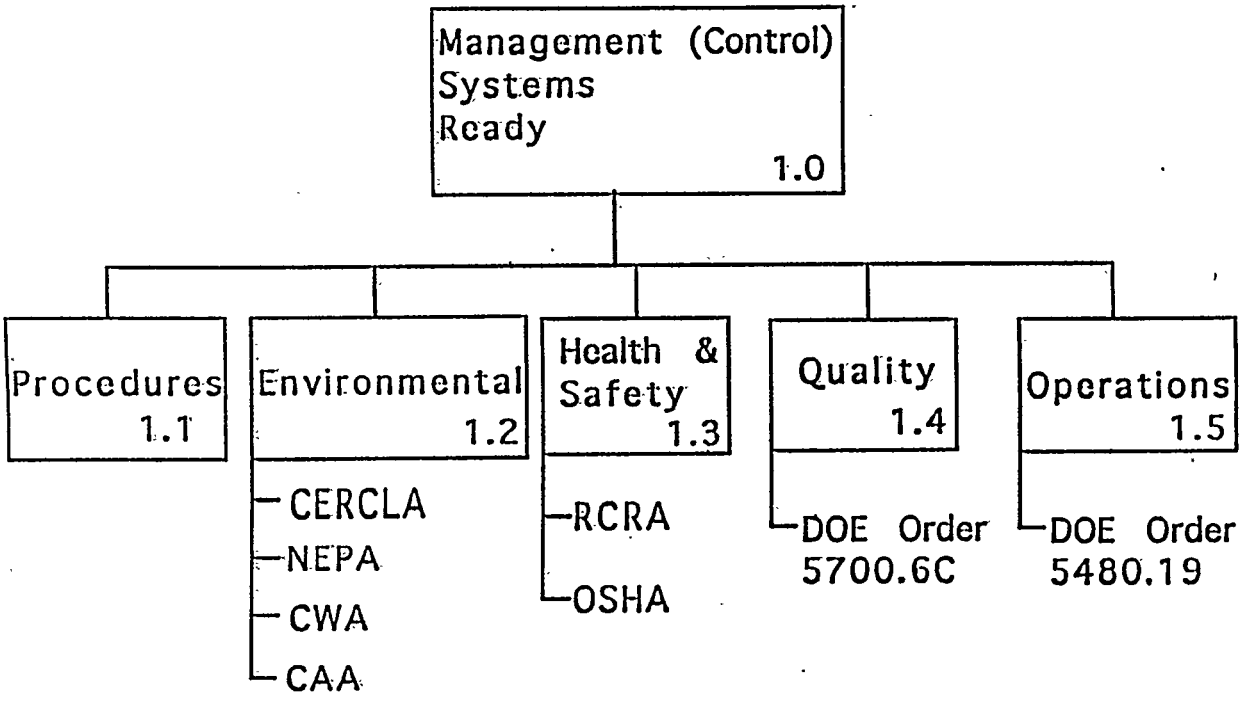


Figure 5

DOE's Approach to Groundwater Compliance on the UMTRA Project

Donald Metzler
U.S. Department of Energy

James P. Gibb
Geraghty & Miller, Inc.

William A. Glover
Roy F. Weston, Inc.

SUMMARY

Compliance with the mandate of the Uranium Mill Tailings Radiation Control Act (UMTRCA) at Uranium Mill Tailings Remedial Action (UMTRA) Project sites requires implementation of a groundwater remedial action plan that meets the requirements of Subpart B of the U.S. Environmental Protection Agency's proposed groundwater protection standards (40 CFR 192).

The UMTRA Groundwater Project will ensure that unacceptable current risk or potential risk to the public health, safety and the environment resulting from the groundwater contamination attributable to the UMTRA sites, is mitigated in a timely and cost-efficient manner. For each UMTRA processing site and vicinity property where contamination exists, a groundwater remedial action plan must be developed that identifies hazardous constituents and establishes acceptable concentration limits for the hazardous constituents as either (a) alternate concentration limits (ACL), (b) maximum concentration limits (MCLs), (c) supplemental standards, or (d) background groundwater quality levels.

Project optimization is a strategy that will aggressively work within the current regulatory framework using all available options to meet regulatory requirements. This strategy is outlined below.

The recommended near-term strategy begins by moving forward with a Programmatic Environmental Impact Statement (PEIS) to cost-effectively provide the National Environmental Policy Act (NEPA) compliance framework for all sites. The PEIS effort will be accompanied by an aggressive public outreach Project that will be implemented in conjunction with the scoping process. The other important near term activities include the following:

- Using the Gunnison site to demonstrate the use of institutional controls.
- Using the Salt Lake City site as a demonstration project for application of supplemental standards.
- Using the new Rifle site for demonstrating secondary source term mitigation techniques and application of ACLs.
- Developing groundwater modeling requirements for natural flushing demonstration to the U.S. Nuclear Regulatory Commission.

The recommended long-term strategy will be based on the successful demonstration of the available regulatory options explored during the near-term activities. Proposed decisionmaking processes are presented for each type of regulatory and technical option. The long-term strategic goal is to use site-specific risk assessments to select and justify the most cost-effective compliance option for each site.

The recommended near-term strategy can be accomplished with currently projected fiscal year (FY) 1993 and FY 1994 funding. However, as additional and more difficult sites are undertaken, higher levels of funding will be required.

To minimize these costs, the UMTRA Project advocates the use of the observational approach to accomplish all of these compliance goals. Data from the Superfund program have proven that site characterization followed by pilot plant installation, and implementation of the selected remediation is both costly and time consuming. The observational approach allows for immediate application of a selected corrective action approach without undue site characterization.

The estimated cost, fully loaded and escalated, of the proposed project optimization approach is $426 million with a contingency of $162 million. This represents a better than 50 percent cost savings over the earlier, more conventional approach to remedial action.

INTRODUCTION

Legal Mandate

The U.S. Congress enacted the UMTRCA on November 8, 1978. The initial purpose of the Act was to conduct assessments and remedial actions at designated sites to "stabilize and control such tailings in a safe and environmentally sound manner and to minimize or eliminate radiation health hazards to the public..." (PL 95-604, 1978). Title I of the Act authorizes the Uranium Mill Tailings Remedial Action Project and directs the Secretary of Energy to enter into cooperative agreements with the affected states and Indian tribes. Title II of the Act sets forth licensing and regulatory requirements for uranium mill tailings.

Section 275 of the Atomic Energy Act (AEA), as amended by section 205 of the UMTRCA, requires the EPA to promulgate standards "for the protection of public health, safety and the environment from radiological and non-radiological hazards associated with residual radioactive material...located at uranium mill tailings sites and depository sites for such material... Standards promulgated pursuant to this subsection shall, to the maximum extent practicable, be consistent with the requirements of the Solid Waste Disposal Act, as amended... After October 1, 1982, if the Administrator has not promulgated standards in final form under this subsection, any action of the Secretary of Energy... shall comply with... the standards proposed by the Administrator under this subsection until the Administrator promulgates the standards in final form." UMTRCA further amends the AEA to give the NRC enforcement and licensing authority to ensure compliance with the EPA standards.

Although the 1978 Act has no explicit mention of groundwater, the need for groundwater protection is inferred from the requirement to be consistent with the Solid Waste Disposal Act (SWDA). Senate Report 100-543, which accompanied the 1988 UMTRA Amendments Act, explicitly authorizes the U.S. Department of Energy's (DOE) authority to perform groundwater restoration without limitation, and also recognizes that Section 112 contemplates a two-phased remedial action project at sites where long-term groundwater remedial action will be required. The need for the NRC to conduct concurrence and licensing in two phases is also recognized here.

In October 1982, the EPA issued a Final Environmental Impact Statement for 40 CFR 192 and on January 5, 1983, the EPA issued final standards for control and cleanup of residual radioactive material (RRM). On September 3, 1985, the Tenth Circuit Court of Appeals remanded the groundwater portion of the standards to the EPA because they were not consistent with the requirements of the Resource Conservation and Recovery Act (RCRA), which amends the SWDA. On September 24, 1987, the EPA issued new proposed standards for groundwater protection based on RCRA regulations for disposal facilities. The September 1987 proposed standard established the groundwater cleanup requirements with which the groundwater compliance strategy of the UMTRA Project must comply.

On January 9, 1990, the Office of Management and Budget (OMB) sent 40 CFR 192 back to EPA to resolve any outstanding issues raised by the DOE and the NRC. OMB still opposed promulgation of the proposed standards.

Regulatory Requirements

The proposed groundwater standards include the following requirements:

- Tailings remedial actions must protect groundwater
- Groundwater under tailings pile must not exceed MCLs or local background concentrations for regulated constituents at the downgradient edge of the disposal facility
- Groundwater contamination caused by milling and related activities must be cleaned up to meet MCLs or background
- MCLs are based on EPA primary drinking water standards with the addition of uranium and other constituents of interest
- For temporary and spatially limited seepage from tailings piles, an alternate concentration limit may be applied until MCLs or background can be met
- If the local groundwater is already polluted or is not suitable as a domestic water supply, then supplemental standards may be assigned
- Monitoring of disposal cell performance is required
- Compliance with subpart B of the standards may not exceed 100 years.

In addition to meeting the requirements of proposed groundwater protection standards 40 CFR 192 (the September 24, 1987, version is still effective), DOE activities must comply with other relevant regulations.

Although DOE is not explicitly required to adhere to relevant state groundwater protection or cleanup standards, the states may withhold concurrence in any cost-shared remedial action if they are not satisfied with the remedial action plan. States may impose their own regulatory requirements on the UMTRA remedial actions.

PROJECT BACKGROUND

Section 206 of UMTRCA directs the EPA Administrator to "...promulgate standards of general application ... for the protection of the public health and safety, and the environment from radiological and non-radiological hazards associated with residual radioactive material ... Standards promulgated pursuant to this section shall, to the maximum extent practicable, be consistent with the requirements of the SWDA, as amended." The Uranium Mill Tailings Remedial Action Amendments Act of 1987, which went into effect on September 23, 1988, amended section 112(a) of the UMTRCA as follows:

> ...the authority of the Secretary to perform groundwater restoration activities under this title is without limitation.

This is the statutory language that explicitly allows for a groundwater remedial action project.

On January 5, 1983, the EPA Administrator promulgated final standards (40 CFR 192) for the disposal and cleanup of inactive uranium mill tailings sites under the UMTRCA. These standards were challenged in the U.S. Tenth Circuit Court of Appeals and on September 3, 1985, the court set aside the provisions for groundwater protection because they were not consistent with the provisions of the SWDA, as amended by RCRA. The RCRA regulation set uniform, as opposed to site-specific, standards for the protection of groundwater. On September 24, 1987, standards were proposed for the protection and cleanup of groundwater. These proposed standards are essentially identical to the basic provisions of the RCRA standards of 40 CFR 264.92.94 regarding groundwater protection at waste disposal facilities. In addition,

provisions were added allowing for the application of supplemental standards, institutional controls and natural restoration through passive flushing where no community drinking water source is involved. This is the standard to which the UMTRA Project is now subject.

As part of the surface remediation requirements, groundwater protection strategies were required for each site to ensure that continued contamination of groundwater resources does not occur. In developing those strategies, groundwater data has been collected that documents that past milling and disposal activities have contaminated the underlying groundwater resources at 20 of the 24 UMTRA sites. Thirteen of the 20 sites may pose potential health risks or violate existing Federal or state groundwater regulations. The major contaminants are uranium and nitrate. The surface remediation activities have essentially been limited to removing or controlling the source of groundwater contamination but have not begun to address the groundwater contamination problems at each site.

Development of the groundwater protection strategies required for the surface remediation portion of the UMTRA Project has not only documented the nature of the groundwater problems at each site, but has also heightened the awareness of those problems at several sites to the general public, the states and tribes, and to the NRC. It is clear to all concerned that the surface remediation actions have not solved the groundwater contamination problems. In several communities, such as Gunnison, Colorado, the public is very anxious to not only have the visible contaminants at the surface removed or stabilized, but to eliminate the potential health hazard associated with the groundwater contamination migrating from the site. The state of Texas is similarly eager to ensure that the DOE addresses the groundwater contamination problem at Falls City, Texas. The Navajos are concerned about cleaning up the groundwater contamination at the Monument Valley, Arizona site. Finally, the NRC anticipates that the UMTRA Project will quickly and efficiently address the groundwater problems at all sites so the total restoration and licensing of the sites can be accomplished in a timely and environmental sound fashion.

PROJECT PLANNING DOCUMENTS

Groundwater restoration will be guided by several programmatic documents. The PEIS will provide the decisionmaking methodology for selecting a compliance method. The Technical Approach to Groundwater Restoration (TAGR) document provides an overview of how technical business for the groundwater project will be conducted. The TAGR covers the regulatory basis and requirements for compliance and provides a framework for the field activities needed to meet those requirements. As discussed in the TAGR, the field activities will follow the observational method.

Procedures for field activities are specified in numerous standard operating procedures that are filed in the Jacobs Engineering Albuquerque Operations Manual. Quality assurance (QA) issues are addressed in the Quality Assurance Implementation Plan (QAIP), which provides QA specifications for the collection of environmental samples and data, and for the analysis of environmental samples. The QAIP will specifically address data quality objectives for collection and analysis of data. Quality issues associated with data and samples related to geology, hydrology, chemistry, biology, and engineering are covered by the QAIP.

Other programmatic documents include the Environment, Safety, and Health Plan and the Public Information and Participation Plan. These two documents are very important to the Project and reveal a commitment to the "new culture" in the areas of environment, health and safety and, in particular, in the area of proactive public involvement.

THE GENERAL STRATEGY

Observational Approach to Site Characterization

The traditional approach to site characterization has been to spend considerable time and money to characterize completely site conditions and the extent of groundwater contamination. The ultimate goals of site characterization are to identify the contaminants of concern, determine the extent of contamination, and gather adequate hydrologic and chemical data to design a remediation project and to predict how the system

will react to the selected remedy. Once a remedy is selected, a pilot program is normally instituted to determine how the groundwater system will react to the proposed remediation and to gather adequate data for final treatment design parameters.

Data collected to date at the 24 UMTRA sites have identified the contaminants of concern and, at most sites, the extent of groundwater contamination. Preliminary hydrologic data have also been collected. However, these data are not adequate to determine how the groundwater system will react to various remediation strategies or what kinds of treatment equipment would be required, if pumping and treating were the necessary option. These data are not sufficient to conduct comprehensive baseline risk assessments.

To minimize expenditures and expedite groundwater remediation design, it is proposed that the observational approach to site characterization and remediation design be used. A minimum number of monitoring wells will be installed to gather appropriate water level and water quality data. Selected wells would be tested to determine necessary hydrologic data for modeling of the site to evaluate natural flushing or gradient manipulation techniques.

If contaminant removal is anticipated, a pumping well would also be installed somewhere in the contaminant plume to determine the reaction of the hydrologic system to pumping and the water quality to be treated. A portable treatment plant would be used to treat the contaminated water being pumped and to test the relative effectiveness of various combinations of treatment strategies. Modifications to the systems would be made and the resulting changes in system operations would be observed. Use of this approach to site characterization and remediation design collects only the required data in direct response to proposed remediation strategies. If pumping is required, early action also retards or checks the further spread of contaminants until the permanent remediation program can be approved and installed.

Remedial Action Decisionmaking

Although the physical, chemical, and risk characteristics of the UMTRA sites vary, a common decisionmaking pattern for attaining compliance with the groundwater standards applies to all of them.

The remedial action decisionmaking process for all sites is guided by the PEIS. The first decision point in the PEIS comes after it is determined whether there is any groundwater contamination above MCLs or background. For those sites with no groundwater contamination, no action is required and the sites may proceed directly to the licensing stage.

For those sites with contamination, a series of steps follows. First, data are collected and a baseline risk assessment is performed. If there is an acceptable level or risk from the contamination, a petition for supplemental standards or ACLs will be prepared. After acceptance of the petition, and completion of appropriate monitoring, licensing will be completed.

If the baseline risk assessment shows that the groundwater risk is unacceptable, site investigation using the observational method and selection of a remedial action will follow. Passive restoration (natural flushing) will be considered first. If a demonstration can be made that contaminant concentrations can be reduced to MCLs or background within 100 years, and that human health and the environment will be protected during this period, then licensing can be completed. Alternatively, an ACL petition may be filed to show that human health and the environment will be protected, even if MCLs or background will not be achieved in 100 years.

In other cases, it may be determined that passive groundwater restoration is not acceptable, and active restoration options must be considered. These options include the following:

- Plume management and redistribution
- Secondary source remediation ("hot-spot" removal)
- Bioremediation (particularly for nitrate)

- Extraction and land application
- Other innovative technologies.

For any of these technologies, when background water quality for MCLs is achieved, licensing can be completed. In cases where even active restoration does not achieve background or MCLs, an ACL application may be submitted. Current plans call for applying for an ACL after 10 years of natural flushing, if it can be shown that no further improvement in aquifer quality can be expected. If the ACL demonstration is successful, then licensing can begin. Alternatively, if an ACL demonstration cannot be made, then an additional investigation may be performed and another restoration option may be selected.

The Role of Risk Assessment

Risk assessment will be used, from the earliest stages, to aid in the evaluation of sites. Risk assessments are conducted for the following four purposes on the UMTRA Groundwater Project:

- Preliminary risk assessments are used to aid in prioritizing sites, scope data collection, and determine if a site presents immediate health risks
- Baseline risk assessments, where needed, provide a comprehensive integration and interpretation of demographic, geographic, physical, chemical, and biological factors at a site to determine the extent of actual or potential harm. This information is useful in determining the need for remedial action
- Risk evaluation of remedial alternatives is performed to evaluate risks to humans or the environment associated with the various remedial strategies. For example, this may include evaluation of environmental impact resulting from groundwater pumping and discharge or may include a demonstration of no impact for ACLs
- After remediation, an evaluation of residual risks is conducted.

The information gathered for each of these risk evaluations is used to determine the need for subsequent evaluation. Several sites may be eliminated from active restoration consideration after a preliminary risk assessment if there is no current or future threat to the environment. Likewise, much of the data from a baseline risk assessment can be used to support ACL or supplemental standard demonstrations, or identify sensitive habitats or receptors that may be of concern in selecting a remedy. It is anticipated that this risk assessment process will provide a cost-effective basis for making remedial action decisions.

PROJECT OPTIMIZATION

Project optimization involves working within the current regulatory framework using all available regulatory compliance mechanisms. Since the DOE is under no legally limiting time constraint to initiate or to complete groundwater remedial actions, the DOE is in a better position to aggressively pursue ACLs, supplemental standards and other mechanisms to achieve regulatory compliance. The UMTRA Project tended to yield to some less than reasonable regulatory demands during surface remedial action because of the statutory deadlines imposed on the project. Since there are no such severely limiting statutory deadlines for groundwater remediation, the DOE is free to explore with the regulators the use of alternative approaches that will allow for the most cost-effective approach to compliance with regulatory requirements.

Assumptions

The following assumptions are made relative to project optimization:

- ACLs will be granted, if aggressively pursued and if states cooperate

- It will be in the financial interest of the states to cooperate with the DOE in finding the most cost-effective approach to regulatory compliance
- States will cooperate with the DOE in establishing effective institutional controls
- Natural flushing will be acceptable where there is no significant potential for exposure
- States can be persuaded to support DOE supplemental standards applications, where the groundwater resource is of minimal utility (as compared to zero utility)
- Provision of an alternate water supply system, as at Gunnison, Colorado may be viewed by the state as part of an acceptable institutional control mechanism
- Baseline risk assessments will be an essential component for decisionmaking and implementation of the observational approach.

If DOE successfully obtains state support by optimizing its use of regulatory compliance options, the NRC may demonstrate a greater degree of flexibility than has been assumed in earlier groundwater project scenarios. It is reasonable to believe that the NRC and the states and tribes will also be more receptive to innovative remediation approaches, since the traditional "pump-and-treat" schemes can be very expensive and have variable benefits. The DOE is not likely to have success with compliance optimization at all sites, but an aggressive implementation of this approach can be expected to have considerable success and substantial cost savings.

Positive Observations

The following are positive observations:

- This approach results in full regulatory compliance
- There is significant potential for cost savings over the previous project planning assumptions
- The approach is fully consistent with management alternatives in the proposed PEIS
- Developing this approach with the regulators and affected states and tribes may prove useful at other DOE sites
- There is greater potential for early successes for the project
- Programmatic guidance and policy documents, currently in draft form, are compatible with this approach.

Negative Observations

The following are negative observations:

- The DOE may be perceived as uncooperative by performing the minimum amount of remediation instead of what the public may consider a complete job
- There may be negative public reaction as the DOE aggressively seeks regulatory relief that will be perceived as non-compliance
- States and tribes will need to be full partners as well as participants
- Remediation of some low risk sites may still be required

- The DOE may be perceived as taking a shortcut by addressing site-specific risks instead of cleaning the groundwater to numerical standards.

THE STANDARDS

As noted above, the primary form of complying with the standards is by meeting the MCLs. In the proposed approach, the preferred method of attaining MCLs would be via natural flushing. The actual method of compliance and the numeric limitation to be achieved will be determined, in conjunction with the states, tribes and regulatory authorities on a case-by-case basis.

Supplemental Standards

At those processing sites where the groundwater is of limited use, the project may obtain a supplemental standard in lieu of meeting the MCL, background or an ACL. Limited use groundwater means the amount that can be withdrawn from a domestic well is not sufficient to meet the daily needs of a family of four (150 gpd), is of such poor quality that it is not suitable for any domestic use (>10,000 mg/L TDS), or there is widespread ambient contamination not due to the processing of RRM that cannot be cleaned up by using treatment methods reasonably employed in public water supply systems. In addition, a supplemental standard may be obtained if restoration of groundwater is technically impracticable from an engineering perspective, or if the remedial actions would directly produce environmental harm that is excessive compared to the health benefits of remedial action.

Successful supplemental standard arguments have been made for surface remedial action at Spook, Wyoming, Falls City, Texas and for both surface and groundwater at Ambrosia Lake, New Mexico. The Falls City supplemental standard was based on the fact that the uppermost aquifer had widespread ambient contamination that was not amenable to remediation using treatment methods used in public water supply systems.

Alternate Concentration Limits

At sites that do not qualify for supplemental standards, ACLs may be obtained in lieu of meeting MCLs or background under certain circumstances. To obtain an ACL for any constituent in the groundwater the DOE would have to provide data to support a finding that the proposed concentration limit would not pose a substantial present or potential hazard to human health or the environment. For hazardous constituents for which the EPA has not promulgated an MCL, background water quality is the standard. To obtain an ACL, the September 1987 version of the proposed groundwater protection standards requires that the DOE must demonstrate that the concentration is as low as reasonably achievable (ALARA). The May 1991 version of the standards now under review at OMB has omitted the ALARA requirement.

The EPA views the granting of ACLs as a standard setting activity, which it is unwilling to delegate to the NRC in the absence of a formal rule-making that would demonstrate that the NRC's ACL procedures would be as stringent as the EPA's. Thus, there is currently dual jurisdiction in the granting of ACLs, with concurrence by both the EPA and the NRC.

The DOE has not yet attempted to obtain an ACL for the UMTRA Project. If the states share costs in groundwater remedial actions, it is reasonable to expect their support in obtaining ACL approval from the NRC and/or EPA.

Natural Flushing and Institutional Controls

Natural flushing is an option where passive restoration can be expected to occur naturally in less than 100 years and where groundwater is not now or projected to be used for a community water supply, provided that satisfactory institutional control of public water use and an adequate monitoring program is established and maintained throughout the remediation period. The EPA observes that this approach is particularly apropos where active methods are impracticable or if partially cleansed groundwater can achieve the levels

required by the standards through natural flushing. Natural restoration is most viable when the contaminated aquifer discharges into a surface water body that will not be adversely affected by the contamination.

Natural flushing may be used as a follow-on to a period of active remediation methods. The rule implies that flushing to standards may be achieved by using an ACL as the ultimate cleanup goal.

Institutional controls will be required for the successful implementation of natural flushing. The institutional controls should be enforceable by permanent government entities or have a high degree of permanence. The controls should be reliable for the natural flushing period.

Institutional Controls

As stated above, institutional controls are allowed as an adjunct to natural flushing. The greater the variety and effectiveness of institutional controls, the greater the viability of natural flushing as a remediation approach. Currently available institutional controls include the following:

- Physical control of land over the relic plume
- Zoning restrictions
- Property record annotations
- Restrictions on well installation.

In some cases, the provision of alternate water supply systems may be a significant part of developing a viable institutional control plan; however, the provision of an alternate water supply should not be considered to be an institutional control mechanism. The DOE may also consider seeking legislation or rule-making by an affected state or tribe to provide additional control mechanisms. It should be noted that water rights in the western states are a very sensitive issue and any efforts to restrict the rights may be very controversial.

Risk-Based Strategies

Unless the regulatory basis for the UMTRA Groundwater Project is changed by amending the UMTRCA, DOE may not justify a "no action" decision solely on the basis of a lack of a current risk to human health or the environment. Nonetheless, risk assessment will play an important role in the currently available regulatory strategies. Demonstrating a lack of significant current or potential risk to human health or the environment is a key factor in obtaining a supplemental standard or alternate concentration limit, or in justifying the use of natural flushing.

Active Remediation Techniques

The primary contaminants of concern at the 20 UMTRA sites where groundwater contamination has been documented are nitrates and uranium. Additional contaminants present at some sites do not constitute a major portion of the problem at any sites. If ACLs, supplemental standards, or natural flushing will not satisfy the regulatory requirements for all sites, active technical approaches to remediating contaminated groundwater at the UMTRA sites will be considered in conjunction with available passive techniques.

TARGET SITE REMEDIATION STRATEGIES

The basic approach to remedial action on a site-by-site basis was reexamined using the assumptions of project optimization and by applying the decisionmaking logic discussed earlier.

The reevaluation process yielded only two candidate sites where active methods would be warranted, five sites where supplemental standards would be appropriate, four sites where ACLs would be the primary method

of compliance, four no action sites that would be dealt with in the PEIS and nine natural flushing sites. Several of the natural flushing sites would be ACL candidates after a 10-year observation period.

Because the success of the aggressive project optimization approach relies on public support, a very thorough and attentive public participation and involvement activity is integral to the overall groundwater project.

NEW GROUNDWATER PROJECT COST ESTIMATES

The budget assumptions for the UMTRA Groundwater Project were reexamined in light of the proposed project optimization approach. The detail of the site-by-site budget is presented in Appendix A. The estimated cost, fully loaded and escalated, of the proposed project optimization approach is $426 million with a contingency of $162 million. This represents a better than 50 percent cost savings over the earlier, more conventional approach to remedial action.

Key budget assumptions that are not obvious from the project optimization assumptions include the following:

- An interim groundwater monitoring project to be conducted between the conclusion of surface remedial action and the initiation of groundwater remedial action
- It is conservatively assumed that after 10 years of natural flushing the project will take an additional three years to obtain an ACL at each of the nine natural flushing sites
- Monitoring periods are not expected to exceed a maximum of 13 years after initiation of a site-specific remedial action. Site-specific monitoring strategies are presented in Appendix A
- NEPA documents and remedial action plans will be prepared for all but the "no action" sites.

NEPA COMPLIANCE

Programmatic NEPA Compliance

The proposed approach to NEPA compliance is a two-phased plan that will provide an appropriate and responsive vehicle for meeting NEPA requirements related to the UMTRA Groundwater Project. The first phase would use the PEIS format to provide Project level guidance and an assessment of cumulative impacts. The second phase would evaluate site-specific issues in EAs.

The PEIS would provide project level guidance for identifying the criteria that would be used to (a) determine whether groundwater restoration would be pursued on a site-specific basis, (b) identify and evaluate appropriate methods of groundwater restoration, (c) indicate those UMTRA Project sites where the local groundwater quality is very poor and where it might be demonstrated that no action is appropriate, (d) identify sites where no contamination is present, and (e) contain a cumulative assessment of the programmatic and environmental impacts associated with the groundwater restoration phase. It is anticipated that the PEIS would result in the following:

- Identification of the criteria that would be used to determine the need for and extent of groundwater remediation at each site. Based on existing NEPA project guidance, the Project will develop a defensible, decisionmaking process that will evaluate the applicability of groundwater remediation methods to the variety of conditions encountered at UMTRA Project sites.
- Identification of UMTRA sites where no action may be appropriate and the identification of appropriate institutional controls.

- The acceptance of a PEIS as a part of the NEPA decisionmaking process is well documented. The DOE, as well as other Federal agencies, has successfully used the PEIS as a means to facilitate project planning, to provide an early assessment of potential problems, to assess cumulative impacts, and to reduce the overall scope of subsequent NEPA documents.

Without a PEIS there is no up-front buy-in by the states, tribes and regulators on DOE's approach to compliance. The decisionmaking process will have to be rejustified in every site-specific NEPA document. The PEIS is also a very important mechanism for positively and proactively involving the public in the DOE's decisionmaking process at an early stage. This has great potential to reduce any controversy associated with future DOE actions on the UMTRA Project.

Site-Specific NEPA Compliance

It is anticipated that the site-specific NEPA documents would tier off the PEIS and incorporate existing EAs and other technical reports by reference. It is assumed that the general EA format will be used for the site-specific documents. For the most part, these documents will (a) be between 10 to 20 pages in length, (b) reference the PEIS for detail on groundwater restoration methods and the criteria for selecting the type and extent of restoration, (c) reference other UMTRA Project EAs for environmental background information, and (d) reference in-house technical documents for specific information related to aquifer characteristics. A proposed EA format follows:

1. Summary: Provides a brief summary of relevant issues

2. Proposed Action: Provides a brief summary of the proposed groundwater restoration project

3. No Action: Provides a discussion of the impacts of not undertaking the proposed action

4. Affected Environment: Provides geographic description, concentrates on potentially affected components, summarizes the characteristics of the aquifer relevant to the proposed restoration method, and references in-house technical documents

5. Environmental Consequences: Evaluates only impacted components, but must include evaluation of threatened and endangered species, floodplain/wetland assessment, and archaeological analysis (one-sentence disclaimers)

6. Conclusions: Summarizes any significant impacts and recommended course of action.

PUBLIC INVOLVEMENT

The groundwater project is legally mandated to provide to the public information concerning the environmental consequences of proposed actions, and to "encourage and facilitate public involvement in decisions that affect the quality of the human environment" (40 CFR 1500.2(d) (CEQ, 1978). Meaningful public involvement early on in the project will result not only in better decisions, but also in broader public acceptance of those decisions (Eiguren, 1991).

As stated by DOE Secretary Watkins in SEN-15-90:

> ... compliance with NEPA should be entirely consistent with efficiency in achieving mission goals if NEPA requirements are considered early in the planning process. Indeed, mission goals are best served by early and adequate NEPA planning ... (DOE, 1990)

In light of the legal obligation to solicit public involvement and the potential for advancement of the Project's goals as a result, the groundwater restoration project has committed to proactive, relevant public involvement in the decisionmaking process.

Initially, public outreach orientation efforts will focus on communicating project scope, and on learning citizen values, concerns, and preferences. The public involvement program will be dynamic to accommodate the range of information and participation requirements for the various communities involved, and the decisions to be made regarding remediation activities.

Various project-related educational sources will be available to communities, including site-specific fact sheets, a toll-free telephone information line, site field trips, and demonstrations and discussions by technical professionals. The objectives of the project's educational outreach efforts are to familiarize the public with project specifics, developments, and implementation, and maintain a "no-surprises" approach to UMTRA groundwater restoration.

Early in the project, specific NEPA public involvement requirements will be fulfilled by conducting public scoping hearings for the PEIS, as described in Section 4.0 of this report. These activities are to be preceded, at each site, by community orientations in which the groundwater project is introduced, community concerns are ascertained, and community, state/tribal, and DOE contacts are reaffirmed. The vehicle for this orientation will depend on community needs and preference.

The following is a proposed agenda for community meetings to be held for orientation purposes. The orientation meeting will support public scoping efforts as there is no opportunity in the formal scoping process for interactive dialogue among participants.

Community Orientation Meeting Agenda

An orientation meeting agenda is outlined as follows:

1. Prior to the orientation meeting, the community will be contacted to determine issues the community would like to have discussed at the orientation meeting. At this time, the community will be requested to address the participants at the orientation meeting.

2. The orientation meeting will begin with a community-specific update of UMTRA progress; a discussion of surface accomplishments and obstacles; and a suggestion for public involvement vehicle(s) to be used for resolving community concerns.

3. A presentation by the community will discuss community issues of importance. The DOE will request that suggestions be made for both DOE and community involvement in resolving any concerns.

   Community spokesperson: selected representative of the community who knows community concerns and viewpoints.

4. The groundwater restoration project will be introduced, and differentiated from the surface project. Key components of the new project will be discussed, including the application of the observational method, the role of risk assessment, the commitment to public involvement, the purpose of the PEIS, and public involvement in the scoping process and the implementation plan. In addition, the function and impact on the project of concurrence chains, regulatory framework, and cooperative agreements will be described.

5. A presentation by a state representative will explain the participation of the state in the project and factors impacting state progress.

   State spokesperson: A representative of the lead state agency.

Community Involvement in Site-Specific Activities

After completion of the scoping process, public involvement will be focused on site-specific activities. The project will support extensive public outreach efforts at each site scheduled for site-specific remedial

action. The project recommendation will be to hold six community meetings the first year of site-specific activity at each site, and then to reduce the number of meetings each successive year to a minimum of one meeting as long as remediation is conducted. Public involvement activities will be conducted under the umbrella of the program's Public Information/Public Participation (PI/PP) plan (see Appendix C). The PI/PP plan details the overall approach to public involvement and establishes a project philosophy for public outreach efforts.

RELATED ISSUES

Vicinity Property Groundwater

The statutory and regulatory mandate that requires the remediation of processing sites also applies to groundwater contamination attributable to residual radioactive materials at vicinity properties. At this time, no vicinity properties that require groundwater remedial action have been identified. To fully satisfy its legal obligations, the DOE UMTRA Project must develop some reasonable means to ascertain which vicinity properties may warrant closer examination, and what criteria would be used to determine if a groundwater problem exists.

Licensing

Title I of the UMTRCA of 1978, as amended, authorized the DOE, upon completion of the remedial actions, to care for the permanent disposal sites under a general license issued by the NRC to ensure future protection of public health and safety. The NRC's licensing regulations, 10 CFR 40.27, General License for Custody and Long-term Care of Residual Radioactive Material Disposal Sites, took effect on November 30, 1990 (55 FR 45591). A disposal site comes under the general license after the NRC concurs in DOE's certification that all remedial actions were completed according to all applicable standards.

There are three types of disposal sites: (1) those where the RRM is stabilized-in-place (SIP) at the designated processing site, (2) those where the RRM is moved but stabilized in a disposal cell that is within the designated processing site boundary (i.e., stablized-on-site (SOS)), and (3) those where the RRM is moved to an off-site area. For the first two types of disposal sites, there is a potential need for additional remedial action to clean up the groundwater beneath the processing site that was contaminated as a result of the uranium processing activities.

The NRC will allow licensing of Title I disposal sites where the tailings are not being moved to occur in two steps, if needed, to avoid lengthy delays in licensing. Because groundwater restoration activities could take decades to complete, 10 CFR 40.27(b)(2) allows this two-step approach for those disposal sites where the RRM has not been relocated and where there are continuing groundwater restoration requirements. This allows the DOE to complete all remedial actions except groundwater restoration, which include complying with the groundwater protection standards addressing the design and performance at the disposal site for closure and licensing.

For the first step, when the surface remedial action activities are completed at the processing and disposal sites, the NRC will concur in DOE's certification that all remedial actions, except for groundwater restoration activities at the processing site, were completed in accordance with all applicable requirements. The general license will be in effect for these disposal sites after the surface remedial action activities are completed so the long-term care of the RRM and the disposal site can begin.

The second step in the certification, concurrence, and licensing process is completed when the NRC concurs in DOE's certification that all groundwater restoration requirements at the processing site have met the EPA standards.

For disposal sites where the RRM was relocated and there is no preexisting groundwater contamination as a result of the uranium processing activities, the NRC will license the disposal site in one step. However, for the processing sites where the RRM was originally located, the NRC will concur in DOE's certification

for the completion of all remedial action except groundwater. Certification and concurrence that groundwater restoration requirements at the processing site have met the EPA standards also will be completed as a separate activity.

Innovative Technology

In addition to the use of the PEIS and the observational method approach to site characterization and remediation design to minimize costs and speed the environmental restoration process, the UMTRA Project is committed to seeking out innovative technologies and applying them to the groundwater remediation problems associated with the UMTRA sites. Close communications with DOE research and development programs have already been instituted through the new UMTRA Technology Transfer Program. Dialogues with researchers at Los Alamos National Laboratory and Sandia National Laboratories and others are continuing to determine if the results of their programs are applicable to the UMTRA problems and to make them aware of the "field laboratories" available for testing of appropriate new technologies.

The experienced UMTRA Project staff are uniquely suited to seek out appropriate innovative technologies without impacting the ultimate regulatory compliance goals of the UMTRA Project. Knowledge of the NRC and EPA regulatory requirements and procedures coupled with practical state-of-the-art problem-solving experience will ensure that project goals are maintained and that only realistic new technologies are applied. Early successes of the UMTRA Project will be directly applicable to the problems associated with other DOE facilities.

REFERENCES

Council on Environmental Quality, 1978, "Regulations for Implementing the Procedural Provisions of the National Environmental Policy Act," Title 40, Code of Federal Regulations, Part 1500, Washington, D.C., 1978.

Department of Energy, 1990, "National Environmental Policy Act," Secretary of Energy Notice SEN-15-90, issued February 5, 1990, Washington, D.C.

Eiguren, R. L., 1991, "NEPA Public Involvement--The Challenges and Opportunities," in *Fulfilling the Commitment--Implementing the Letter and Spirit of NEPA, Proceedings of the National Environmental Policy Act Conference, November 20-21, 1991, McLean, Virginia.*

PL95-604 (Public Law 95-604), 1978, *Uranium Mill Tailings Radiation Control Act of 1978,* 42 USC 7901, November 8, 1978, 95th Congress of the United States of America, Washington, D.C.

Nuclear Regulatory Commission's Technical Position on Concentration Averaging and Encapsulation for Waste Classification Purposes

William R. Lahs
Division of Low-Level Waste Management and Decommissioning
Office of Nuclear Material Safety and Safeguards
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555

ABSTRACT

Nuclear Regulatory Commission regulations in 10 CFR 61.55 provide two tables of radionuclide concentration values from which a low-level waste can be classified as either Class A, Class B, Class C, or greater-than-Class C (GTCC). In §61.55(a)(8), it is stated that the concentration of a radionuclide in LLW that is to be compared with the tabulated values may be averaged over the volume or weight of the waste, as appropriate. To interpret this requirement in terms of the different types, forms and mixtures of LLW, the NRC issued a technical position in May 1983. A section of that position generally discusses the appropriate volumes and masses over which concentrations should be determined.

Because of (a) the desirability of attempting to achieve consistent waste classification practices among the Commission and Agreement State regulatory authorities, and (b) the impact of waste classification positions in defining GTCC waste for which the Federal Government is responsible, both NRC and State regulators recognized the need to expand upon and further define the concentration averaging and encapsulation guidance presented in the 1983 Technical Position.

For the above reasons, the NRC initiated an effort to expand the 1983 Technical Position a little over a year ago, and on June 30, 1992, noticed in the *Federal Register* (57 *FR* 29105) the availability of the proposed expansion. The proposed expansion was developed with the cooperation of the E-5 Committee on Low-Level Radioactive Waste Management of the Conference of Radiation Control Program Directors.

TECHNICAL POSITION—BASES AND PURPOSE

A technical position must have a basis in existing regulations. In essence, it represents an NRC staff position that some, not necessarily unique, set or subset of procedures, practices or approaches is acceptable in demonstrating compliance with NRC regulations. In the case of the proposed concentration averaging and encapsulation technical position, the regulatory bases are those previously indicated. Thus this Technical Position is intended to describe a subset of acceptable practices for establishing the volumes or masses of LLW upon which concentrations can be calculated and classifications can be determined. Other practices for determining a waste's classification, not specifically addressed in the Technical Position, may be approved if evaluated and found to be acceptable by the appropriate regulatory authority (i.e., either NRC or an Agreement State regulatory authority). In fact, the Proposed Technical position, as noticed, describes this possibility in its "Alternative provisions" paragraph. As a result, it is very important to recognize that the technical position defines a subset of "acceptable" practices and does not identify a "sharp" breakpoint between acceptable and unacceptable positions.

Along these lines, the initial 1983 "Technical Position on Radioactive Waste Classification" provided guidance directed at three principal subjects. First, it described wastes that could be considered "homogeneous" for classification purposes. The wastes identified (e.g., resins, filter media, solidified liquids, and contaminated soil) do not necessarily contain uniformly distributed radioactivity. However, in the context of the "regulatory-defined" constructs upon which protection of public health and safety are based, these waste streams can be presumed to result in effectively uniform activity distribution. Second, the 1983 position pointed out the need to consider waste volumes as opposed to container volumes when determining

concentrations. And finally, the position documented the acceptability of using regulation-required stabilized waste volumes or weights in these determinations.

NEED FOR FURTHER POSITION DEVELOPMENT

Under the Low-Level Radioactive Waste Policy Amendment Act of 1985, the States were given responsibility for providing for the disposal of Class A, B, and C waste while the Federal Government was assigned responsibility for GTCC waste disposal. This separation of responsibilities between Class C and GTCC waste highlighted the need to more specifically define the boundary between these two classes, which in turn meant more specific definitions of acceptable waste classification practices.

A major purpose of this effort is to achieve the greatest degree of consistency in defining practices that would be acceptable by both NRC and Agreement State regulatory authorities. Indeed, the Department of Energy had encouraged expanded definitions on what practices could be considered acceptable for encapsulation of sealed sources. They recognized that this could help them carry out their responsibilities for GTCC waste disposal and storage by providing more definitive estimates of GTCC waste types, volumes, and activities.

THE GOALS OF AN EXPANDED TECHNICAL POSITION

The primary goals of the technical position are to (a) maintain the envelope of safety and public protection that currently underlie the classification system as defined in the regulations; (b) minimize occupational exposure associated with waste management and disposal; and (c) define acceptable waste "mixing" practices that are clearly intended for purposes other than lowering a waste's classification. In essence, attaining the first goal requires an understanding of the underlying bases for the concentration values that appear in the two tables in the regulations. These bases have been directly used, extrapolated, or interpolated to develop the acceptable concentration averaging or encapsulation positions for those specific wastes or waste combinations addressed in the revised-expanded technical position.

The intent is to achieve the aforementioned primary goals without losing sight of the practicalities faced by generators in determining waste classifications and by remaining cognizant of the "real-world" wastes that are specifically covered in the technical position and those which would need to be accepted, if justified, under the position's "Alternative Provisions" paragraph.

MAJOR FEATURES OF REVISED TECHNICAL POSITION

The major features of the expanded position as initially published in July 1992 include: (a) a more specific waste encapsulation position; (b) "concentration averaging" positions for mixtures of waste streams or waste types that single out the waste's gamma-emitting concentrations or activity levels for special consideration; (c) several specific positions for waste type or waste stream mixing; and (d) an alternative provisions paragraph to address the process for gaining approval for practices not specifically covered.

The encapsulation position for sealed sources specifically permits averaging over a $0.2m^3$ volume or 500 Kg weight of an encapsulating media. The media should meet the regulation-defined stability criteria of §61.56(b) and the source should be reasonably centered in the encapsulating media. Both the encapsulation position and the other "concentration averaging" positions, single out the waste's gamma-emitting concentrations or activities for unique consideration in the averaging process. The June proposal specifically addresses the mixing of homogeneous waste types or streams, mixing of activated metals, contaminated materials and cartridge filters, and the mixing of dissimilar miscellaneous waste streams.

CURRENT DEVELOPMENTS

In response to the request for comments on the proposed technical position, twenty comment letters were received, principally from nuclear utilities and their supporting organization but also including extensive comments from DOE. Both disposal facility operators also submitted comments. In total, the comments

included views that the position: (a) had not been sufficiently justified; (b) did not go far enough in defining acceptable existing practices; (c) was overly conservative in the treatment of gamma-emitting nuclides; (d) will drive wastes to higher classifications at increased costs with no commensurate benefit; and (e) should be adopted through the rulemaking process.

The NRC staff has developed responses to these major comments and has made appropriate changes and additions to the position as proposed. The staff has also made a number of editorial changes based on commenter suggestions. The additions to the position have been substantial and have principally occurred in an effort to respond to the second view listed above. The expanded revised position now includes acceptable positions for classifying discrete metal or material wastes that require sectioning for operation reasons such as transportation. Several additional examples have been included in the position together with a logic diagram to clarify the classification process for activated metals.

The position has also been revised to allow concentration averaging between items containing or contaminated with the predominantly gamma-emitting nuclides: Co-60, Nb-94, and Cs-137. While the June proposal provided no concentration averaging provision for mixtures of discrete wastes (i.e., the mixture would be assigned the highest class associated with any waste contributing to the mixture), averaging is now defined as acceptable if the individual concentrations of these gamma-emitting nuclides in any waste contributing to the mixture are within a factor of 1.5 of the averaged individual nuclide concentrations in the mixture as a whole. This limited degree of flexibility avoids placing a "bright line" significance on the "breakpoint" concentrations between waste classes.

FUTURE PLANS

Initial indications are that the staff's further revisions to the proposed Technical Position should alleviate many of the commenter's concerns within the safety envelope of 10 CFR Part 61. But to ensure that this is the case, the staff intends to reissue the position in a proposed form. This reissuance is expected in early 1993.

The Constitution, Waste Facility Performance Standards, and Radioactive Waste Classification: Is Equal Protection Possible?

Robert V. Eye
General Counsel
Kansas Department of Health and Environment[a]
Landon State Office Bldg., RM 901
Topeka, KS 66612

INTRODUCTION

The process for "disposal" of so-called low-level radioactive waste is deadlocked at present. Supporters of the proposed near-surface facilities assert that their designs will meet minimum legal and regulatory standards currently in effect. Among opponents there is an overarching concern that the proposed waste management facilities will not isolate radiation from the biosphere for an adequate length of time. This clash between legal acceptability and a perceived need to protect the environment and public health by requiring more than the law demands is one of the underlying reasons why the process is deadlocked.

Perhaps the most exhaustive public hearing yet conducted on low-level radioactive waste management has recently concluded in Illinois. The Illinois Low-Level Radioactive Waste Disposal Facility Siting Commission conducted 71 days of fact-finding hearings on the safety and suitability of a site near Martinsville, Illinois, to serve as a location for disposition of low-level radioactive waste. Ultimately, the siting commission rejected the proposed facility site for several reasons. However, almost all the reasons were related, to the prospect that, as currently conceived, the concrete barrier/shallow-land burial method will not isolate radioactive waste from the biosphere.

Facility supporters in Illinois and elsewhere are saddled with a difficult position. Specifically, supporters assert that their designs will meet the standards set by the Nuclear Regulatory Commission, and therefore, the design is adequate to protect the environment and public health. Facility opponents point to the fact that long-lived radionuclides like iodine-129 will be placed in these facilities and that no concrete barrier/shallow-land burial method can be relied upon to prevent the eventual breach-leach-transport sequence from occurring. Facility supporters are then given the considerable burden of proving that their designs will outlast the radiation hazard placed therein.

From a review of the proceedings of the Illinois Low-Level Radioactive Waste Siting Commission, it is clear that facility supporters did their best to convince the commissioners of facility design and site adequacy. In the end, their proof was deemed inadequate and the site was rejected by a unanimous vote. Commissioner William Hall, Ph.D., an engineering professor at the University of Illinois, described several grounds for his vote to reject the site. He noted that the regulatory 500-year offsite travel time criterion for radionuclides is not sufficient. Consider this observation by Dr. Hall:

> However, I remain unconvinced of the value of 500-year travel time criterion, in the light of the long-lived radionuclides destined in some volume for disposal. (Transcript of Proceedings, p. 20513)

While Dr. Hall did not cite the regulatory radioactive waste classification system as being premised on questionable assumptions, such is implicit in his remark that long-lived radionuclides present special and very difficult isolation problems. Specifically, the questionable regulatory assumption is that while long-lived

---

a. This paper presents the views of the author and is not intended to represent the policy positions of the State of Kansas.

radionuclides are undeniably present in low-level radioactive waste, the concentration of such is sufficiently low as to not warrant isolation comparable to greater concentrations of the same or similar long-lived radionuclides present in high-level waste. Until this seeming contradiction is reconciled, the result reached by the Illinois Low-Level Radioactive Waste Disposal Facility Siting Commission will be repeated in any intellectually honest proceeding. Unless this reconciliation is accomplished, the low-level radioactive waste management process will continue to be deadlocked.

This paper will review the relevant legal framework of the radioactive waste classification system and will argue that it is inadequate for long-lived radionuclides. Next, the paper will present a case for altering the classification system based on high-level waste regulatory considerations.

RADIOACTIVE WASTE CLASSIFICATION SYSTEM

The Nuclear Regulatory Commission's provisions that constitute the low-level radioactive waste regulatory framework are found at 10 CFR 61. Conceptually, disposal facilities are defined to include "all the land and buildings necessary to carry out the disposal" of low-level radioactive waste. (10 CFR 61.7(a)(2)) However, of even more importance are the safety objectives by which these disposal facilities are to be judged. 10 CFR 61.7(b)(1) provides as follows:

> Disposal of radioactive waste in near-surface disposal facilities has the following safety objectives: protection of the general population from releases of radioactivity, protection of individuals from inadvertent intrusion, and protection of individuals during operations. A fourth objective is to ensure stability of the site after closure.

The safety objectives, as stated, are laudable and, as proposed to be implemented, quite unachievable because of the radioactive waste classification system. 10 CFR 61.7(b)(2-5) establishes the timeframes after which the Nuclear Regulatory Commission considers radioactivity remaining in near-surface facilities will have decayed to acceptable levels. The longest time that the Nuclear Regulatory Commission requires so-called intruder barriers to be effective is 500 years. At the end of this time, according to the Nuclear Regulatory Commission, "remaining radioactivity will be at a level that does not pose an unacceptable hazard to an intruder or public health and safety." (10 CFR 61.7(b)(5))

10 CFR 61.55 defines the classes of waste and thereby, in conjunction with 10 CFR 61.7(b), sets the 500-year maximum standard for facility barrier integrity. The classification system regulation is premised by a candid admission by the Nuclear Regulatory Commission that long-lived radionuclides will pose a hazard after the precautions, like intruder barriers, no longer can be counted on to contain radiation. 10 CFR 61.55(a)(1) states that the classification system is bounded by two considerations, the first of which is

> [the] concentration of long-lived radionuclides (and their shorter-lived precursors) whose potential hazard will persist long after such precautions as institutional controls, improved waste form, and deeper disposal have ceased to be effective. These precautions delay the time when long-lived radionuclides could cause exposures. In addition, the magnitude of the potential dose is limited by the concentration and availability of the radionuclides at the time of exposure.

This regulatory consideration sets the stage for a compromising of environmental protection and the public's health. It says, in effect, that given the assumptions associated with near-surface facilities, radiation will inevitably escape after these facilities are "sealed." Precautions such as enhanced packaging, concrete barriers, plastic liners and clay caps will likely delay the breach-leach-transport events but not prevent them. While accepting this reality, the regulatory consideration excuses it by legitimizing the dilution/solution method by suggesting that slow transport and diluted concentrations will, in effect, result in adequate public radiation protection. Several problems emerge when this regulatory premise is closely analyzed. Consider the Nuclear Regulatory Commission's own pronouncement concerning exposures to nonnatural radiation:

> Exposure to even low levels of radiation, in addition to the natural background radiation that exists, is generally believed to increase the likelihood of certain diseases and increase certain genetic defects. (Nuclear Regulatory Commission, Reactor Safety Study, 1975)

This 1975 NRC statement is consistent with the conclusions of other scientific research, which suggests that any exposure to nonnatural ionizing radiation carries health risks. [For examples see Boice, J. D., "Studies of Atomic Bomb Survivors: Understanding Radiation Effects," *J. Am. Med. Assoc. 264*: 622-623 (1990), Marwick, C., "Low-Dose Radiation: Latest Data Renew Questions of 'Safe' Level," *J. Am. Med. Assoc. 264*: 553-554 (1990).] Dilution of radiation originating at low-level radioactive waste facilities is, therefore, of questionable value in terms of environmental and public health protection.

This recognition of low-dose exposure hazards also calls into question the premise of low-level radioactive waste facility performance objectives at 10 CFR 61.40 - 61.44. 10 CFR 61.41 permits releases of radiation to groundwater, surface water, air, soil, plants and animals so long as annual individual public doses do not exceed 25 millirems to the whole body, 75 millirems to the thyroid or 25 millirems to any other organ. These limits, while perhaps relatively low, will cause quantifiable increases in radiation related health problems if one accepts the radiation dose-response relationship. Clearly, to the extent that these specified release limits are exacerbated by accelerated breach-leach-transport events, environmental quality and the public's health are further compromised.

The second classification consideration specified in 10 CFR 61.55(a)(1) recognizes that concentrations of shorter-lived radionuclides can be effectively managed by institutional control, waste forms, and disposal methods. Conceptually, this regulatory consideration is an acknowledgment that duration of decay time (i.e., hazardous duration) determines whether precautions (structural and otherwise) will be effective. This consideration further implicitly recognizes that if short-lived radionuclides can be sufficiently delayed in their offsite transport, the environment and public health will be better protected. Clearly, as demonstrated by the widespread safe use of short-lived radionuclides in medical applications, preventing or minimizing public exposure is closely related to decay time.

The balance of 10 CFR 61.55 is devoted to a numerical classification system based on the concentration of curies per cubic meter of radioactive waste and the presence or absence of long-lived radionuclides. This classification scheme is arguably a meaningful system to describe radiation concentrations in a given package of radioactive waste. The problem is that the overall classification system of 10 CFR 61 does not effect a meaningful relationship between these regulatory descriptions and the public's expectation that long-lived radionuclides will be isolated from the biosphere for the duration of their hazardous lives.

The contradiction inherent in the Nuclear Regulatory Commission's classification system for low-level radioactive waste, i.e., the acknowledged incapacity to isolate long-lived radionuclides by using shallow-land burial/engineered barrier techniques, is that there is a regulatory scheme for isolation of long-lived radionuclides when such are present in high-level wastes. That is, many of the radionuclides in low-level radioactive waste have hazardous durations comparable to those radionuclides found in high-level wastes. Yet, distinctly different regulatory schemes are currently in place for the two classes of waste.

The regulatory standards for high-level waste are codified at 10 CFR 60 and 40 CFR 191 Subpart B. (For purposes of this paper, the more stringent containment requirements established by the Environmental Protection Agency in 40 CFR 191.13 will be considered.) Pursuant to 40 CFR 191.13(a), a disposal system for high-level waste "shall be designed to provide a reasonable expectation . . . that the cumulative releases of radiation to the accessible environment for 10,000 years after disposal from all significant processes and events that may affect the disposal system" will have either a one in ten or one in one thousand chance of exceeding release limits specified in Appendix A of Subpart B. Importantly, the radionuclides found in high-level waste and listed in Appendix A for which release limits are applicable include numerous radionuclides that are commonly found in low-level waste, such as iodine-129.

Perhaps even more striking is the Nuclear Regulatory Commission's adoption of the zero-release value in its generic rules related to evaluating the environmental impacts of the nuclear fuel cycle. (This is

frequently referenced as the Table S-3 rule.) Essentially, the Nuclear Regulatory Commission has adopted a position which assumes that, once sealed, a high-level repository, utilizing a deep geologic concept, would not allow a radiation release to the biosphere for at least 10,000 years. This Nuclear Regulatory Commission rule was challenged and ultimately affirmed by the United States Supreme Court in Baltimore Gas and Electric Co. v. NRDC, 462 US 87 (1983). The Court had little difficulty in allowing the zero-release rule to stand even in the light of substantial uncertainties. This conclusion was reached primarily because the Nuclear Regulatory Commission had conducted extensive fact-finding proceedings to conclude that the probabilities favored the eventual establishment of containment technology sufficient to meet the 10,000 year zero-release assumption (462 US at 98-99). Whether one agrees with the Court's conclusion is not the issue. Rather, the issue is whether the two-tiered system for management of long-lived radionuclides established by 10 CFR 61 et seq., 40 CFR 191 et seq. and the zero-release standard of Table S-3 is justifiable if the regulatory objective is minimizing public exposure to radiation.

The two-tiered regulatory system can result in the following circumstance to develop after a deep-geologic repository for high-level wastes and a shallow land burial facility for low-level radioactive waste are both "sealed" and left for natural forces to impact. A person living at the boundary of a high-level facility would, assuming the efficacy of the facility achieves the zero-release standard, be exposed to less radiation than a person living at the boundary of a low-level radioactive waste facility. A person near a high-level facility enjoys the benefit of an administrative process which has concluded that it is reasonable to assume that a deep geologic repository can be located, constructed, and sealed to a degree that makes any release of radiation to the biosphere for 10,000 years unlikely [44 FR 45362, 45368 (1979), 462 US at 99].

On the other hand, the regulatory regime for low-level radioactive waste makes no such assertion. Rather, 10 CFR 61.41 allows radiation releases in effluents, albeit with specified quantitative limits. However, these specified quantitative limits are not comparable to the zero-release standard for high-level waste facilities. Arguably, this violates the general rule of constitutional law that, under equal protection doctrine, requires substantially similar entities to be subject to substantially similar government treatment.

This equal protection argument has not been persuasive to date in the federal court system. Both the United States District Court in Nebraska and the Eighth Circuit Court of Appeals rejected this argument and cited the radionuclide concentration limits in the 10 CFR 61 classification scheme as the rational basis for not requiring management of long-lived radionuclides present in low-level waste and high-level waste in substantially similar ways. See *Concerned Citizens of Nebraska et al. v. U.S. NRC et al.*, (Dist. Ct., Neb., Case No. 90-L-70) and *Concerned Citizens of Nebraska et al. v. U.S. NRC et al.*, (8th Cir., Case No. 91-2784). Neither opinion addressed the differential treatment that results because a high-level facility will be required to isolate long-lived radionuclides for at least 10,000 years while long-lived radionuclides in low-level radioactive waste facilities are subject to drastically less stringent isolation requirements.

One could perhaps dismiss this equal protection argument as being grounded in an overly legalistic interpretation of esoteric regulatory standards. However, it is not difficult to conclude that the decision of the Illinois Low-Level Radioactive Waste Siting Commission in the Martinsville case would have been different if the evidence had indicated that the proposed facility would isolate long-lived radionuclides from the biosphere for at least 10,000 years. Instead, the siting commission cited the inability of the proposed facility to isolate long-lived radionuclides for an adequate duration as one of the primary reasons for rejecting the facility proposal. The Illinois siting commission was not primarily concerned about the concentration per cubic meter of long-lived radionuclides in low-level radioactive waste. Rather, the commission noted that long-lived radionuclides would be present in sufficient volumes that made permanent isolation from the biosphere most unlikely if the technology of choice was a near-surface facility utilizing engineered barriers. Again, one need not use wild imagination to conclude that had the siting commission been confronted with a proposal to place long-lived radionuclides in a deep geologic repository that had a reasonable assurance of meeting the 10,000 year zero-release standard, its decision could have been different.

A caveat requires mention at this point. The author neither endorses nor accepts the validity of the 10,000 year zero-release standard. Given that the hazardous duration of many radionuclides is much longer than 10,000 years, such a standard is inadequate. Additionally, the current high-level repository siting process,

which has focused on Yucca Mountain, Nevada, is fraught with grave constitutional, policy, and technical problems. However, for purposes of this paper, the 10,000 year zero-release limit is recognized as the controlling standard and a vast improvement over the 500-year maximum regulatory standard in 10 CFR 61.7(b).

A PROPOSAL FOR REFORM

In order for the low-level radioactive waste management deadlock to be broken, several things must happen. Chief among these is to convince the public and decision makers that facility performance standards and duration of the radiation hazard are closely linked. Additionally, facility standards must consider the specific radionuclides intended for disposition, calculate their hazardous durations, and design a facility to isolate radiation accordingly. Anything less than such a framework will be vulnerable to attacks that such fails to be adequately protective of public health and natural resources to which future generations have a right.

A suggested reform would establish a radioactive waste classification system that uses a duration of hazard standard and thereby rejects the concentration of radionuclides per cubic meter standard. Such a classification system would explicitly recognize that any exposure to nonnatural radiation should be avoided irrespective of its origin or magnitude. Such a system would utilize considerations which recognize that decay time should determine how to classify radionuclides for disposal rather than concentration of radionuclides per cubic meter.

This reform has limited precedent. In recent years, the Nuclear Regulatory Commission has amended 10 CFR 61 to require that "upper end" low-level radioactive waste (so-called Greater-Than-Class C wastes) be managed as high-level wastes. 54 FR 22583 (1989) While this reclassification of Greater-Than-Class C wastes is arguably consistent with the Nuclear Regulatory Commission's assumptions about hazards being linked to radionuclide concentrations rather than decay time, it still recognizes that some types of wastes ought not be subject to placement in a near-surface facility. The reform proposal offered herein simply extends this logic to all radionuclides that cannot reasonably be expected to be isolated from the biosphere when emplaced in a near-surface facility.

Certainly, some obvious problems would emerge if the reform proposal were adopted. Volumes of long-lived radionuclides anticipated for disposition at a high-level facility would increase, perhaps substantially. Segregation of long-lived from short-lived radionuclides in the same waste package would perhaps be required to avoid utilizing high-level facility space for short-lived radionuclides. Nevertheless, adoption of the hazardous duration standard and rejection of the concentration standard would directly address one of the central objections in current low-level radioactive waste facility siting efforts and the primary objection that doomed the Martinsville, Illinois, proposed site.

CONCLUSION

The fierce ongoing struggles between supporters and opponents of low-level radioactive waste facilities will not diminish under current conditions. Indeed, the confrontations are likely to become more frequent and intense. Supporters may point to opponents and argue that their fears are irrational and that near-surface facilities will be "over-engineered" to ensure safety. However, if opponents can identify long-lived radionuclides intended for disposition in a near-surface facility and prove that engineered barriers will not outlast the radiation hazard, it is unlikely whether any proposed facility will fare better than the Martinsville site.

Finally, it is reasonable to expect that any government regulatory system for radioactive waste management will treat similarly hazardous radionuclides in similar manners. This is likely to result in technical difficulties. However, failure to adequately deal with long-lived radionuclides present in low-level radioactive waste will surely prolong the current deadlock and increase the potential for more intense confrontations between facility supporters and opponents.

The Social Basis of Public Policy Disputes

Michael P. Elliott
Director, Public Policy Program
Georgia Institute of Technology
Atlanta, GA 30332-0155

Social Structures
Regulates the Basic Allocation of Resources in Society;

Decision-Making Procedures
Establishes ongoing rules for policy-making and alter control over political and private decision making;

Substantive Issues
Focuses on the outcome of individual decisions; and

Uncertainty
Alters expectations of future outcomes.

RISK—WHAT IS IT?

RISK IS A CULTURAL/SOCIAL VALUE

- Models of risk focus attention
- Models structure how we search for risks
- Models structure which risks we isolate for management
- Models structure how we design management systems.

Technical Conceptions of Risk	Lay Conceptions of Risk
Emphasizes expected values	Emphasizes variability, extreme outcomes, uncertainty, catastrophe
Usefulness depends on the power of the concept to predict future outcomes	Useful for stabilizing extreme risk
Delineated by measurable indicators such as mortalities and defined by quantifiable variables such as probability of mortality	Less concerned with proof than with potential
Theory of Knowledge:	Theory of Knowledge:
PREDICTION	DETECTION
Theory of Action:	Theory of Action:
PREVENTION	MITIGATION

WHY TECHNICAL ANALYSIS IS NOT COMPELLING

ANALYSIS IS INCOMPLETE

Focuses primarily on the potential for mortality as defined by probability analysis

ANALYSIS IS AMBIGUOUS

Cannot clearly state what the impact will be in the particular situation under consideration (e.g., whose death?)

ANALYSIS IS UNCERTAIN

- Differing assumptions
- Incomplete information
- Incomplete problem definition
- Complexity of systems
- Failure of past analyses.

SPONSORS

Values

- Economic development and community growth
- Orderly change
- Free enterprise.

Perceptions

- Focus on expected outcomes
- Probability of extreme outcome is virtually nil
- Trust current systems of expert management and technology to optimize safety
- Hazardous waste is dangerous only when poorly managed.

  "... A community without waste is nothing, a dry shell."

PRESERVATIONISTS

Values

- Stability
- Aesthetics and a traditional life style

- Control over their own environment.

Perceptions

- Focus on extreme outcomes
- Perceive risks of hazardous waste to be unpredictable and uncertain.

> ... There is no benefit to this (hazardous waste facility), and we really don't know much about the risks. It's like the atomic bomb: we know it's terrible and potentially disastrous, but we've never been directly confronted with it. We haven't had to raise our children with this thing festering in our community. Unless I was absolutely convinced that nothing could go wrong, I wouldn't even consider it.
>
> a structural engineer by profession

GUARDIANS

Values

- Orderly growth that protects and promotes "the public interest"
- Protection of health and safety
- Local autonomy and self reliance
- Civic duty and responsible governance.

Perceptions

- Focus on likely variation in predicted risks
- View risk as a system of management and technology
- Look for sources of variability and emphasize reliability of these systems.

> "... My responsibility is to protect this town, and it is the plant operator's duty to make the changes necessary for this to happen."

1. PREDICTION/PREVENTION

Community residents and facility operators need not agree on the precise likelihood of a risk.

They must, however, reach agreement on the characteristics of risks to be managed and the standards of acceptable variation.

- Joint fact finding provides a structure for considering the science-intensive aspects of the dispute.

2. DETECTION SYSTEMS

Considerably more emphasis should be placed on the design of systems for quickly and reliably detecting hazards and variations in operating conditions.

- Knowledge becomes more complete and predictability more precise as consequences evolve.

- Repair and recovery after error is possible only if the error is detected.

3. MITIGATION SYSTEMS

Detection systems become effective tools for managing both risk and risk perceptions only when integrated with systems for effectively mitigating hazards and unacceptable shifts in operating conditions.

- Incentives are important to the design of mitigation systems.
- Systems for guaranteeing performance are necessary.
- Contingent promises provide a basis for negotiating guarantees when perceptions of risk differ.

THE RELATIONSHIP BETWEEN THE COMMUNITY AND THE PLANT OPERATOR

4. VISIBILITY AND COMPREHENSIBILITY

The technologies and management of prevention, detection and mitigation systems must be visible and comprehendible to at least some locally trusted community representatives and possibly to the community as a whole.

- Monitoring is an essential aspect of visibility
- Expert analysis is an essential aspect of comprehensibility.

5. ONGOING RELATIONSHIP

A structure must exist for jointly solving problems and resolving disputes as conditions and concerns evolve, and for altering prevention, detection and mitigation systems as knowledge improves.

- Contingency planning is not perfect
- Learning must be possible
- Interdependency exists and must be acknowledged
- Interdependence must be institutionalized.

6. OPERATOR FLEXIBILITY

The community should be involved only in the overview of safety operations, not in the minutia of plant operations.

- The community cares about risk, not plant operations
- Control implies responsibility
- Decision making power must be clearly delineated
- Ultimately, the level of control is less essential than the level of trust.

7. ACCOUNTABILITY

The community must have the power to hold the operator accountable for hazards as specified in a safety agreement.

The community must have the power to move decisively against hazardous conditions should the operator fail to do so.

- Sanctions must be prespecified
- Sanctions must have a high probability of being imposed quickly if needed.

REBUILDING THE NEGOTIATION PROCESS

1. Identifying parties with a stake
2. Ensuring appropriate representation of the parties
   - Representatives open to scrutiny
   - Process open to wider participation
   - Emphasis on legitimacy
   - Dealing with recalcitrant participants
3. Selecting a mediator
4. Building the capacity of the represented parties to engage in meaningful negotiation
   - Providing technical assistance
   - Vertical team bargaining
5. Defining the issues
   - Clarifying differences in
     - Interests
     - Values
     - Perceptions
   - Confronting differences in assumptions
6. Generating alternatives for further consideration
   - Brain storming
   - Expanding options
   - Developing new solutions
7. Jointly assessing impacts of alternatives
   - Joint fact finding
   - Data mediation of existing analysis
   - Designing new studies

8. Expanding options
    - Redesigning alternatives
    - Compensation
9. Implementing the agreement
    - Legal structure, current and future
    - Commitments

Verbal Risk in Communicating Risk

Joseph C. Walters, Ph.D.
School of Communication
Northern Arizona University

Harley W. Reno, Ph.D.
Idaho National Engineering Laboratory[a]
EG&G Idaho, Inc.
P.O. Box 1625
Idaho Falls, ID 83415

ABSTRACT

When persons in the waste management industry have a conversation concerning matters of the industry, thoughts being communicated are understood among those in the industry. However, when persons in waste management communicate with those outside the industry, communication may suffer simply because of poor practices such as the use of jargon, euphemisms, acronyms, abbreviations, language usage, not knowing audience, and public perception.

This paper deals with ways the waste management industry can communicate risk to the public without obfuscating issues. The waste management industry should feel obligated to communicate certain meanings within specific contexts and, then, if the context changes, should not put forth a new, more appropriate meaning to the language already used. Communication of the waste management industry does not have to be provisional. The authors suggest verbal risks in communicating risk can be reduced significantly or eliminated by following a few basic communication principles. The authors make suggestions and give examples of ways to improve communication with the general public by avoiding or reducing jargon, euphemisms, and acronyms; knowing the audience; avoiding presumptive knowledge held by the audience; and understanding public perception of waste management issues.

INTRODUCTION

If the "waste management industry"[b] operated in isolation, there would be little need for communicating risk to society. It does not. As a member of society, the industry has an obligation to discuss the risks of hazards confronting society. During the past decade, much has been written about risk communication. Guidelines have been developed for improving the art of communicating risk to the public (Committee on Risk Perception and Communication 1989, Krimsky and Plough 1988, and Hance, Chess, and Sandman 1990). Most authors agree, however, there is no single solution to improving the art. They also agree the process of communicating risk needs improving. Even then, some members of society will not be assuaged. This paper offers some suggestions for lessening verbal risk in communicating risk to the public.

JARGON, ACRONYMS, AND EUPHEMISMS

Most professions have developed a shorthand form of communicating with one another—jargon. Lutz (1987) defined jargon as the specialized language of a trade, profession, or similar group. Jargon, however, is "doublespeak" when used to communicate to those outside the group. Lutz contended that doublespeak is not the product of careless language or sloppy thinking. He felt that, "...most doublespeak is the product of

---

a. Work supported by the U.S. Department of Energy, Office of Environmental Restoration and Waste Management, under DOE Contract No. DE-AC07-76ID01570.

b. "Waste management industry" as used in this paper is a generic term encompassing all forms of waste management, at all levels of government, and inall types of private industry.

clear thinking and [it] is...designed and constructed to appear to communicate when in fact it does not." According to Cherry (1966), "Words are signs which have significance by convention, and those people who do not adopt the conventions simply fail to communicate." Both Lutz and Cherry identified shortcomings of using jargon to communicate risk. Lutz indicated the purpose of jargon is to mislead the public. Most communicators in the industry today probably would disagree with Lutz but agree with Cherry.

Maybe Lutz is correct. For example, here are two definitions formulated by agencies of the federal government, the first being the product of the Environmental Protection Agency and the second articulated by the Department of Energy. Definitions are as follows:

> (1) ACID DEPOSITION: A complex chemical and atmospheric phenomenon that occurs when emissions of sulfur and nitrogen compounds and other substances are transformed by chemical processes in the atmosphere, often far from the original sources, and then deposited on earth in either a wet or dry form. The wet forms, popularly called "acid rain," can fall as rain, snow, or fog. The dry forms are acidic gases or particulates.
>
> (2) ANTICIPATED OPERATIONAL OCCURRENCES means those conditions of operational occurrences that result in equipment service conditions more severe than those associated with normal facility operations but are less severe than those service conditions associated with more severe accidents. Equipment may be exposed to service conditions associated with anticipated operational occurrences many times throughout its life as these occurrences do not result in prolonged or permanent facility shutdown such as would result from design basis accidents, external events, or natural phenomena.

What the general public would make of those definitions is uncertain; however, rest assured the public better understands "acid rain" than "acid deposition." The authors do not think anyone knows what an "anticipated operational occurrence" might be, although the term seems to imply a malfunction. The point is: It is difficult and risky to translate the preciseness of the technical and scientific language into common language of the general public. Therefore, care must be taken when communicating concept, meaning, and intent of "risk." Blair (1987) defined the purpose of risk communication as "...serv[ing] the general welfare by providing people with the information they need to make knowledgeable judgments on risk."

Jargon tends to impede the risk communication process, because people do not receive the information they need to make knowledgeable judgments. We suggest that jargon-like words, in general, tend to be negative and passively encourage mistrust by the public. Reno and Walters (1990) addressed the issue of jargon of the nuclear industry as a fomenter of negative public perception. The message sent is not always the message received. Cherry (1966) pointed out that, "A word is more than an arbitrary written or spoken sign, it is all that it carries in association as well. Words can play upon our feelings and tap our memories." What is the public perception of nuclear, radioactive, hazardous, mixed radioactive-hazardous and low-level radioactive waste? Our guess is that anything with the words "nuclear," "radioactive," and "hazardous" attached is perceived as perilous. Meyrowitz (1985) indicates that some scholars develop their own special language to appear mysterious and more valuable. He noted specifically:

> The communication patterns encouraged by print make it difficult for experts in one discipline to communicate with experts in other disciplines. Outsiders who want to gain access to a discipline must often become neophytes all over and work their way up a new ladder of segregated information-systems. Barriers of time and pride generally keep people within the confines of their own "field." Such a system allows for many interactions that might be called "private-public," that is, the situations are technically public, but functionally restricted to members of a single group.

For reasons identified by Meyrowitz, government documents are perceived as incomplete, unusable, and nonprofessional if they are not replete with jargon and acronyms. In the age of more open communication between government and public, the use of such devices makes a mockery of the free exchange of information. Acronyms might save the user time in required repetition of common thoughts and abstractions, as well as save the taxpayer some money in wasted space on paper. However, acronyms defeat the purpose of effective

communication, because (a) they exclude receivers from understanding the message thereby preempting or lessening the ability to make an informed decision, and (b) they force the reader to invest inordinate amounts of time repeatedly fumbling through the "List of Acronyms." The return on that type of investment is certainly questionable. Indeed, we perceive the use of acronyms as a reflection of laziness on the part of the user, an unwillingness by the user to communicate openly and effectively with all segments and members of society, and an unnecessary amplifier of measured or perceived risk.

If the communicator of risk insists upon using acronyms, especially acronyms not incorporated into the reading and spoken vocabularies of the public, each acronym should be spelled out routinely. For example, HRUP should be identified as a High Risk Urban Problem, otherwise the reader may be HAD - Health Assessment Document. In short, risk communication demands that the communicator accept the risk of concise communication outside of the peer group.

An article in the U.S. Council for Energy Awareness Newsletter (1991) showed the consequences of using euphemisms in a national survey. Of the people surveyed, half was asked, "Which way of handling high-level radioactive waste do you think is more helpful to our environment in the long run - taking the waste to a permanent *waste disposal facility* [italics added] or leaving the waste at the plant sites where it is now?" The other half was asked the same question, but the word "dump" was substituted for "disposal facility." Seventy percent said taking the waste to a disposal facility would be best for the environment. Sixty percent said the same for a dump. Reno, Lattin, and Walters (1991) have argued that **isolation** would be the better choice of words. Word choice does make a difference. For example, the "incident" at Three Mile Island was referred variously to as an "abnormal evolution" and "a plant transient." The general public understood "*accident.*" In our opinion, the use of euphemisms has no place in risk communication.

LANGUAGE USAGE

Dale and Hager (1948) studied how to communicate abstract educational materials from the health profession to the general public. They found seven interrelated techniques are necessary for readable writing: (a) define the audience; (b) define the purpose; (c) make sure that the logic of the material is clear; (d) break the material into digestible parts; (e) keep vocabulary as familiar as possible; (f) summarize and repeat at appropriate points throughout the material; and (g) personalize the approach. If nuclear researchers and incipient nuclear community recognized and used those techniques from the beginning, perhaps much of the adverse publicity of the past several decades would have been avoided. It did not. As a result, the last decade has been a period of playing catch-up and putting things right. Each of us knows the drill; all of us need to practice it.

Of the techniques identified by Dale and Hager, two are overlooked by most managers and communicators of and in waste management programs: "Make sure that the logic of the material is clear" requires a simple and easy flow of related ideas. The number of ideas should be limited, and the writer must not provide more information than is needed for understanding by the intended audience. Most scientists and engineers tend to document rather than communicate when writing for public consumption. Each idea must be developed adequately—not telescoped or crowded. Many times the scientific community squeezes too many ideas into too short a space by using familiar shorthand expressions (jargon). If the audience is to understand fully, concrete explanatory material must be used, not the familiar jargon typically used among peers.

"Keep vocabulary as familiar as possible" is especially difficult for writers of technical material. The writer must balance a specific vocabulary for the intended audience against effective ways of presenting the technical material. An effective way of achieving such a balance is envisioning someone in the audience using the English language as a second language. That forces the writer to choose words and combinations of words having singular meanings. If that imaginary individual can be made to understand the message, there is no doubt that everyone else will understand also. Keep the technical terms limited to only those essential to the central theme. The good writer defines technical terms in context whenever possible. A new technical term should be introduced carefully by a short, clear explanation followed by repetitious use of the term. The good writer also uses positive, familiar words whenever possible.

KNOW THE AUDIENCE

In discussing strengths of community psychology, Brody (1986) identified four important aspects of a community, namely, (a) to gain access to a community, understand how it works and what it needs; (b) members of community can be powerful allies and resources for solving complex issues, if they are respected and informed; (c) communities are most often heterogeneous, with people representing most facets of society; and (d) communities are influenced by powerful external forces, so a commitment to empowerment is a commitment for the future. She argued that the Department of Energy failed to recognize those aspects of a community when it named Deaf Smith County (Texas) as one of three candidates for the federal, high-level radioactive waste repository. In Brody's opinion, the Department of Energy did not know its audience nor did it effectively communicate with that audience regarding the need for or locations of such a repository. Much of the "anti-dump" conviction by legislators of the State of Texas might be attributed to poor communication on the part of the Department of Energy with the locals. Both politics and geology are important considerations in any siting process. The Department of Energy cannot change the geology of a site, but it [or any other governmental entity] can change or influence politics, provided the communicator understands the public being influenced, deals with that public in a forthright manner, and freely and openly shares information with protagonists, neutrals, and antagonists alike. Most state legislators have good understandings of who put them in office. If they are going to stay in office, chances are they will vote controversial issues in ways their constituencies favor.

PRESUMPTIVE PRIOR KNOWLEDGE

When waste management practitioners engage in risk communication, there is always the concern of how knowledgeable the public is about the risks being communicated. Before one worries about public knowledge, one must be concerned with whether the communicator of risk is credible in the eyes of the public. Paustenbach (1989) suggested that scientists and technicians involved in risk assessment should use all the appropriate scientific data to describe the degree of risk associated with a given hazard. That gives the manager of risk the requisite, objective information needed in formulating a course of action. The old adage, "If it ain't broke, don't fix it," does not apply to communicating risk. People are concerned about risks to them and the environment, if "it" does break! If the assessor and manager keep their processes separate, the risk communicator has less difficulty with credibility. Most people would like companies and community to resolve common concerns together.

Many companies recognized the political and social advantages of community outreach programs and use them as a means of communicating risks. Hance, Chess, and Sandman (1990) developed a "Ladder of Citizen Participation" for improving dialogue in an outreach program. Through an outreach program, companies are made aware of public concerns, and they gain an appreciation for prior knowledge of the community at large.

ACTION

The waste management industry must educate the general public from the bottom up, NOT the top down. At a fundamental level, there are four possible attitudes to be held by an individual: (a) positive, (b) negative, (c) neutral, and (d) "no opinion." The neutral position is defined as a reasoned position arrived at logically by the individual; however, the individual's predispositions predict which direction he or she will go, when influenced by communication. Mass communication does not create an opinion, it merely reinforces an individual's predispositions. The no opinion position is conceived *a la* blank chalkboard. There are five possible effects from communication: (a) creation, (b) reinforcement, (c) minor change, (d) conversion, and (e) "no effect." Table 1 illustrates possible effects of communication on the audience.

For example, if an individual has a positive attitude toward management of low-level radioactive wastes before a communication message and a positive attitude after the message, there are three possible effects of the message: (a) no effect, (b) minor change (in either direction), or (c) reinforcement. If an individual has a positive attitude toward management of low-level radioactive wastes before a communication message and

a negative attitude after the message, the individual experienced conversion. Conversion is the least likely effect of a message.

Table 1. Possible Effects of Communication on an Audience

Position before exposure	Position after exposure			
	Positive	Negative	Neutral	No opinion
Positive	[a]	Conversion	Minor change	Convdersion?
Negative	Conversion	[a]	Minor change	Conversion?
Neutral	Reinforce	Reinforce	[a]	Conversion?
No opinion	Creation	Creation	Creation	No effect

a. Three possible effects can be noted for these cells: (a) No Effect, (b) Minor Change, (c) Reinforcement

Therefore, the message from the waste management industry to the public is probably not going to bring about conversion. And, for that matter, neither is a negative message from the local news department going to convert those who have a positive attitude toward management of low-level radioactive wastes.

What, then, can be expected by presenting positive messages to the public? Communicators of risk must try to bring those with neutral and no opinion positions to a positive position. What can be hoped for is movement—however slight—away from a negative position toward a neutral position. In order for the public to hold a positive attitude about the waste management industry, individuals with neutral positions and no opinions first must be moved toward a positive position. Those individuals with negative positions about the waste management industry must be moved toward a neutral position. Once a series of minor changes has occurred from negative to neutral, then focus can be shifted to moving individuals from neutral to positive attitudes. The process is slow, but it does work. Attitudes of individuals can be changed. We also know that the younger the individual the fewer the predispositions. The process works faster on younger people, particularly those that have not formed opinions.

CONCLUSION

The difficult task is accepting the risk of communicating risk. At various times the communicator of risk will appear arrogant and at other times uncaring. Most of the time he or she is neither. People with different predispositions process information to match their predispositions. The waste management industry must be aware of those individual "publics" that comprise the general public. Each "public" may need a different form of the message to augment or offset its predispositions. Each may have differing levels of prior knowledge. As we have pointed out, the communicator must know the audience and communicate with that audience.

One way to reduce the verbal risks in communicating risk is to communicate fully and openly. When questions are raised within a given communication, they must be answered and the answer must be in close proximity to the question. A practice that will lessen negative perception is avoiding the use of jargon, particularly jargon that has negative connotations. When communicating with the public, avoid using acronyms altogether; indeed, avoid using them in any situation. Remember you are trying to reduce the risks in communicating risk, not trying to save time or paper. Avoid using euphemisms altogether.

On the whole, public perception will improve when good communication is used in the risk-communication process. Reducing verbal risks in communicating risk means accepting the risk of concise communication with the public. If the communicator of risk addresses different "publics" within the community, the long-term risk associated with concise communication is reduced. The inevitable realization and conclusion is "Risk communication requires a long-term commitment to the community."

REFERENCES

Blair, E. H. in J.C. Davies, V.T. Covello, and F.W. Allen (Eds.), *Risk Communication,* National Conference on Risk Communication, Washington, D.C.: The Conservation Foundation, 1987.

Brody, J., "Community Psychology in the Eighties: A Celebration ofSurvival, *American Journal of Community Psychology,* 1986, 14(2), 139.

Cherry, C., *On Human Communication,* (2nd ed.), Cambridge, Massachusetts: The M.I.T. Press, 1966.

Committee On Risk Perception and Communication, *Improving Risk Communication,* National Academy Press, 1989

Dale, E., and H. Hager, "How to Write to be Understood," *Educational Research Bulletin,* 1948.

Hance, B., C. Chess, and P. Sandman, *Industry Risk Communication Manual: Improving Dialogue with Communities.* Boca Raton, Florida: Lewis Publishers, 1990.

Krimsky, S. and A. Plough, *Environmental Hazards,* Dover, Massachusetts: Auburn House Publishing Company, 1988.

Lutz, W., "Language, Appearance, and Reality: Doublespeak in 1984," et cetera. 1987, 44(4), 382.

Meyrowitz, J., *No Sense of Place.* New York: Oxford University Press, 1985.

Paustenbach, D. (Ed.), *The Risk Assessment of Environmental Hazards.* New York: John Wiley & Sons, Inc. 1989.

Reno, H., W. Lattin, and J. Walters, "How Does One Communicate Isolation of Wastes From People and Environment?" *Symposiumon Waste Management '91, Tucson: University of Arizona Press, 1991, 1,* 353-358.

Reno, H., and J. Walters, "Jargon of the Nuclear Industry: A Fomenter of Negative Public Perception," *Symposium on Waste Management '90, Tucson: University of Arizona Press, 1990, 1,* 299-301.

U.S. Council for Energy Awareness Newsletter, *Perspective on Public Opinion,* December 1991.

Is Low Level Radioactive Waste Different? Lessons Learned from Other Industries

Patricia D. Fleischauer and Caren Arnstein
ENSR Consulting and Engineering
Acton, MS 01720

Contributing Co-authors:
Dr. Norma Morin and Ann Lockhart
Colorado Department of Health

INTRODUCTION

Risk has long been an issue for the nuclear industry. Whether it is an accidental release analysis or the issue of waste disposal, the nuclear industry has always looked at the potential health effects of its operations. The issue of health effects as they relate to other industrial operations is newer and one that is both surprising and sometimes annoying to managers of "clean" industries. Paper mill managers and pharmaceutical company executives alike are often annoyed when they have to talk about the chemicals their facilities use and discharge, and any potential human and ecological health effects that may result.

It is a fact, however, that almost any company proposing to develop a new facility or expand an existing one will require a federal or state air permit or environmental impact statement. As part of the process the company will have to address potential health effects through a more or less formalized risk assessment and then communicate the results to the community and various regulatory agencies.

How these risks are communicated is critical to public and regulatory agency acceptance and the granting of necessary environmental permits. This paper will examine risk communication associated with two proposed projects and identify the keys to the communication process. In relating these to the current Rocky Flats communication program, we will show how lessons learned from these cases are all directly applicable, and indeed essential, to communicating the risks associated with nuclear facilities.

RISK ASSESSMENT REQUIREMENTS

Depending on the state in which the facility is developed, the risk assessment will be more or less prescribed. New Jersey has a relatively simple but conservative method of estimating facility related risk for certain "small scale" facilities and more comprehensive requirements for resource recovery facilities or similar major sources. For hospital incinerators, for example, the State uses a simple screening level risk assessment that looks at the air pathway only, limits the number of chemicals to be evaluated, and bases the calculation on an assumed 70-year life of the facility. Each of the chemicals arsenic, cadmium, hexavalent chromium, nickel and 2,3,7,8-TCDD is evaluated separately and if found to yield an incremental cancer risk of less than one-in-a-million (1×10^{-6}) for carcinogenic pollutants, or less than 1.0 on the Hazard Index for noncarcinogenic pollutants, the risk is considered negligible and the risk assessment is complete. Risk greater than 1×10^{-4} is unacceptable; between 1×10^{-4} and 1×10^{-6} the risk is evaluated on a case-by-case basis. Risk is expressed in terms of increased individual risk; a total population risk is not calculated. Pollutants are considered individually and risks from the different contaminants are not added to derive a "total" facility risk. The analysis can be readily completed almost by using specified unit risk factors multiplied by predicted ambient impacts and filling in the form.

Minnesota, on the other hand, has developed the air toxics source review guide. This guide identifies classes of chemicals based on their known toxicity and specifies a risk assessment process that requires interaction and review by the state at every step of the analysis. At the screening level, facility emissions are compared to allowable ambient levels (AALs) that have been set based on the toxicology literature, already derived potency slopes, use of worst case dispersion modeling, and adjustments made to reflect various levels of uncertainty. Minnesota does not limit its focus to risk associated with noncriteria pollutants only. While

it can be argued that the national ambient air quality standards address acute health effects, recent risk assessments have included carcinogenic, noncarcinogenic, chronic and acute health effects of both criteria and noncriteria pollutants.

Regardless of the specificity of the risk assessment procedures, the desired results are usually a guideline number such as 1×10^{-6}. What happens to a facility whose calculated risk exceeds this number is only part of what we will address; equally important is how to present the calculated number, whatever it is. Can we simply assert that we comply? Possibly, depending on our audience. Can we simply show that we comply? Possibly, again depending on our audience.

Two recent permitting efforts, one for a pulp mill and one for a pharmaceutical company, will be reviewed to identify the interested audiences and how the risk results were communicated to them. We will see that, in addition to satisfying regulatory requirements, successful project development requires giving the requested information in a way that can be understood by the requesting audience.

PULP MILL CASE STUDY

Potlatch Corporation proposed a near doubling of the pulping capacity of its Cloquet, Minnesota, mill. The facility expansion would result in an almost total replacement of its old chlorine-based bleaching system. Using extended cooking and oxygen delignification, the facility would be using state-of-the-art technology to become as chlorine free as their brightness paper would allow. Before the expansion, the facility produced approximately 192,000 tons of pulp annually and used approximately 75.5 pounds of chlorine per ton. After the expansion, the facility would produce approximately 425,000 tons of pulp, using chlorine at a rate of 0.2 pounds per ton. The new process was clearly an environmental improvement because of the reduction in amount of chlorine used per ton of pulp. However, the calculated risk, due principally to dioxin, exceeded the guideline number of 1×10^{-6}.

The corporation felt frustrated at the resulting public outcry. If Potlatch had continued with the existing operation, no one would have bothered them . . . at least for a couple of years. Instead, the company was trying to do something good—stay in business, be competitive, install an environmentally improved process—and found themselves in a mess. And not just because of chlorine. Suddenly they were under scrutiny for everything by everybody.

Those interested in the Potlatch expansion can be divided into five different groups:

- The general public
- Environmental groups such as the Sierra Club
- Commenting public agencies such as the Minnesota Department of Health
- The state permitting agency, the Minnesota Pollution Control Agency
- The citizen review board.

There are obviously many more groups, such as employees and elected officials, but the above five dominated the debates on the Potlatch risk assessment.

The main result of the risk assessment is summarized in Table 1. This table indicates that the incremental cancer risk due to the facility was 1.63×10^{-6}. Because the risk was greater than the guideline number, some opponents asserted that the expansion should not be allowed. It was permitted, and is under construction, but not before each group had its own explanation of what the risk assessment results meant.

The general public was provided with an interpretation of the risk number. It was not simply that the facility would mean that everyone's chance of getting cancer, over and above the background cancer rate, was

increased by 2 in 100,000. Since the background cancer rate is 1 in 3, or approximately 0.3, the risk of cancer would increase from 0.30000 to 0.30002. While this is very small, it was not the expected risk for the local community. In communicating the risk estimate it was explained what one would have to do to incur that risk. Specifically, the public was told in words the assumptions used to calculate that number, and implicitly asked to made their own judgment about the acceptability of the estimated risk. It was presented this way:

> When the expanded mill opens, there would have to be a woman living in the area of highest chemical concentration outside Potlatch property. She always lives there, she never works, vacations, goes to visit anyone—she constantly breathes at that location for 70 years. She raises 100 percent of her beef and dairy cows at that location; she makes all of her own cheese, butter, and ice cream from her own dairy cows, who also have maximum exposure. She grows 50 percent of all the vegetables she eats in her back yard, and catches 100 percent of her fish from the St. Louis River. She also swims often in the Thompson Reservoir. She does all of these things for 70 years, and then she has a baby. Her baby is the maximally exposed individual who potentially has the estimated risk. The child nurses for 1 year, and is therefore exposed to all the chemicals that his/her mother was exposed to throughout her lifetime through her milk. The child then is exposed to chemicals being emitted from the mill at maximum rates, to the same degree that his or her mother was, for 70 more years. Then his or her risk of getting cancer is increased by 2 in 100,000. In other words, 140 years of maximum exposure is necessary to experience this risk.

The environmental groups, more informed about risk assessments, focused on technology. They claimed that the paper was not needed and/or that technology did exist to produce the desired product without using chlorine. They felt that technological changes should be made until the guideline numbers were achieved. For some chemicals, the guideline numbers were as low as zero discharge.

The commenting public agencies, in particular the Department of Health, noted that while the risk assessment was not perfect, it allowed comparison with other facilities being proposed and hence contributed to determining the best allocation of resources. By using a standardized approach, that may or may not have incorporated the latest scientific data, the Department felt that it did allow a valid comparison with other projects that the agency was reviewing.

The permitting agency used the risk assessment process to look at all sorts of risks. As a result of the agency review of carcinogenic, noncarcinogenic, chronic and acute risks, both technological as well as process and operating changes were required. That the permit was granted with a calculated risk greater than the guideline number speaks to the intent of the risk assessment—a decisionmaking tool, not the source of an absolute answer. Aware of the many conservative assumptions involved in the calculation, the agency worked with the company to explore reasonable process and operational means of moving toward the guideline number.

The citizen board, responsible for the final granting of permits based on the permitting agency's recommendation, and charged with bringing all issues to bear on the permit decision, focused on technology and required a permit condition that specified that as soon as chlorine-free technology was available, it would be adopted. Rather than looking at the total facility risk, this group focused on the individual chemicals contributing to this risk.

In communication with each group, the discussion focussed on their issue of primary concern. Based on the combination of this dialogue and the technical data, the permit was granted.

PHARMACEUTICAL CASE STUDY

Like Potlatch, Merck, as well as several other pharmaceutical companies, set out to update operations and provide a system that was environmentally improved. But it too wound up in discussions with both the public and regulatory agencies that seemed to give no credit to these good intentions.

Merck currently operates two small pathological waste incinerators and one large incinerator used for disposal of municipal-type waste. All three facilities operate without state-of-the-art air emission controls. Merck proposed closing down all three incinerators and replacing them with one state-of-the-art small-scale medical waste incinerator. The facility would allow Merck to respond to the ban that as of January 1, 1993, would prohibit out-of-state disposal of low-level radioactive waste associated with its research operations as well as provide for improved waste disposal in general.

The analysis performed demonstrated compliance with the state risk assessment guidelines, NRC guidelines, and all state requirements for air and solid waste permits. Such assurances, however, were not sufficient for the interested audiences. These included the general public, the local planning board, and two departments within the New Jersey Department of Environmental Protection and Energy, each with permit responsibility.

The general public focused on the low-level radioactive waste. Basically they ignored the extremely low exposures (millions of times lower than natural background). They feared that the facility would result in nuclear power plant-level emissions. In focusing on risks associated with low-level radioactive waste, the opposition was able to marshall much more public and agency support than if they focused on any of a number of other issues associated with the current or future Merck facility.

The planning board focused on the issues for which it had responsibility and did not allow the public to discuss issues that were the responsibility of other agencies. The result was that when the state agency hearing was held, the public was less convinced of the merits of the project, instead of more convinced.

One of the departments within the state regulatory agency with permitting responsibility went beyond its assigned areas. Despite the directives of the low-level radioactive waste land ban, the agency focused on seeking alternative means of disposal as well as assuring the absolute necessity of using radioactive compounds in medical research. The department recognized that the decision affected not just this pharmaceutical company but all such companies in the state. Now in November 1992, with the land ban just a few months away, this project effectively brought to light the potential disposal crisis the state faces.

The other permitting department, regardless of the facility's compliance with air and effluent guidelines, wanted a full accounting of all low-level radioactive compounds. While the department purview was limited to discharges to air, regulatory jurisdiction was overstepped with respect to radionuclides, which is the jurisdiction of the Nuclear Regulatory Commission.

Again, in meeting with these four groups, it was not sufficient to merely assert or show compliance with applicable regulations. To gain acceptance, the issues of concern to each group had to be addressed in terms they understood.

LESSONS LEARNED

These examples and countless others clearly answer both our questions with at best "maybe" and more likely "no." If we cannot merely assert compliance or show compliance, what can we do? The lessons learned are the following:

1. Do not wait for the public to come to you, whoever that public might be. You must go to them at the outset of the project and identify who they are and what their concerns are. This means listening and responding to each of the critical audiences.

2. Speak to the issues of interest. Yes, you must comply with the law, but permits for new or expanded facilities give all audiences the opportunity and license to ask questions that go beyond the letter of the law and beyond the issues at hand. Telling them that something is none of their business is a sure step to failure.

3. Speak in terms that will be understood. Few in the general public understand what an increased cancer risk of 1×10^{-6} means. But they do understand what it means to live in one place for 70 years, to grow all of their own beef, etc.

This all sounds so simple yet we know if not done properly our projects can die. Many an otherwise good project has failed because an audience was opposed to it, and not enough effort was spent to understand various group's true concerns and adequately address those concerns. It is clear through these examples and others, that regulators do consider public opinion and news reports in making their decisions.

Generally, the core issue for gaining public support is credibility. Today, in order to accomplish objectives related to environmental or health issues it is essential to earn public trust and credibility for technical studies and the organization. Even the best science and technology has little value, if the public does not believe the study results or data. The fact is, most people do not trust the government or industry to protect their interests. Survey after survey shows that Americans believe that the government and corporations lie about their environmental records to save money and improve their public image.

While LLW may not be different than other environmental risks, the public often perceives a difference. People dread radioactive waste much more than toxic chemicals. Contributing to this perception, no doubt is the mass destruction and long-term adverse health effects caused by past explosions of nuclear weapons. Another fear factor is that radioactive emissions are invisible and undetectable to people. A former war correspondent covering the Three Mile Island accident concisely expressed this fear when he said, "At least in a war, you know when you've been hit."

Many proactive companies in the chemical, manufacturing, pulp and paper, and pharmaceutical industries are using communication as a tool to achieve their business objectives and become more responsible corporate citizens. The LLW community can use the same type of risk communication process to accomplish its goals. In fact, communication may be more critical to LLW projects due to the fear factor and public perception of these less familiar and more exotic risks. An excellent example of a proactive communication program is the one being conducted by the Colorado Department of Health for the Rocky Flats Toxicological Review and Dose Reconstruction project.

THE ROCKY FLATS CASE STUDY

First, some background. Rocky Flats, located about 16 miles northwest of downtown Denver, has produced nuclear weapons components for 40 years. This DOE facility used radioactive materials in the manufacturing process, such as plutonium and uranium, and other hazardous materials including beryllium and carbon tetrachloride.

A number of incidents such as fires and spills have released contaminants from the Rocky Flats plant to the surrounding community. Leaking drums of waste stored on site contaminated soil that was carried off site. Tritium was also inadvertently released to a community drinking water supply in 1973. Little information was provided to the public about these incidents, and people are still concerned about past releases. Local residents continue to worry about groundwater, surface run-off or treated wastewater discharged at the plant flowing off site, possibly affecting their drinking water.

In June 1989, a surprise raid of the Rocky Flats plant by 100 agents from the FBI, U.S. Justice Department, and the Environmental Protection Agency resulted in a grand jury investigation and an $18.5 million fine assessed in 1992 against Rockwell International, a former plant operator, for environmental, health, and safety violations. The raid caused renewed public fears of unknown hazards at Rocky Flats. Concern over the government's secrecy in handling of the investigation continues today. There is public pressure for criminal indictments and to unseal the grand jury report, making it public. Public sentiment is that, once again, information is being withheld under the cloak of "national security" and guilty parties are being protected. The perception is that in the name of political expediency, DOE continues to direct and endorse illegal activity.

Following the 1989 raid, Colorado's Governor Roy Romer met with U.S. Department of Energy Secretary Admiral James Watkins to obtain additional funding from DOE for state oversight of Rocky Flats. He felt that more intense scrutiny by the state would reassure concerned citizens. Romer and Watkins developed an "Agreement in Principle" that includes four action items:

- More environmental monitoring around the plant
- More attention to the plant's compliance with environmental laws
- A speedier cleanup of onsite contamination
- A series of health studies.

In 1990, the Colorado Department of Health (CDH) began an extensive, multiyear study to assess the possible health effects of past operations on people who lived near Rocky Flats. Called a toxicological review and dose reconstruction, the study will determine the possible long-term human health risk associated with exposure to toxic and radioactive substances from 1952, when the plant began operating, through 1989.

But the CDH had another major challenge. The study team needed to overcome general public distrust related to Rocky Flats created by the plant's history of secrecy, major accidents, and bad press. Would the public trust the State's study and its results? Would the study address the issues of concern to the public? Could the highly technical study results be presented to the public in a clear, meaningful form?

Public Perception

In the early years, most people accepted the "shroud of secrecy" surrounding Rocky Flats plant operations in manufacturing nuclear weapons parts as necessary to protect national security. But public attitudes have changed over the years. News stories about incidents at Rocky Flats and potential offsite contamination have created concern. The growing environmental and anti-war movements resulted in increased public attention throughout the 1970s and 1980s. Activists have vigorously demonstrated against nuclear weapons at the plant site many times over the years.

There is ongoing public concern among Denver and Boulder area residents about the plant's use of radioactive materials, such as plutonium and uranium. Plutonium creates the greatest fear, since it is a very toxic, radioactive metal with a long life. People wonder if plutonium that was released in the 1950s and 60s is still present in the environment, causing adverse health effects, and whether releases have occurred in more recent years.

Other health studies related to the Rocky Flats Plant have been done, but scientists and the public disagree on which studies they believe and the potential health effects from the plant. As the current health studies began, a Colorado Department of Health contractor interviewed activist group leaders, community leaders, and interested citizens. The survey found many feared that this proposed study would be "like every other study done of Rocky Flats—a whitewash." Most did not trust the U.S. Department of Energy because of its tradition of secrecy and operating behind closed doors. CDH didn't rate much higher.

The Rocky Flats health studies present specific challenges to communicating the risk estimates. Phase I is a historic review of contaminant usage, exposure pathways, and source-term estimates. The study includes a review of the area's historical demography and land uses for the purpose of evaluating potentially exposed populations. Extensive records were kept on use of radionuclides at the plant, but complete records on chemical use may not be available for the years before 1970. Public acceptance of Phase I results will depend on the perceived validity of the historic data and reconstruction methodologies, especially because people are suspicious of DOE data.

Uncertainty, which is inherent in risk calculations, is a difficult concept to explain and uncertainty means one thing to scientists and a very different thing to the public. This uncertainty is often the basis for public

fear and mistrust. Phase II will involve the application of sensitivity analyses to fine-tune the estimates of toxic materials released from the plant. The risk characterization in Phase II will provide "plausible risk ranges," describing the acute, chronic, and carcinogenic health risks for the populations and exposure scenarios developed in Phase I.

CDH recognized that to build credibility for the health study results, it was essential to involve the public in the process from the beginning and communicate throughout. Presenting such complex scientific information and explaining uncertainty so that nontechnical people can understand the results is the first challenge. Reducing outrage and gaining public trust and confidence will require a sincere public outreach and involvement effort. A scientific risk communication approach was the best hope of changing public perception.

APPLYING THE LESSONS LEARNED

The Rocky Flats risk communication and public involvement program applied the lessons learned from other industries and other DOE sites, such as Hanford.

- Lesson 1: Reach out to all interested parties, listen, and respond. At Rocky Flats, this meant all groups that came forward, as well as an outreach effort to the "silent majority."

- Lesson 2: Speak to the issues of interest to each audience, which often includes emotional as well as technical issues. When people feel their family's health and safety are at stake, they want empathy and straight answers.

- Lesson 3: Speak in terms that will be understood. People often feel that complex technical information is used as a smokescreen to hide the truth.

Bridging the gap between the scientific results of risk assessment and the public perception of risk is the challenge faced by risk communicators. Scientific risk estimates are a function of hazard plus exposure. Public perception of risk is different. According to Dr. Peter Sandman, the public views risk as a function of hazard plus "outrage." ("Risk Communication: Facing Public Outrage" *EPA Journal*, Nov. 1987.) Outrage factors influence public reaction to risks; for example, we all view voluntary risks as more acceptable than risks imposed by others. Familiar and natural risks are more acceptable than the exotic or man-made; risks we can control are feared less than those we cannot. Therefore, the risk communicator works to recognize and reduce outrage. In this manner, communication is used to bridge the gap between the views of the scientist/technical expert and the public.

Public concern and reaction to risk information is also a factor of how people are treated. People who are involved in the process, who feel that their concerns are recognized, and who feel they are being treated with fairness and respect are more likely to understand and accept the results. Establishing the credibility of the source of risk information, being honest and open, speaking in plain language and with compassion are all essential to effective risk communication.

THE RISK COMMUNICATION PROCESS

CDH recognized that the risk communication process needed to start when the dose reconstruction began. This lead time was critical to the credibility of the study and its results, and was used to involve the public in the study process. By discussing public concerns at each step of the study and presenting technical issues in a clear, direct manner, CDH is earning public trust and credibility.

An independent 12-member Health Advisory Panel (HAP), led by Dr. Ellen Mangione of CDH and made up of local representatives and national experts, was appointed by the governor to oversee the study. From the outset the HAP panel members stressed that all its activities, work sessions and meetings be open to the public. During the first two years, the team has held eight technical work sessions and six public meetings and distributed over 500 copies of the draft Rocky Flats History report.

The technical and communication contractors are working closely with the Health Advisory Panel and CDH to:

- Establish an ongoing public involvement program to reach as many interested citizens as possible, including the "silent majority" as well as local activist groups. A broader outreach effort will include presentations at community groups, neighborhood associations and professional organizations, as well as placing articles in a variety of specialty publications.

- Provide information on the dose reconstruction study steps, process and findings to the community via public meetings and publications. Keeping people informed of study progress and providing accurate, timely nontechnical publications for public distribution is building credibility and enhancing understanding.

- Assist local health care providers in communicating accurate risk information to patients and provide physicians with immediate access to health study results. A risk communication program for physicians is a key component of the outreach effort, since people usually rely on their doctors for health information.

- Provide media training and risk communication training to CDH staff and the Health Advisory Panel to assist them in clearly communicating about the study with laypersons. Because they serve as the primary liaisons with the public, the CDH staff and HAP members need the skills to communicate effectively about the risks specific to Rocky Flats.

- Provide information for the local news media and monitor and analyze news story contents. Reliable spokespersons and consistent release of information will reduce misinformation and expand outreach efforts.

These programs were designed to establish a dialogue with the constituencies most interested in the Rocky Flats Health studies:

- Communities near the plant and the general public

- Local officials

- Local activists groups

- The news media

- Local doctors and health care providers.

Communication is, by definition, a two-way process that involves listening as well as speaking. The first step in effective communication is to listen to others and understand their concerns. Responding to and addressing their concerns is the next step, using appropriate means to give and receive feedback. Providing information (speaking) is only one aspect of the process. The goal of the Rocky Flats health studies public outreach initiative is to create a climate where effective communication can occur.

Central to developing an effective program for involving the public and communicating health risks is a clear understanding of the issues and information needs of the people involved. Listening to the issues and perceptions of community members and opinion leaders provides the basis to create the most effective means of establishing two-way communication. The public involvement program must then be tailored to involve key individuals and allow for meaningful input as the studies progress in order to earn public trust and confidence.

Therefore, the establishment of an effective public involvement program at an early stage of the technical study is the foundation for the entire health studies communication initiative. The importance of identifying

who is most affected or concerned, and understanding their issues and information needs, cannot be overemphasized. With the number of groups and individuals involved and the range of issues at Rocky Flats, it is essential to target those specifically concerned about health risks and to reach out beyond the vocal minority.

Most importantly, once communication channels have been opened, it is critical to explore and discuss the issues of interest to those groups. Often this includes emotional issues of fear and fairness, as well as trust. Regarding the technical studies, we must be willing to talk about what we don't know and data we are unsure of, as well as data we are certain about. Today's sophisticated audiences are most interested in what we are doing to reduce the risk, not an endless discussion on the magnitude of the risk. Once they are satisfied on these issues, the public is generally interested in the decision-making process, technical tools and methods, and ongoing monitoring and safety controls.

CDH and its contractors are working directly with local interest groups to address issues, reach an understanding, and develop mutual respect. One local group that reads every technical report, often comes to different conclusions than the technical experts. Leaders of this group faithfully attend all HAP meetings, comment on draft technical reports, and even review draft newsletters for accuracy. Although sometimes frustrating, the study process and its credibility are continually improved as a direct result of this interaction.

Surveys have indicated that the public involvement effort is improving the credibility of the health studies. Specific comments on a survey of community leaders and activists taken one year into the communications program included positive comments on members of the CDH staff, saying they are doing a good job, are trustworthy, and are willing to share information. Survey respondents also said, "CDH is doing a good job," "It appears that the people performing the study know what they're doing," and "There has been great improvement in CDH community involvement effort."

CONCLUSION

The risk communication lessons learned from other industries are especially important and relevant to the LLW field. And, early indications of the successful public involvement approach being applied to the Rocky Flats health studies is encouraging and instructional. We believe that LLW is not different from other industries in terms of the value of the risk communication process. Communication is even more critical to LLW projects due to public fear and perception of these less familiar, more exotic risks.

Conversely, the American nuclear power industry is an example of what can happen if an industry does not tell its own story: the extremists tell it for you. The absence of honest dialogue has perpetuated fear, suspicion, and intolerance. And, the lack of communication, credibility, and trust has affected the number of permits granted in the U.S. for construction of nuclear power plants, dropping from 82 in 1980 to only nine permits granted a decade later.

An effective communication program that takes into account the lessons learned from other industries can help earn public support for LLW projects. Without a two-way dialogue, there is no chance of building trust, understanding other viewpoints or finding common ground. Communication is absolutely essential to any health and environmental program's long-term success.

REFERENCES

Dr. Norma Morin, project director, and Ann Lockhart, senior public information officer, with the Colorado Department of Health, "Public Involvement—the Pluses, the Minuses and the How-tos," National Health Physics Society, 1992.

TABLE 1

Incremental Cancer Risk
Proposed Potlatch Expansion

Compound	Inhalation	Swimming	Soil	Produce	Fish	Dairy	Beef	Mother's Milk	Total
TCDD-TE	5.10E-08	4.35E-12	2.08E-09	6.42E-08	3.69E-08	1.66E-06	5.12E-06	2.97E-06	9.91E-06
Chromium VI	5.95E-08	(a)	(a)	(a)	(a)	(a)	-	-	5.95E-08
Chloroform	4.91E-06	(b)	(b)	(b)	(b)	(b)	(b)	-	4.91E-06
Arsenic	8.92E-07	6.50E-13	5.02E-12	1.49E-08	3.26E-12	8.42E-09	-	-	9.15E-07
Formaldehyde	5.21E-07	(b)	(b)	(b)	(b)	(b)	(b)	-	5.21E-07
Chromium III	(a)	(a)	(a)	(a)	(a)	(a)	-	-	(a)
Mercury	(a)	(a)	(a)	(a)	(a)	(a)	-	-	(a)
Total	6.43E-06	5.00E-12	2.08E-09	7.92E-08	3.69E-08	1.67E-06	5.12E-06	2.97E-06	
								Summed Risk =	1.63E-05

Notes:
(a) This chemical is not carcinogenic by this route of exposure.
(b) This chemical is not deposited, therefore it is not included in this pathway.

R:\PUBS\DMM\ARNSTEIN.TBL

When You Speak, Why Don't They Listen?

Rose T. Pfund, Ph.D.
University of Hawaii Sea Grant College Program
Honolulu, HI 96822

INTRODUCTION

Regulatory agencies for the first time in history are being confronted with public opposition as they seek to manage the mountains of wastes generated by human beings and other animals and the engineered systems that enable most of the world's population to enjoy an unprecedented level of comfort and convenience. When waste was largely biodegradable and limited because of a smaller world population and simple technology, their disposal did not attract public debate. Moreover, visible trash in urban centers was removed to designated dumpsites or used as landfill. Cities were designed to use waterways as waste disposal channels that eventually discharged the effluent and slurried solids into the ocean. Conventional wisdom, until very recently, considered the world's oceans to be a limitless receptacle for everything from sewage to industrial waste.

The dilemma of hazardous waste management today lies not only in the sheer magnitude of the volume of waste produced, but also in the inability of current technology to refix the released toxic elements and other adverse properties of natural resources and return them to their former benign state. Arguably, radioactive waste is the most fearsome waste product that has been produced because of its potential for mass destruction and death. This also makes it the most difficult waste to manage. There is widespread public perception that radioactive wastes are ticking time bombs with a built-in tendency to explode and that their long half-life will outlive the security of the storage containers. The purpose of this paper is not to debate the scientific or engineering merits of proposed disposal designs and the stability of proposed sites. What will be discussed here is the amplification of the confusion and negativism caused by communication dysfunction in an already negatively charged field. The consequences of communication failure have been known in ancient times and is recorded in the biblical account of the tower of Babel.

> Now the whole earth had one language and few words. And as men migrated from the east, they found a plain in the land of Shinar and settled there. And they said to one another, "Come, let us make bricks, and burn them thoroughly." And they had brick for stone, and bitumen for mortar. Then they said, "Come let us build ourselves a city, and a tower with its top in the heavens, and let us make a name for ourselves, lest we be scattered abroad upon the face of the whole earth." And the Lord came down to the city and the tower. . .And the Lord said, "Behold, they are one people, and they have all one language; . . . and nothing that they propose to do will now be impossible for them. Come, let us go down, and there confuse their language, that they may not understand one another's speech." . . . Therefore [the city's] name was called Babel, because there the Lord confused the language of all the earth. . . *Holy Bible*, RSV, Genesis, Ch. 11:1-7.

What is striking in this excerpt of the writing of an ancient author (or authors?) is his understanding of organizational and communication theories. The molding of a community is associated with the creation of a place—a city with a tower. Without a place, there is clear understanding that the people would scatter "abroad upon the face of the whole earth." The writer in the persona of the "Lord" notes that the unity of language and place would allow the people to carry out anything they desired. What is implied here is the unifying power of a single language and a single race that can be directed toward collective action for the accomplishment of a goal. In modern times, Japan's post-World War II economic recovery is a product of "one language" and "one people." Japan's awesome global economic dominance can stand as a modern example of a Tower of Babel.

The reference to "few words" in the first verse (sentence) is also important. The successful organization of the people's efforts to build the city and tower indicates that a simple common language was adequate for coordinating complex specialized functions. Just as bitumen was the mortar that held the bricks together, there

is clear understanding by the early writer that language was the mortar that held together the complex organization, composed of diversified functions, and directed its focus on the massive construction projects. The final sentence is the curse that brought the construction of the city and tower of Babel to a halt, "[T]here the Lord confused the language of all the earth." The world has been embroiled in confusion ever since.

There is a lesson to be learned from the biblical explanation of the origin of languages. God's remedy for preventing human beings from building a power base from which "nothing they propose to do will now be impossible for them" was to disrupt their communication flow. Lacking a common language, the building of the city and tower of Babel, in essence, self-destructed because it was no longer possible for the people to coordinate their activities and "the Lord scattered them abroad from there over the face of all the earth, and they left off building the city" (Genesis, Ch. 11:8).

Like the confused city of Babel, humankind's heritage of confusion is everywhere in the United States, but, in recent years, nowhere more evident than in environmental and resource management. There is no shortage of verbal, visual, and printed information in the United States where free speech is a basic right, but the most costly and nonproductive evidence of the Babel syndrome[a] can be seen in the overloaded courts. Here the two parties who have failed to communicate go before third parties, a judge and jury, to obtain a ruling on their dispute. What is often overlooked is the fact that the court's judgment is based on an entirely different set of principles and values than those held by the litigants.

This procedure boils down to the abdication of decisionmaking in environmental management issues by the most knowledgeable parties because of communication failure. Legally binding, but appealable, decisions are thus increasingly being made by the courts and judges who have little or no scientific and technical training. These juridical decisions, supported by copious amounts of costly evidentiary information, are predicated on adversarial principles that only serve to polarize opposing litigants. There is nothing in the legal process that promotes resolution of the points of contention through open discussion and compromise. The numbers of appeals that are filed in appellate courts attest to the ineffectiveness of the legal system for resolving disputes.

The tragedy of the Babel syndrome in environmental management is the misdirection of funds and human resources to nonproductive courtroom battles instead of to the mitigation of the environment. A recent trade newsletter of the insurance industry noted that "Superfund (funding for cleanup of sites that pose serious environmental and/or public health threats) is less an environmental program than a litigious nightmare" (Gilbert, 1991). Dauer (1992) cited a national study that revealed that litigation is siphoning off nearly 90% of the insurer's Superfund costs.

Although the principle of organizational behavior underlying the Babel syndrome was understood in ancient biblical times, over the four or five thousand years ago, little use has been made of this knowledge. Is there today an overriding reason so compelling that whole political and economic infrastructures will change to embrace open communication to promote a common good? Is Japan's accomplishment an anomaly? Is there the political will to overcome the Babel syndrome? This paper will explore underlying reasons why the Babel syndrome has turned the management of the environment into a fiscal and legal nightmare. The thesis of this paper can be summarized, thusly, communication is the key to mitigation of delays and skyrocketing costs associated with hazardous waste management.

Discussion will be presented in three parts:

1. A theory of communication

2. The human environment

---

a. The term, the Babel syndrome, is defined here as "the inability of individuals and groups to work together cooperatively because of communication dysfunction."

3. Some suggestions for rethinking communication strategies.

While the Babel syndrome basically defines communication failures, it can be used to develop new ways of communicating with the concerned public.

A THEORY OF COMMUNICATION

Communication is defined as "a process by which information is exchanged between individuals through a common system of symbols, signs, or behavior; a technique for expressing ideas effectively" (Webster's New Collegiate Dictionary). Webster's definition is modified to reflect the negative influence of the Babel syndrome in the following three propositions:

1. There is no true "common system of symbols" that is shared among the scientific/professional disciplines and the lay public

2. All messages are altered

3. No communication occurs without a profound knowledge of the audience.

These three propositions will be explored in the discussion on the growth of technical languages that have evolved around disciplines to compromise the "common system of symbols," described as "one language and a few words" in the Bible. The many breaks in the information flow between the transmitter and the receiver can also be attributed to the Babel syndrome.

Technical and Professional Languages: Deliberate Destruction of a Common System of Symbols

There is ample anthropological evidence that isolated locations develop a unique language. As societies evolve into complex social structures, within the major language, the lingua franca, practitioners of specialized functions also develop their own in-group language, partly because it facilitates communication within the group, but partly to exclude nonmembers. In the preindustrial period, when society was stratified into classes, profession/trade-specific language was acceptable because there was little or no necessity to communicate technical information across classes. Common activities, such as marketplace transactions, were communicated through the lingua franca of the nation or region. Over time, professions and trades also developed common cultural and value systems that further enhanced their "oneness" and supported the exclusiveness of their technical language. Undoubtedly, the closed culture of these groups added to their preservation and perpetuation to modern times.

Ironically, the discoveries that catapulted scientists and technologists to new heights of power and prestige during the industrial age have become their downfall in the postindustrial society. Scientists and technologists no longer enjoy their former stature as creators of the artifacts that fueled the industrial revolution and modernization of society. Their fall from grace since the 1960s was partly brought on by the failure of fail-safe systems, the rising level of education among the general public, and the advent of electronic data transmission that allows instantaneous global telecommunication. The manipulation of the environment with principles of science and technology for the mass production of goods was not mysterious and magical to an educated public. But it was the necessity for explaining the impact of environmental pollution and natural resource exploitation to the lay public that set the stage for the need for cross-functional communication and for risk and risk-related communication to come into its own.

As the artifacts of technology and science permeated society and as natural resources were depleted at ever increasing rates, government in its role as trustee to ensure the safety and well-being of the people and the environment has assumed new regulatory roles in the use and management of both manmade artifacts and natural resources. Many scientists left laboratories and academia to work for regulatory agencies. While it seemed to be an efficient solution to the need for scientific information, the strong tradition-bound biases that are socialized in the training of scientists are incompatible with the public outreach/education responsibilities

of regulatory agencies. The positivistic orientation of traditional scientific training does not include an understanding of the seemingly random behavior (often described as irrational) of the lay public. Without this understanding, it is impossible for scientists to communicate with the public. Moreover, to compound communication dysfunction, in addition to the language barriers erected by the language of science, the agencies have also developed their own in-group bureaucratic behavior, first described by Max Weber and by hundreds of writers subsequently, and a legalistic language as an outgrowth of their regulatory function.

Unlike the class-partitioned, preindustrial societies, today's technology-driven society requires scientific and technical information to understand the many regulatory rules that are being promulgated and more so when the rules attempt to control risks. The communication barriers that have been erected between the agencies and the public are caused by the inability of the agencies to communicate both the risks and societal need for a product or a facility. This paradox was also noted by Krimsky and Plough (1988) in their case studies of risk-related communication. Strange as it may seem, the public appears to make no distinction in their reaction to the level of risk of the location of a nuclear waste storage site and the reduction in the level of treatment of the city's sewage. Public protest has been just as loud and vociferous for the one as for the other. What this behavior illustrates is the insignificance of scientific data on projections of morbidity, for example, as a decision criterion for the lay public.

The persistent use of scientific and technical jargon by scientists and technologists to present inappropriate information has contributed much to misunderstanding and mistrust and little to the public's peace of mind and their willingness to cooperate with government, in general, and regulatory agencies in particular. Engineered systems and genetic manipulations are seen as objects of suspicion instead of benefits to society. Reflecting the trend that questions government authority, few, today, accept the "miracles of science" without question (English, 1992).

One of the reasons for continuing to transmit inappropriate information may well be the lack of understanding of the communication process. A typical communication effort by a government agency, say an agency attempting to locate a hazardous waste disposal site, would be to provide scientific and technical data to the residents in the surrounding neighborhoods at an informational meeting. The information might include geologic, hydrographic, and soil data as well as engineering protocols and the chemical composition of the waste. The question that needs to be asked is, will this information satisfy the public's information needs? The litmus test for the adequacy of the information provided will be evident in the concurrence or opposition of the residents to the proposed disposal site. I would not be optimistic that there would be overwhelming support for the proposed siting project based on the scientific and technical information given to the residents in the above example.

What can be counted on is the following scenario. There will be one or more challenges on the reliability and the methods used to acquire the data. In addition, the people will demand nothing less than zero risk and they will not be bashful about questioning the honesty and integrity of the agency and its representatives. There will also be questions raised on the reduction of their property value and quality of life. Environmental organizations could add fuel to the controversy by quoting data that do not coincide with those presented by the agency. There is now a polarization and the accusations have become emotional. It is not too long after this stage that a lawsuit is filed and the dispute put into the hands of attorneys and the courts.

If not this, what options are there? Can this scenario be changed? I believe that it can, but it will not be easy because of bureaucratic reliance on current standard operating procedures and the public, once polarized, can be intractable. To truly address the issues, government agencies need to change their procedures to include the affected publics early in the planning stage. Regulatory agencies also need to include new procedures and personnel who are capable of analyzing the communications process and developing appropriate risk communication procedures.

A Heuristic Model of the Communication Process

A heuristic model of the communication process can be used to explain the all too common scenario described above. A schematic of an electromagnetic engine is a simple and useful model for explaining the

process of communication (Figure 1). The model is a modification of models used in cybernetics, the mechanical modelling of the brain (Ashby, 1976). The two principal components are the transmitter, which sends the message, and the receiver, which receives the message. The regulator functions as the filter that determines which messages, if any, reach the receiver. Although the communication channel is shown as a straight line, communication is anything but linear. Two influences illustrate the nonlinear nature of communication. These are the attenuator and the amplifier that can be activated by external or internal (within the receiver) stimuli. Messages can be amplified or attenuated either by external events or by the presence or absence of the receiver's negative or positive physical and emotional/mental state.

Though simplified, the model can explain how anthropogenic control processes operate. For example, the transmitter in the hazardous waste disposal site scenario is the environmental agency which has made a scientific and technical presentation covering the stability of the proposed site, benign nature of the waste, etc. If, coincidentally, say, there was a recent media report on administrative wrong-doing in any governmental agency, this information could act as a negative enhancer that will tune out or impede message transmittal. The influence of "guilt by association" phenomenon should not be minimized.

The public's perception may be further be skewed negatively by additional negative messages transmitted by other stakeholders, such as environmental groups. These negative messages that target the public are usually well-orchestrated and developed by activists who know how to hit a sensitive nerve. Within this negatively charged context, the agency's message is shut out by the receiver's "regulator" because whether a message is rejected or accepted is dependent on how well it coincides with the filters that influence the receiver's perception. A message could be rejected without any evaluation of its content if an individual's communication system is "wired" to reject messages from a source. This short-circuit can only be remedied by reestablishing new channels that penetrate the receiver's filter/value system.

THE HUMAN ENVIRONMENT: STAKEHOLDERS AND THEIR VALUE SYSTEM

Who are the public stakeholders in environmental issues? Their composition changes with specific issues. But generally, in issues related to siting of a public facility, the "public" tends to be residents who own real estate around the perimeter of the site in question and special interest groups that may be an ad-hoc coalition or national or international organizations, such as the Sierra Club. Intensity of interest of the resident stakeholders generally diminishes with distance from the site (Figure 2).

In the issues related to the City and County of Honolulu's request for a 301(h) waiver (Clean Water Act) to downgrade sewage treatment in Hawaii, for example, the residents of Kailua and Honolulu, two districts within the City and County of Honolulu, who were battling the city and county government over the same issue, did not join forces in protesting the downgrading, even though they are only about 30 miles apart. There was a common link, however, in the involvement of the Sierra Club and Hawaii's Thousand Friends at the two sites. The Yucca Mountain (Nevada) radioactive storage site issue was looked upon with interest nationally, but no sustained national protest was generated. These and other examples indicate that when the issue is site-specific, the protest activity is generally localized. Risks that generate protests transcending local boundaries tend to be those related to products that are marketed nationally or pollutants that cross local boundaries.

A Profile of the Activist-Public

For the most part, then, the "public" is composed of individuals who are residents of a finite area. A profile of community activists, defined as those who participate in environmental cleanup activities, was developed as part of a 1990 study on the effectiveness of public service announcements (PSAs) as a public education tool (Pfund, In Preparation). A total of 111 individuals participated in 15 focus groups statewide in the pretest and 833 responded to the statewide mail survey posttest. The survey respondents, which included the focus group participants as a subset of the sample, exhibited the composite characteristics shown in Table 1.

The fit of the distribution of the sample to the state's population was significant at $p=.05$. However, the nature of environmental issues is such that self-selection bias cannot be completely ruled out even though the

Table 1. Profile of community activists.

Age	30 to 50 years
Years of residence	20 years to life
Education	College
Gender	Both male and female
Community activities	Participates 1 to 3 times a year

distribution was statistically significant. The demographics of this segment of society is useful because of the high numbers who indicated participation in such activities as litter cleanup programs.

The willingness of this segment of the population to participate in litter cleanup is strongly indicative of its high interest in the preservation of environmental esthetics. Furthermore, their high education level suggests middle to upper-middle income. Their comfortable economic status is clear indication that this population is not preoccupied with the necessity for securing physical and safety needs.

According to Maslow (1965), an individual can be psychologically reachable for higher level activities, such as social activism, only after his/her survival needs are satisfied. Therefore, a social activist will have to be at the fifth and highest level of Maslow's hierarchy. A high education level can be an index of higher household income as well as a shadow indicator of readiness for involvement in higher-level activities beyond those that satisfy physical needs. The profile of the survey respondents, using age, education, and stability of their community, as exemplified by length of residence, places them at level 5.

An openness-closedness matrix based on two socio-psychological attributes, rigidity and dogmatism, can be used to define the value system of nonscientific/technical individuals who are stakeholders in a specific issue area. The results of a study of fishermen, who are neither scientists nor bureaucrats, provides some general insights into the decisionmaking and problem-solving style of lay stakeholders. The study found that the fishermen's high scores on the two attributes, rigidity and dogmatism, put them at the closed end of the openness-closedness continuum on their ability to use new information for decisionmaking (Pfund, 1984). This indicates that lay stakeholders have strongly held values that preclude the acceptance and use of new information that require changes in their behavior. What this boils down to is that lay stakeholders make decisions based on the internal logic of their held values that serve as filters.

What are these values? For activists in the profile given in Table 1, a significant criterion is the maintenance of the quality and way of life as they are living it. Their willingness to participate in community cleanup is indicative of their interest in preserving their environment. Stability is also important to this segment of society because they are likely to own their homes. Hence, these stakeholders have a dual interest that must be addressed: environmental esthetics and economics as reflected in the value of their homes. Maintenance of property values will be a high priority and the most important information would be answers to the question, will the value of my home drop? How will the proposed project enhance or undermine my long-term and short-term economic well-being? But a key clue to addressing this question is the generally closed nature of lay stakeholders. When coupled with a high level of stability evident in the long residence in a given community, the chances of getting the community to accept change may be nil.

No matter how the question may be phrased, the real question that is being asked is, how will this project change life as I now know it? One of the more important characteristic of people who have lived a comfortable and predictable lifestyle for many years is the reluctance to change their behavior. When threatened, the manifestation of this characteristic could range from anger to fear, emotions that can be easily manipulated by a third party.

RETHINKING COMMUNICATION STRATEGIES: TOWARD A VALUE-ORIENTED APPROACH

The communication issues that are faced in such activities as the siting of a low-level radioactive disposal facility, can be summarized in a phrase, "mismatched values." Most public administrators in environmental and natural resource regulatory agencies have scientific training. As such, they have been trained to use value-free, rational approaches. It is doubtful that many environmental administrators have had any formal training in either market analysis, including decisionmaking processes, or use of mass media for public education. But this type of training is exactly what is needed for developing risk communication processes and messages to reach the public.

As indicated earlier, the target for environmental messages should be the educated middle class if educating community leaders is the goal. A study on the impact of public service announcements (PSAs) revealed that this group can be reached by the mass media (Pfund, in preparation). The study also found that newspapers, as the preferred source of information, was only 2% below television, 72 and 74%, respectively (Pfund, in preparation). Considering the education level of this strata of society, high readership of newspapers should not be surprising. Radio was listed as a preferred medium by nearly 66 percent of the respondents. In addition, the study showed a gender difference in preferred sources of information. Females indicated that they preferred nonauthoritative figures like entertainers and males preferred authority figures like community leaders.

Communicating with Community Activists: A Framework

A communication framework can be developed by using the schematic given in Figure 1. The hazardous waste disposal site scenario is used for developing the public education/outreach program.

Message

The message from the environmental agency: a proposal to locate a hazardous waste disposal site at the outskirts of this community. Assumption: site selection and disposal method based on scientific analysis of meteorological and geological data and proven technology, etc.; careful analysis of economic and esthetic impacts is needed; visibility of a proposed site is a progressive negative factor, increasing negativism in direct relationship with proximity to the site; an important consideration is that the residents' homes predate the disposal site—they did not chose to live near a disposal site.

Transmitter

Environmental agency and/or positive surrogate communicator for mass media messages: popular local female entertainer to target women and male community leader to target men; local newspaper to obtain news coverage to augment purchased ad space or broadcast time.

Receiver

Characteristics of the community, including their held values, must be clearly understood; small group process is the best way to obtain socio-economic information and insight into the held values of residents closest to the disposal site; radio, television, and newspaper are useful for disseminating general information; targeting educated long-time home owners closest to disposal site is very important and must be done in small group sessions or by identifying key opinion leaders.

Amplifier

Positive. If there is the slightest chance that the disposal site will impact property values, there will need to be serious consideration given to developing of perquisites, such as a buffer zone/green space next to the disposal site, as part of the project, and other amenities that add to property value. This is not a novel idea. Private sector developers are well aware of the value of this type of tradeoffs. Also pluses to property

values are good schools; well maintained school buildings and excellent programs; community centers and recreational amenities. Small group (focus group) sessions with community leaders are very important. These sessions can serve as a two-way communication channel that can be used to provide information to participants in a nonthreatening forum. Worst case: Property swaps or purchase (voluntary or condemnation). However, even this avenue will be closed if the community is polarized. Mitigation: Do homework—get demographic data; establish resident concerns/values through small groups or one-on-one interview.

Negative. Negative feelings will be amplified by rushing the process of interacting with the community leaders—this will be a long process (but so is a court battle); refusing to listen to community desires and questions; holding meetings when residents are at work; mitigation: get demographic data; establish resident concerns/values.

Attenuator

Positive. Negative influence of special interest groups will be the strongest attenuator; mitigation: specific individuals who are leaders of such groups should be a special target to develop consensus on issues.

Negative. Environmental groups which have access to national funds and professional resources like lawyers can jeopardize the interaction process, particularly if the residents do not trust agency officials; the politician or community activist who is grandstanding for personal reasons; mitigation: can be short-circuited by other community leaders—agency administrators would be ineffective.

Regulator

The held values of the community must be clearly understood. Small group focus sessions using a disinterested moderator would be an effective way to obtain information about the community's feelings on environmental issues; small group meetings need to be held very early in the project; target groups: local chamber of commerce, church groups, local chapter of the League of Women Voters, community associations, Parent-Teacher Associations (PTAs), service organizations, e.g., Lions Club, Rotary, Kiwanis, etc.; identify opinion leaders who may serve as the community's "regulator" or information screen.

CONCLUSION: SOME THOUGHTS

Regulatory agencies more often than not find that communicating with the public is difficult at best because they are suspect without uttering a single word. The necessity for couching technical information in lay terms adds to the difficulty. It is my contention that communication dysfunction is caused by sending messages that have no receivers or which trigger unintended reaction. It is important that the information be "appropriate" and make sense from the receiver's viewpoint and not that of the transmitter. The notion that communication is merely an act of transmitting sounds and images needs to be changed. If it is to be meaningful, the message needs to make sense within the context of the held values of the receiver.

One of the messages of this paper is, regulatory agencies need to do a careful study to understand a community's values as well as its fears and biases before any effort is made to "communicate" with the people. Without this information, there will be a communication glitches because the message will either be ignored or inflame the community. Community values can be determined indirectly through analysis of noninteractive means, such as census data, if survey research is not possible.

The second message is that scientists, technologists, and bureaucrats must understand that their advanced educational degrees and knowledge do not automatically make them good communicators. As the saying goes, a Ph.D. degree and a dollar will get you a cup of coffee. What is "appropriate" from a scientific viewpoint may be gibberish to lay persons. Even though the intent was to allay their fears, the message can have the opposite effect because it can trigger unintended reactions.

The third message is that regulatory bureaucracies need to rethink their priorities. The importance of meaningful communication has yet to really reach the core of most public organizations. It is clear that

developing scientific information is important. What is not clear is why there is not an equal emphasis given to understanding the people who must be educated about the science and technology of a proposed project that involves them and their space. It may not be an exaggeration to note that there is probably greater understanding of wildlife and their habitat than humans and theirs by most governmental agencies.

In the final analysis, while it may come as a shock to Ph.D.s and bureaucrats, like Rodney Dangerfield, they get no respect. It has to be earned. The bottom line is that without something approximating the biblical "one language"—a common basis for open communication—which must now include technical and scientific terms, we will continue to suffer the curse of the Babel syndrome. Under current economic conditions, we cannot continue to expend more public funds in transaction costs than in environmental mitigation and allow public anger and frustration to be vented through demonstrations that can cost million of dollars in project delays. We are at a stage where communication strategy must be as carefully planned as the proposed technology or project. Without credible communication, it will not be possible to win the trust of the public that is necessary to develop waste management programs.

REFERENCES

Ashby, W. Ross, 1976, *An Introduction to Cybernetics*, London: William Clowes & Sons, Limited.

Dauer, Christopher, 1992, "Pollution Claims in Legal Quagmire," *National Underwriter*, August 31, 1992, p. 3.

English, Mary R., 1992, *Siting Low-level Radioactive Waste Disposal Facilities: The Public Policy Dilemma*, Quorum Books.

Gilbert, Evelyn, 1991, "Experts Clash on Superfund Reform," *National Underwriter*, October 28, 1991, pp. 3, 8, 42.

Krimsky, Sheldon and Alonzo Plough, 1988, *Environmental Hazards*, Dover, Massachusetts: Auburn House Publishing Co.

Pfund, Rose T., (In Preparation). "Impact of Public Service Announcements as a Medium for Transmitting Environmental Information." University of Hawaii Sea Grant College Program, Honolulu.

ACKNOWLEDGEMENT

The research upon which this paper is based was supported by funding provided by the University of Hawaii Sea Grant College Program under NOAA Grant no. NA89AA-D-SG063. This is Publications no. UNIH-SEAGRANT-CP-93-02.

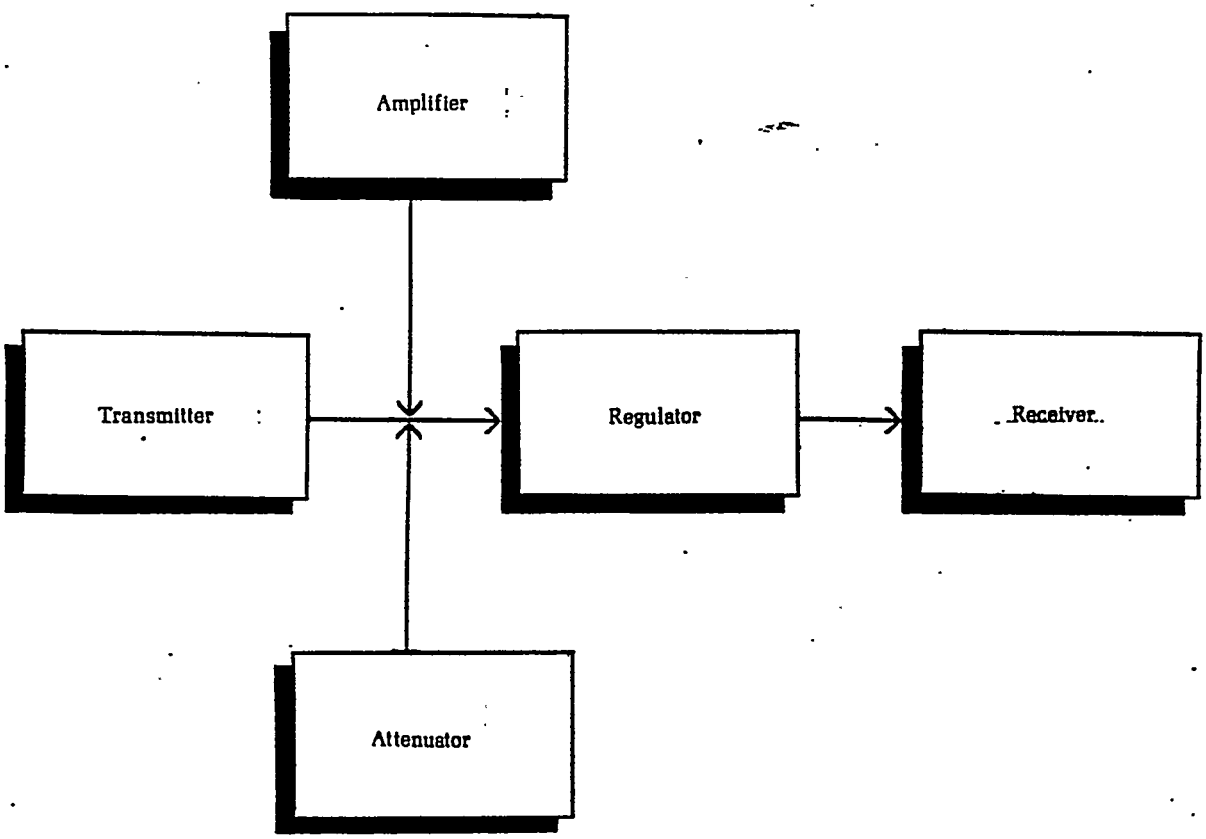


Figure 1. Schematic of the communication process

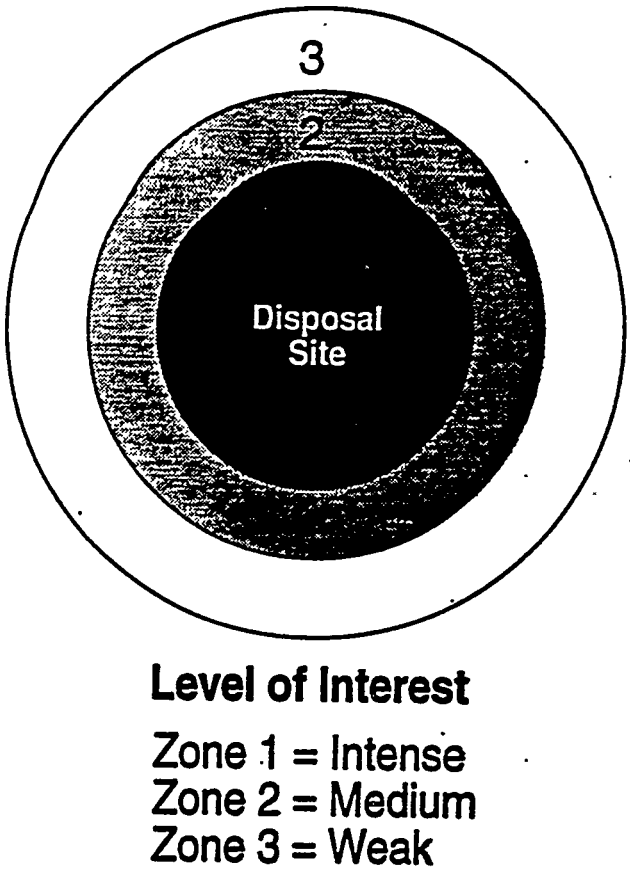


Figure 2. Zones of interest intensity

DOE Acceptance of Commercial Mixed Waste— Studies Are Under Way

Terry L. Plummer
Manager, National LLW/GTCC Program
Technical Support Program
U. S. Department of Energy

Colleen M. Owens
National Low-Level Waste Management Program
Idaho National Engineering Laboratory
Idaho Falls, ID 83415

The topic of the Department of Energy acceptance of commercial mixed waste at DOE facilities has been proposed by host States and compact regions that are developing low-level radioactive waste disposal facilities. States support the idea of DOE accepting commercial mixed waste because (a) very little commercial mixed waste is generated compared to generation by DOE facilities (Department of Energy--26,300 cubic meters annually vs. commercial--3400 cubic meters annually), (b) estimated costs for commercial disposal are estimated to be $15,000 to $40,000 per cubic foot, (c) once treatment capability becomes available, 70% of the current levels of commercial mixed waste will be eliminated, (4) some State laws prohibit the development of mixed waste disposal facilities in their States, (5) DOE is developing a nationwide strategy that will include treatment and disposal capacity for its own mixed waste and the incremental burden on the DOE facilities would be minuscule, and (6) no States are developing mixed waste disposal facilities.

DOE senior management has repeatedly expressed willingness to consider investigating the feasibility of DOE accepting commercial mixed waste. In January 1991, Leo Duffy of the Department of Energy met with members of the Low-Level Radioactive Waste Forum, which led to an agreement to explore such an arrangement. He has stated that this seems like a cost-effective way to solve commercial mixed waste management problems.

Also in 1991, the Nuclear Regulatory Commission sent a letter to the Department of Energy Secretary, Admiral James Watkins, stating, "NRC is ready to support any effort to resolve the mixed waste issue that is consistent with our responsibility to protect the public health and safety and the environment. NRC would like to believe that through the joint efforts of NRC, DOE, EPA, the States, and the regulated community, the increasingly urgent problems surrounding mixed waste management and disposal can be successfully resolved."

Several similarities exist between DOE facilities and commercial industries regarding the problem of mixed waste. Treatment technologies are not able to treat all types of mixed waste streams, no disposal capacity exists, communities oppose developing new treatment and disposal capacity, and treatment and disposal costs may be significant. DOE and the States recognize that mixed waste must be treated and disposed of in only a few States. It is recognized that if a national strategy for mixed waste is to be successful, the treatment and disposal facilities must be distributed in an equitable manner across the country.

A significant effort is already under way to develop information to facilitate a decision on whether it is feasible for DOE to accept commercial mixed waste. A strategy was initiated and developed and presented to upper DOE management.

DOE conducted a meeting in July to identify mixed waste policy issues and analyze commercial treatment capabilities, determining that (a) treatment capabilities must be analyzed on a "by waste stream" basis, (b) commercial mixed waste treatment may become available before DOE develops such capability, (c) private sector treatment is being encouraged by DOE, and (d) 70% of commercial mixed waste is presently treatable.

A preliminary study was conducted to analyze whether commercial mixed waste streams can be included in the DOE treatability groups. It was determined that at least 80% of the commercial mixed waste streams can be included in the DOE treatability groups. DOE and commercial problematic mixed waste streams are related.

Other studies under way to:

- Analyze the legality of DOE accepting commercial mixed waste. Does DOE have authority to assume responsibility for commercial mixed waste?

- Study the regulatory and liability issues associated with DOE accepting commercial mixed waste. Do commercial generators still have responsibility for the hazardous portion of the mixed waste after being accepted at DOE facilities? Must national legislation be drafted or amended for commercial mixed waste to be managed by the Department of Energy?

- Determine the need for the National Environmental Policy Act (NEPA) process. Will DOE acceptance of commercial mixed waste require a separate Environmental Impact Statement, or will it be able to be included in the Programmatic Environmental Impact Statement?

- Develop a frame work identifying all known policy issues to ensure that all interested parties have adequate input into the process. Over 50 individual issues have been identified that are related to DOE acceptance of commercial mixed waste

- Assess the capabilities and compatibility of any existing or planned commercial treatment or storage facilities.

- Analyze commercial mixed waste streams for compatibility with the DOE mixed waste streams. Some mixed waste generated commercially may not be compatible with DOE mixed waste streams. Another consideration for waste acceptance is the status of the waste matrix. If waste has not been fully characterized before compaction or solidification, it may be excluded from acceptance criteria at DOE facilities.

By early 1993, the above studies will be complete and DOE management will decide whether to proceed. Questions that will need to be answered are: Is it feasible? What are the potential risks, liabilities, benefits? If DOE decides to proceed, DOE will develop negotiating positions for terms and conditions of cooperation with States and compacts.

Other considerations will involve DOE's own strategy for managing its own mixed waste. How will commercial mixed waste be incorporated into this planning?

If DOE management approves the terms and conditions, negotiations will be initiated; if negotiations are successful, DOE will accept commercially generated mixed waste for management.

1993: Where is the Low-Level Waste Going?

Sherol Bremen, M.R.P., Ted Buckner, J.D. and Kathryn Visocki, M.P.H.
Southeast Compact Commission
Raleigh, NC 27603

This paper explores the near future of low-level radioactive waste disposal—November 1992 through June 30, 1994—in the context of historical developments as well as plans for the distant future when a new generation of regional disposal sites is expected to be in operation.

THE LOW-LEVEL RADIOACTIVE WASTE PLAN AS ENVISIONED BY CONGRESS

When the United States Congress enacted the Low-Level Radioactive Waste Policy Act (LLWPA) in 1980, it envisioned that a new regionalized system of disposal sites would be operating by 1986. This would enable the existing three national facilities to close down or exercise their congressionally granted authority to restrict use of their sites to in-region use only. By 1985, it was clear that the new generation of sites would not be ready by 1986, so Congress extended the deadline to December 31, 1992, allowing other regions access to the existing facilities for seven more years.

As we approach the December 31, 1992, deadline, there are still no new disposal facilities in operation. Time is running out and the compacts and regions with existing facilities are preparing to exercise the authority granted to them by Congress beginning January 1, 1993. The facility in Beatty, Nevada, will close on December 31, 1992. The facility in Hanford, Washington, will only accept waste from states within the Northwest Compact and the Rocky Mountain Compact. Although South Carolina has authority from Congress to shut its facility down entirely, access to the facility in Barnwell, South Carolina, will be allowed for a limited period with restrictions (we will say more about this later).

What happened to Congress's great vision? Where is the New Generation of Sites? While great progress has been made in implementing the plan set out by Congress, we are still probably at least five years away from having a new system of regional disposal sites to serve most of the nation, and it will probably be ten years beyond that before the system serves the entire nation.

As shown in Exhibit A, according to current siting schedules, new facilities are scheduled to be open in California, Nebraska, Texas, and North Carolina by 1996. Together with the facility that will continue to operate in Hanford, Washington, these sites will serve five regional compacts including 29 states, and representing approximately 46% of the nation's waste.[a]

Exhibit B shows the number of facilities that should be open by 2006. During this second stage of development, facilities are scheduled in Pennsylvania, New York, Ohio, Connecticut, New Jersey, Vermont, Massachusetts, and Maine to serve 10 states. This brings the total number of states served to 45, representing approximately 92% of the nation's waste.[b] Thus, by 2006, the vast majority of states and the vast majority of waste would be served.

THE NEW GENERATION OF SITES: GETTING THERE

The LLWPA served as a helpful guide for site development activities by providing milestones by which to measure siting progress through 1992. However, because Congress envisioned that the implementation of the regional compact system would be complete by then, they provided little legislative guidance as to how to proceed during the interim period between 1992 and the opening of the next generation of sites.

---

a. "Distribution of NRC Documents to the States Concerning the Low-Level Radioactive Waste Policy Amendments Act of 1985" (Public Law 99-240), September 1, 1992, USNRC, Washington, D.C.

b. Ibid.

In the Summer of 1991, the Southeast region began plans to cope with a period of three or more years when no disposal facility would be available. In October 1991, the Southeast Compact Commission publicly requested South Carolina Governor Carroll Campbell, in the interest of public health and safety, to keep the Barnwell site open as a regional facility until the North Carolina facility was up and operating. But feeling strongly that the decision was a South Carolina issue, the Commission made a deliberate decision to stay out of the political process that unfolded during the 1992 legislative session.

Under South Carolina law, the Southeast Compact's regional disposal facility in Barnwell, South Carolina, was scheduled to close on December 31, 1992. Only the South Carolina General Assembly had the power to authorize an extension of the closure date. Development of the Southeast Compact's second regional facility in North Carolina was several years behind schedule and not expected to open until 1996. In late 1991 Governor Carroll A. Campbell, Jr. of South Carolina indicated his support for keeping the facility in Barnwell open. His recommendation to the South Carolina Budget and Control Board for FY 1992-1993 proposed raising millions of dollars in additional revenues for the state by increasing the surcharges on wastes from both inside and outside the region disposed at the facility after 1992.

During the ensuing months, Governor Campbell and Governor James G. Martin of North Carolina worked together to develop a proposal that would allow Barnwell to remain open. They negotiated a plan which would provide for compensation to South Carolina for assuming a greater burden of low-level radioactive waste disposal and incentives for the timely completion of the next regional facility in North Carolina. In February 1992 the Southeast Compact Commission adopted a motion incorporating the proposal of the two governors. However, the final decision to extend operations at Barnwell rested with the state legislature.

Success in implementing the governors' proposal was thus not guaranteed. Many in the General Assembly believed that South Carolina had done more than its fair share by providing a disposal facility for the region and the nation since 1971 and should no longer bear that burden. There was strong sentiment across the state for getting South Carolina out of the LLRW disposal business.

Many South Carolinians believe that North Carolina is dragging its feet in siting the next LLW disposal facility and they are skeptical that North Carolina will ever open a disposal facility for the region. This skepticism is increased by North Carolina's failure in 1990 to fulfill its part of a regional agreement for the management of hazardous waste. The skeptics maintain that continued access to the Barnwell facility will only serve to ease the pressure on North Carolina and cause them to slow down the development of their facility.

Tempers have always run hot on this issue in the General Assembly, and the 1992 session was no exception. Although legislators from Barnwell and its surrounding counties continued to be supportive of the extended operation of the disposal facility, these legislators have limited power in the state. Robert J. Sheheen, the powerful Speaker of the House, and other legislators, especially those representing districts across the border from one of the proposed sites in North Carolina, were adamant in their opposition to keeping the facility open. Several of the bills which emerged during the 1992 legislative session authorizing continued operation of the facility were defeated by narrow margins on the floor of the House.

Finally, on the last day of the legislative session, the General Assembly voted to accept an appropriations bill for fiscal year 1992-1993, which included a provision to allow the Barnwell facility to continue to serve as the disposal facility for the Southeast Compact until January 1, 1996, under specific conditions.

While the legislation deals primarily with the continued operation of Barnwell as the regional disposal facility, it authorizes the facility to remain open to out-of-region waste subject to the approval of the Southeast Compact Commission. The General Assembly also required that any agreements to accept out-of-region waste must provide for a fee of at least $160 per cubic foot to go to South Carolina. The anticipated revenue flow to South Carolina's treasury from this fee was critical to building support in the General Assembly for continued operation of the facility.

The General Assembly took two actions to ensure that South Carolina would not remain in the waste disposal business indefinitely. First, they limited the importation of out-of-region waste to the 18-month period January 1, 1993, through June 30, 1994. Under the bill, the General Assembly must specifically authorize the importation of out-of-region waste after July 1, 1994. Second, the General Assembly designated that the funds collected at the Barnwell facility be used specifically for nonrecurring expenditures, such as the payment of the debt from rebuilding after Hurricane Hugo, to ensure that the state would not become dependent upon the fees to pay for annual budget expenditures.

South Carolina's General Assembly may have been influenced by North Carolina's failure to act in the hazardous waste arena when it placed additional restrictions on the continued operation of Barnwell. A provision added to the final version of the legislation calls for the immediate closure of Barnwell to waste generated outside South Carolina if North Carolina issues a permit for either a hazardous or solid waste facility at a site located within one mile of the border of a neighboring state. Most likely this provision is aimed at a specific solid waste facility being considered directly across the border near Charlotte, North Carolina.

In addition to the hazardous or solid waste facility siting provision, the bill contains a number of other provisions that could trigger the closure of the facility to both regional and out-of-region generators. To ensure that North Carolina proceeds with the development of the next regional facility, the South Carolina General Assembly established two milestones that must be met by North Carolina, those being December 31, 1993, for submitting a license application and March 15, 1995, for approval of the license application. If either of the milestones is not met, the Barnwell site will close one year from the milestone date that was missed.

The General Assembly included a "good neighbor" provision designed to deter North Carolina from selecting the potential site in Richmond County, North Carolina, that is within ten miles of South Carolina. If North Carolina fails to exclude that site by December 31, 1993, or if North Carolina selects a site where it "will pose a threat to human health, the environment, or water resources in contiguous states," the facility will close immediately to waste generated in North Carolina and will close to waste generated outside South Carolina on June 30, 1994.

The final closure provision requires the facility to close to waste generated in North Carolina immediately and from outside South Carolina on July 1, 1994, if the continued use of the facility after December 31, 1992, is declared by the courts to be in violation of, or inconsistent with the compact law.

The bottom line in the South Carolina legislation was that the Barnwell facility would continue to operate as a regional facility for the Southeast Compact until 1996. Out-of-region wastes could continue to be accepted for at least the first 18 months, as long as the Southeast Compact Commission agreed.

Factors Influencing Import Policy

Thus the Southeast Compact Commision was faced with the difficult decision of whether to allow import into the region, and if so, to whom and under what conditions. The Commission found itself quite unprepared for this task, as it was not at all certain that South Carolina would elect to keep the facility open for out-of-region waste. Because no state or compact has had the power to exclude waste before 1993, there was no model to follow in this decisionmaking process. No one has ever done this before. After December 31, 1992, the LLWPA allows compacts to exclude out-of-region LLW from their disposal sites. In fact, the Northwest and Rocky Mountain compacts had publicly announced their decisions to exercise that right. In the years between 1985 and 1992, the LLWPA system of milestones and penalties served as incentives for states and compacts to develop their own LLRW management facilities. After 1992, however, the LLWPA provides little if any specific guidance to compacts in deciding whom to allow, or not to allow, to import waste into the region. Even the Commission was divided on its interpretation of the authority granted to the Commission by the Act. Individual commissioners ranged from liberal to conservative in their interpretation of the authority granted the Commission by the Act. Some believed it gave the Commission broad authority to override the Commerce Clause. Others viewed the Commission's authority as limited to basing decisions upon the system of existing milestones specified within the Act.

Complicating matters were two recent Supreme Court decisions related to hazardous and solid waste: Chemical Waste Management, Inc. v. Hunt, No. 91-471 and Fort Gratiot Sanitary Landfill, Inc. v. Michigan Department of Natural Resources, No. 91-636. These cases complicated the Commission's development of an import policy because of their rulings against the levying of differential fees, which conflicted directly with the differential system of penalties and surcharges authorized by the LLRWPA.

It was clear in the beginning that the Southeast Compact's Import Policy would be guided by several considerations. First, any decision to import waste into the region requires the approval of two-thirds of the Commission, including the affirmative vote of both commissioners from the host state, in this case South Carolina. The South Carolina legislature had also tagged a minimum price of $160 per cubic foot on out-of-region waste. In addition, Speaker of the House Bob Sheheen, an adamant opponent of the Barnwell facility, had indicated in no uncertain terms that he would mount an additional effort in the 1993 legislative session to close the facility if it should fall short of achieving projected revenues, which were slated at $80 million annually.

There were other factors which strongly influenced the development of the Commission's import policy. One was a strong desire on the part of several commissioners to continue to encourage development of the regional compact system. These commissioners felt this was necessary in order to follow through on the Commission's obligation to getting South Carolina out of the LLRW disposal business, and to ensure that the North Carolina facility would not be the only facility available nationally when it became operational. Other factors guiding the Commission's develop- ment of the Import Policy were a desire to be fair and reasonable, and committment to protect public health and safety, and to support the interests of the Southeast Compact.

PROVISIONS OF THE IMPORT POLICY

Progress in Site Development

On September 28, 1992, the Commission passed a Policy for Import to the Barnwell Facility for the period January 1, 1993–June 30, 1992. In deciding which states and compacts to allow to dispose at Barnwell, the Commission continued in the tradition of the sited states. Those states and compacts which had access to Barnwell by December 31, 1992, by virtue of their compliance with the milestones of the LLWPA were determined to be eligible to contract for access to Barnwell during the eighteen month period.

A United States District Court ruling on September 1, 1992, confirmed the authority of the sited states to continually monitor compliance with milestones and deny access to their disposal facilities for non-complying states.[a] This decision strengthens the Commission's use of progress in site development as a basis for determining whether to allow continued access to the Regional Facility.

Deciding that it was important to send a clear message about the importance of continued progress, the Commission included an "overt action" provision in its policy. This provision specifies that the Commission "may terminate access to the Regional Facility if it determines that an overt action has been taken by a compact region, designated host state within a compact region, or unaffiliated state which the Commission determines substantially impedes the state or region's progress in fulfilling its responsibilities for providing, either by itself or in cooperation with other states, for the disposal of its low-level radioactive waste."

The Import Policy also requires compacts and unaffiliated states to provide periodic reports on their progress in site development. These reports are to be evaluated by the Import Policy Committee of the Commission, which will make recommendations to the Commission as to whether access should be continued or denied.

---

a. The Rocky Mountain Low-Level Radioactive Waste Board v. U.S. Ecology, the State of Michigan, the State of Nevada, United States District Court, District of Nevada, September 1, 1992.

Compensation

It was clear from South Carolina's passage of legislation extending Barnwell operations that out-of-region access to Barnwell during the import period would not be cheap. South Carolina's requirement that it receive at least $160 per cubic foot served to push the price of access way above the going rate of $40 to $120 most generators were paying in surcharges.[a] After considering its own revenue needs, the Southeast Compact Commission determined that another $60 per cubic foot was required, thus bringing the total access fee rate to $220 per cubic foot.

The Commission felt that the $220 access fee rate was reasonable, particularly when compared with Nuclear Regulatory Commission estimates for disposal costs at the next generation of sites,[b] which are expected to range from $300–$500. In keeping the access fee rate in line with costs at the new sites, the Commission hopes to provide an incentive to states and compacts for continued development of new sites. It was thought that if prices at Barnwell were maintained below those of the new sites, then states and compacts might avoid developing the costly new sites.

The Commission also believes the $220 rate to be in keeping with the spirit of the LLWPA. The penalties and surcharges specified in the Act have doubled and tripled periodically between 1986 and 1992. If the existing surcharge of $40 were to double in 1993 to $80 as it has historically, then a triple penalty surcharge of $240 could be extrapolated to apply to states and compacts not in compliance with the LLRWPAA. As there are no states or compacts which will have new operating regional disposal facilities by 1993, and thus which will be in compliance with the LLWPA as of 1993, a fee of $240 could be argued to be reasonable.

The Import Policy also establishes a rather elaborate mechanism for upfront payment of access fees. Recognizing that a steady flow of revenues from the site was essential for satisfying the South Carolina legislative initiative, the Commission designed a mechanism to stabilize cash flow from Barnwell. For several reasons the revenue flow from Barnwell has historically been greatest in the last half of the calendar year. This is because, generally, there is less waste disposed in the beginning of the calendar year, and there is a time lag associated with invoicing and payment. The access fee collection mechanism adopted by the Commission is designed to alleviate problems with unstable cash flow by generating $20 million in revenue at the beginning of each calendar quarter. This arrangement requires generators to pay a total access fee, based on the volume of waste they project to dispose at Barnwell over the 18-month period. Payment of the entire access fee is required for the right to access Barnwell at any time during the import period. As a concession to generators, the Commission allowed payment of the fee to be spaced in six quarterly payments.

INDUSTRY RESPONSE TO THE IMPORT POLICY

The aspects of the Import Policy which have caused the most marked industry response have been the access fee rate, the mechanism for its collection, and the provisions relating to continued progress in site development.

The volumes projected by generators to be disposed at Barnwell over the eighteen month period are significantly less than expected. Generators indicate that they will dispose approximately 50% less than what was projected by the site operator prior to the establishment of the $220 access fee rate. Some generators have indicated that the magnitude of the access fee is sufficient for them to initiate storage, since it will eventually be required when the eighteen month import period ends. Some aspects of the mechanics of the access fee may also be encouraging generators to store, such as the upfront collection. In addition, the fear

---

a. Low-Level Radioactive Waste Policy Amendments Act of 1985, Public Law 99-240 Section 5(d)(1)(c) and (d)(2)(G)(2)(D), January 15, 1986.

b. James Kennedy, USNRC, in comments presented to SEG User's Conference, Knoxville, Tennessee, September 16-17, 1992.

that their state or compact may be denied access during the eighteen month period due to lack of progress may be causing some generators to plan for storage.

The access fee provisions of the Import Policy may have conflicting affects on the use of waste minimization or volume reduction technologies. On the one hand, the access fee rate may be of sufficient magnitude to make the increased use of available reduction technologies cost effective and feasible. On the other hand, the structure of the fee itself may serve as a disincentive for industry to pursue such technologies. Since generators must commit to paying a total access fee for a projected waste volume specified at the beginning of the eighteen month period, there is little incentive for pursuing waste reduction below the specified volume. However, many generators appear to have low-balled their volume projections, perhaps planning to increase their use of reduction technologies.

THE NEW GENERATION OF REGIONAL SITES

The unexpected period of access to Barnwell after 1992 is a welcome but temporary reprieve to out-of-region generators. It is only for a maximum period of eighteen months. It is not the long-term solution to our national problems, nor is it a pardon to states and compacts lacking their own disposal facilities.

We must not allow our attention to become diverted from the real task at hand, building a long-term solution in the form of a New Generation of Sites for the nation. We have come a long way from the days when only three states took any responsibility for the disposal of low-level radio- active waste. We have come too far to change direction now. It is time to redouble our efforts to support siting efforts in our states and compacts, to enable our politicians to have the courage and leadership to support the national site development process.

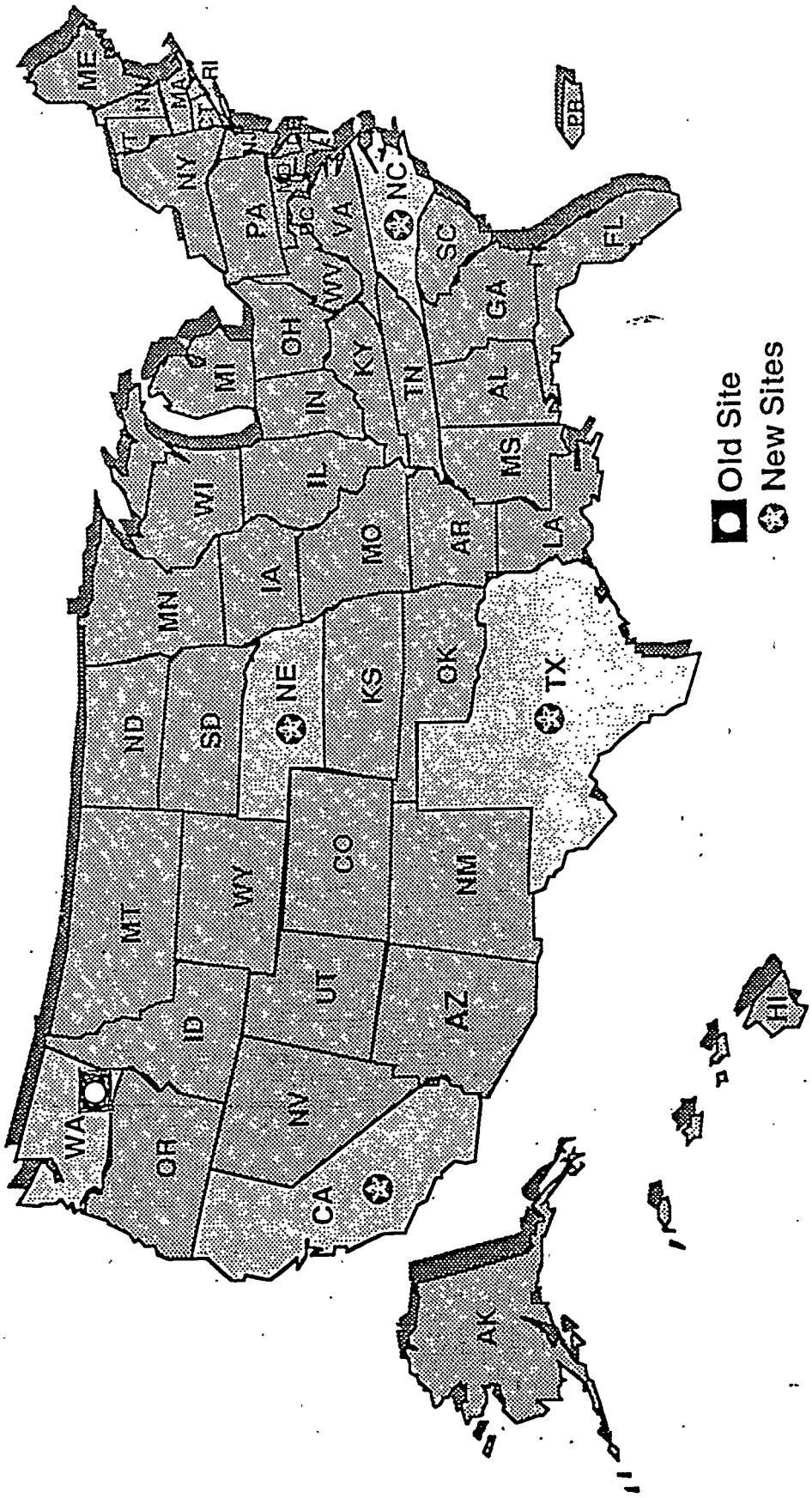


Exhibit A. The next generation of sites: stage one.

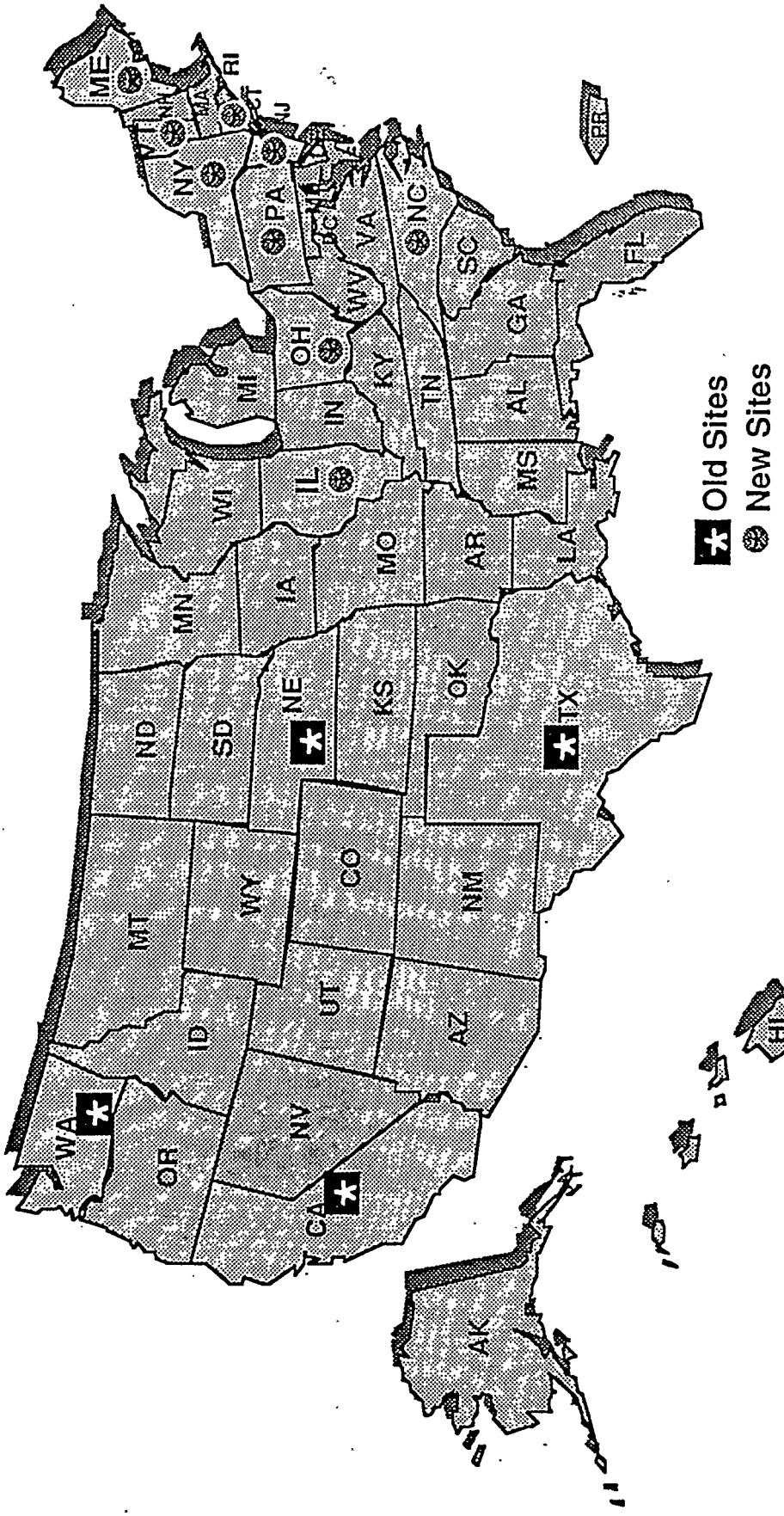


Exhibit B. The next generation of sites: stage two.

Thoughts on the Siting Process

Thomas F. Geselbracht
John Chen
Gail M. Goering
Rudnick & Wolfe
203 North La Salle St.
Chicago, IL 60601-1293

INTRODUCTION

For 71 days through the summer, fall, winter, and spring of 1991-92, the Illinois Low-Level Radioactive Waste Disposal Facility Siting Commission held a public hearing in Martinsville, Illinois, regarding a proposal to site a low-level radioactive waste disposal facility there. Although the commissioners ultimately voted to reject the site, the process of incorporating independent review and public participation established by the Siting Commission provides a key to future site approval.

THE PROBLEM: GAINING PUBLIC TRUST

Successful siting of a low-level radioactive waste disposal facility requires both technical adequacy and public acceptance. First and foremost, the site must be able to isolate radioactive waste.[1] This requirement poses scientific and engineering challenges that are beset by analytical and predictive uncertainty.[2] These uncertainties can be dispelled by reducing them to the extent possible through technical competence. The remaining doubt may be resolved by gaining public trust in the siting effort. Although there always will be opponents to any site, even a technically excellent site will fail without broad-based public support.[3] Two decades of citizen lawsuits and delays in siting other controversial facilities are testament to the importance of public acceptability.

Radioactive waste disposal presents a special challenge because of the magnitude of the scientific uncertainties involved, and because the nuclear institutions that must be the object of such trust are encumbered with the failures of the past.[4] Public opposition should not be dismissed merely as a manifestation of the NIMBY ("Not in my backyard") syndrome--a familiar cry of opponents of many socially necessary facilities. Local opposition groups are composed mainly of individuals who have a strong attachment to the land and who feel their sense of place would be violated by exposure to risks involuntarily imposed by facility siting and operation.[5] Their opposition is fueled by pervasive qualities of dread, revulsion and anger about nuclear waste--feelings that are the raw materials of stigmatization and political opposition.[6] Some

---

1. 42 U.S.C. § 2021b(7); 10 C.F.R. § 61.2.

2. Clark W. Bullard, Low level radioactive waste: Regaining Public Confidence, Energy Policy, Aug. 1992, at 712.

3. Id. at 714 (quoting B. Barber, The Logic and Limits of Trust (1983)).

4. Id. (citing M.R. English, The Siting Dilemma: Low Level Radioactive Waste Disposal in the United States (1991)); see also Flynn, et al., Time to Rethink Nuclear Water Storage, Issues in Science and Technology, Summer 1992, at 42.

5. Bullard, supra note 2, at 718.

6. Slovic, et al., Perceived Risk, Trust and the Politics of Nuclear Waste, 254 Science 1603, 1605 (Dec. 13, 1991).

have characterized the public fears and opposition to radioactive waste disposal plans as a "crisis in confidence" resulting from a profound breakdown of trust in the scientific, governmental, and industrial managers of nuclear technologies.[7] Opponents fear that socially consequential actors will fail to carry out their duties in the necessary ways.[8]

Prior approaches to siting waste disposal facilities have met with limited success. The first--trusting the scientists--leaves site selection in the hands of technicians working out of public view. The siting authority accepts the scientific conclusions, and present its decision to the public as a fait accompli. The public's fears and perceptions about nuclear issues, however, strip the technicians of their usual mantle of authority. When presented only with complex scientific data and unexplained rationales, and without an independent review of the technical conclusions, the public's fears are not dispelled, the opposition is not disarmed, and the siting process may be doomed to failure.

The second approach--requiring local government approval--also leaves site selection to the scientists, but relies on local government to win public acceptance. This approach, too, has proven problematic. In theory, governmental approval should go hand-in-glove with public approval, but in practice approval often comes from a struggling governmental body in need of the substantial economic benefits a disposal facility may provide. Compensation to a nearby town or village is intended to offset remaining public perceptions of residual risk[9] and potential stigma effects.[10] If the community is offered enough money, local officials may be induced to take the political heat generated by opponents of the site.

Even with compensation, however, the underlying public objections remain. Financial benefits may be perceived as a bribe or extortion.[11] If there is no direct referendum on the issues, or if the anticipated impact of a disposal facility extends beyond municipal borders,[12] the public may feel "sold down the river" by their locally elected officials. Without a legitimate outlet for expression of their concerns, citizen opposition--in the form of lawsuits, public demonstrations, and even threatened violence--only is strengthened in its resolve.

Many states now are trying a third approach--to bring the public formally into the siting process itself. This approach combines open, critical scrutiny of the basis for a siting decision with some form of public participation. Critical issues affecting the success of this approach are the independence and rigor of the technical review, and the extent and form of public participation. Although the different compact regions and states are revealing varying degrees of commitment to this approach, experience teaches that it alone offers the possibility of winning widespread public acceptance for low-level radioactive waste disposal facility siting.

---

7. Id. at 1606.

8. William R. Freudenburg, Risk and Recreancy: Weber, The Division of Labor and the Rationality of Risk Perceptions, Address at the American Sociological Association Annual Meeting (Aug. 24, 1991).

9. Bullard, supra note 2, at 716.

10. Flynn, supra note 4, at 47.

11. Bullard, supra note 2, at 717.

12. Id.

HOW THE STATES ADDRESS THE PROBLEM

The Low-Level Radioactive Waste Policy Act of 1980[13] established a policy that made each of the states responsible for the disposal of the low-level radioactive waste generated within their borders.[14] To carry out this responsibility, the states were authorized to enter into interstate regional compacts to provide for the siting, construction and operation of regional disposal facilities.[15] Forty-three states followed the statute's suggestion by signing agreements with other states to form nine regional compacts.[16] Each compact chose a host state[17] to develop siting procedures, to site (within the host state's boundaries) a regional disposal facility, and then to construct it. Five "go-it-alone" states chose not to join regional compacts and undertook active programs to develop their own sites.[18] The various states and compacts have established thirteen different siting procedures. Each embodies a different way to accommodate the need to gain public acceptance of the siting decision through direct public participation, independent review of the technical decision-making, or both. These procedures may be classified into four general groups.

Group I: Agency Autonomy

Three states give minimal consideration to independent review and public participation. They have created separate agencies to survey their states and propose a disposal facility site. The licensing procedures after site selection do not appear to subject the siting decision to independent scrutiny, and public participation can be quite perfunctory.

North Carolina: Southeast Interstate Compact

North Carolina's Low-Level Radioactive Waste Management Authority spearheads the siting efforts of the Southeast Compact.[19] While the Authority must provide an opportunity for "public participation" in the development of provisions and criteria for selecting a site for a low-level radioactive waste disposal facility, this involvement is advisory only.[20] After the development of siting criteria, the statute directs the Authority to identify areas of the state that may be suitable for a disposal facility,[21] and to hold "public information

---

13. 42 U.S.C. § 2021 et seq.

14. Id. § 2021c(a)(1)(A).

15. Id. § 2021d(a)(2).

16. Supko, Edison Electric Institute, Low-Level Waste Compact Status Report, § 1, at 1 (1991) (hereinafter "Compact Status Report").

17. The Northeast Interstate Compact decided to have two host states: Connecticut and New Jersey.

18. The remaining states have not made any significant progress toward a plan for dealing with their waste after December 31, 1992. The host states of Washington (Northwest Compact) and Nevada (Rocky Mountain Compact) have not had to deal with siting, because disposal facilities currently exist in those states and their respective compacts have not yet decided to build additional facilities within their compact region. Compact Status Report, supra note 16, § 3, at 17-19.

19. Authority decisions are made by a board consisting of 15 members. Five of these members are appointed by the Governor; ten members are appointed by the North Carolina General Assembly upon recommendation by the Speaker of the House and President of the Senate. N.C. Gen. Stat. § 104G-5(b), (c) (1991).

20. Id. § 104G-9(b).

21. Id. § 104G-9(c).

meetings" in each identified location.[22] The meetings appear to be explanatory rather than empowering. Once the Authority selects at least two sites for site characterization, it must consider recommendations or other information received from site designation review committees established in the county of each candidate site.[23] Finally, upon receiving the site characterization data, the Authority must select its preferred disposal facility site.[24]

Once the Authority selects its preferred site, there apparently is little, if anything, any agency can do to nullify the decision. Although the statute requires the Authority to file a license application with the "appropriate regulatory agencies," there is no language indicating that the agencies should (or even have the ability to) review the Authority's siting decision.[25] Indeed, because the Authority itself is charged with the development of the applicable siting procedures and criteria, the statute appears to presume that the Authority will make a siting decision that conforms with its own regulations. Even though the statute calls for the establishment of a preferred site local advisory committee[26] and allows the local government of the preferred site to negotiate with the Authority, it explicitly prohibits any such negotiations from dealing with "any decision of the Authority regarding site selection."[27]

North Carolina is making slow progress toward siting a disposal facility. In February 1990, the Authority identified one site in Richmond County and one straddling the Wake/Chatham county line for site characterization. Site characterization on both sites is expected to be completed in July 1993, but a facility is not expected to be operational before 1996.[28]

Texas

Texas, a go-it-alone state, established its Low-Level Radioactive Waste Authority[29] to "determine areas of the state that are relatively more suitable than others" for disposal activities.[30] Once this determination is completed, the Authority is to select at least two potential sites for further examination and investigation.[31] While this further study is to consist mostly of technical and socioeconomic

---

22. Id. § 104G-9(d).

23. Each site designation review committee consists of 11 members, and is established by the board of commissioners of each affected county. Id. § 104G-19(a).

24. Id. § 104G-9(g).

25. See id. § 104G-11.

26. Id. § 104G-20.

27. Id. § 104G-21(4).

28. In the Southeast, The Radioactive Exchange, Sept. 7, 1992, at 7.

29. The Board is composed of six members appointed by the Governor with the advice and consent of the Senate. Board membership must include the following: a licensed medical doctor, a certified health physicist, a licensed attorney, a geologist, and two members of the public-at-large. Tex. Health & Safety Code Ann. § 402.011(a) (1991).

30. Id. § 402.081.

31. Id. § 402.083.

investigations,[32] the Authority may, at its discretion, "appoint a mediator to consider the views of parties interested in the selection of a disposal site."[33]

Once the Authority has completed its review, it is authorized to name a proposed site.[34] This preliminary selection is to be followed immediately by a hearing at the county courthouse in which the proposed site is located.[35] The statute does not further describe the scope of the hearing. After the hearing, the Authority either can officially propose the site or reject it and "call another hearing to consider another proposed disposal site that appears suitable."[36] This process is to continue until a proposed site finally is selected.[37]

Licensing of the disposal site is now the duty of the Texas Water Commission.[38] The Commission has 15 months to complete its review of the Authority's license application. Nothing in the statute itself suggests that the Commission has the authority to analyze or reconsider the Authority's siting decision. The statute explicitly bars the Commission from conducting any sort of public hearing during the licensing review period.[39]

The Texas site selection mechanism has not worked in the way the drafters of the statute had intended. Although the Authority selected a site (Fort Hancock) in Hudspeth County, Texas, the 34th Judicial District Court of Texas, at the request of public opponents and the nearby El Paso County, voided the Authority's selection because of potential earthquakes and groundwater contamination.[40] The court permanently enjoined the Authority from doing any work on the Fort Hancock site, effectively shutting down all of its activities.[41]

In response, the Texas legislature amended the statute in June 1991. Most prominent of the changes was an amendment directing the Authority to select a site within Hudspeth County, Texas.[42] On May 28,

---

32. Id. § 402.084.

33. Id. § 402.087.

34. Id. § 402.085.

35. Id. § 402.088.

36. Id. § 402.091.

37. The Texas statute also creates a Citizen Advisory Committee for the affected area. The Texas statute forbids the committee to begin work "earlier than the 30th day after the date on which construction of the disposal site begins." Id. § 402.031.

38. Licensing responsibility was shifted from the Texas Department of Health to the Texas Water Commission.

39. Id. § 402.152(e)(1).

40. County of El Paso v. Texas Low-Level Radioactive Waste Authority, No. 2588-34 (34th J. Dist. Ct. Jan. 29, 1991).

41. Id.

42. Tex. Health & Safety Code Ann. § 402.0921.

1992, after a public hearing, the Authority designated the Faskin Ranch in Hudspeth County as the proposed disposal site and purchased the property.[43] After site characterization studies are completed (expected in 1993), the Authority will choose a 300-acre parcel on which to build the disposal facility.[44] Part of the license application has been submitted to the Commission for review. If the license is issued, facility operations are expected to commence in 1996.

New Jersey: Northeast Interstate Compact

The New Jersey legislature found that the "most effective . . . efficient, and . . . equitable way" to accomplish siting was to establish an independent board of experts and allow maximum public participation.[45] The body with siting authority is the Low-Level Radioactive Waste Disposal Facility Siting Board.[46] Although located within the Department of Environmental Protection, the Board is to be independent of any supervision or control by the Department.[47] It is directed to "adopt criteria and guidelines for the siting of a regional facility."[48] In formulating these criteria, the Authority must hold public hearings in several geographic areas of the state to permit public comment.[49]

Public input to the Board during site selection comes from the New Jersey Radioactive Waste Disposal Advisory Committee.[50] Some independent review of the siting decision is available through a site suitability study conducted by the governing body of the affected municipality.[51] The New Jersey statute does provide for an "adjudicatory hearing concerning the proposed site" by an administrative law judge.[52] The hearing, to be conducted within 30 days of the Board's receipt of the site suitability study, shall include the affected

---

43. In Texas, The Radioactive Exchange, June 15, 1992, at 8-9.

44. Id.

45. N.J. Stat. Ann. § 13:1E-178 (1990).

46. Under the New Jersey statute, the Board is to consist of 11 members, two of which include the commissioners of the Departments of Environmental Protection and Health, or their designees. The other nine members are appointed by the Governor with the advice and consent of the Senate. The Governor's appointees must include: three members from low-level radioactive waste generating industries, three members with expertise in waste management related disciplines, and three members representing environmental organizations. Id. § 13:1E-180(b).

47. Id. § 13:1E-180(a).

48. Id. § 13:1E-185(a).

49. Id.

50. Id. § 13:1E-183. The thirteen members of the Committee are appointed by the Governor with the advice and consent of the Senate. Eleven of the members shall be individuals recommended by environmental or public interest organizations (three members), organizations representing municipal officials (two members), organizations representing county officials (two members), community organizations (one member), and low-level radioactive waste industrial organizations (three members); the final two members shall be from the general public. Id. § 13:1D-182(a).

51. Id. § 13:1E-187(a)(2). Any costs incurred by the affected municipality during the study are to be borne by the Board. Id. § 13:1E-187(d).

52. Id. § 13:1E-187(a)(3).

municipality as a party-in-interest.[53] No favorable recommendation of a proposed site shall be made unless there is "clear and convincing evidence" that there is no threat to public health, safety, and welfare.[54] However, any decision handed down by the judge is merely advisory, because the Board has the complete authority to either "affirm, conditionally affirm or reject the recommendations of the administrative law judge and adopt or withdraw the proposed site."[55] The only review of the Board's decision is through the courts.[56] Thus, under the New Jersey regime, the Board seems to play the dual roles of both recommending and confirming a site for a disposal facility.

The siting process in New Jersey is still in its earliest stages. The state is currently working on a volunteer process for siting its facility.[57]

Group I Summary

The limited commitment to independent review of the siting decision in these states may spell trouble for successful siting. Without a check on the technical decision-makers, public opposition may not be dispelled, even if the decision-makers have impressive credentials like those required in New Jersey. In fact, opponents in Texas demanded such a review and found it in the courts, where the first Texas site failed the test. By not creating a process for critical scrutiny of the siting decision, the Group I states may have difficulty in gaining ultimate public acceptance.

Group II: Private Contractor

In a second group of states, a private contractor plays the central role in the site selection process. In these states, the siting decision will be critically reviewed by an already-established state agency. Although provision is made for public input and public hearings, the hearings so far have been limited, and have not constituted a full review of the siting decision.

Pennsylvania: Appalachian Compact

The first step in the disposal facility site selection process under the Pennsylvania Low-Level Radioactive Waste Disposal Act is the selection of a private operator-licensee by the state Secretary of Environmental Resources.[58] Once chosen, the operator-licensee screens the state, using the siting regulations developed by the Pennsylvania Department of Environmental Resources (the DER),[59] in conjunction with an

53. Id.

54. Id. § 13:1E-187(a)(5).

55. Id. For that review, the Board must be expanded with members from the affected city and county. Id. § 13:1E-180(c).

56. Id. § 13:1E-187(a)(5).

57. In the Northeast, The Radioactive Exchange, June 15, 1992, at 8.

58. Pa. Stat. Ann. tit. 35, § 7130.306(a) (1991).

59. Id. § 7130.304.

advisor committee,[60] and adopted after an opportunity for public comment[61] by the Environmental Quality Board (the EQB).[62] The operator-licensee then chooses three potential sites.[63] The EQB reviews the operator-licensee's selections and the DER's recommendations[64] to determine if the three potential sites satisfy the applicable siting regulations, holding at least one public information meeting and one public hearing in each of the potentially suitable areas.[65]

Site approval by the EQB gives the operator-licensee broad access to the sites for further studies in anticipation of the licensing process.[66] Once this examination is completed, the operator-licensee selects a proposed site and files a license application with the DER, including a "written justification for the choice of the proposed site over the other two potentially suitable suites."[67]

In licensing, the DER must give the public an opportunity to review and inspect the license application and hold "one public information meeting and one public hearing, not within 30 days of each other, after adequate public notice, in the area where the regional facility is to be located."[68] After such proceedings are completed, the DER then decides whether to grant the license. The DER's written decision must include a response to public comments made during the review period.[69]

Pennsylvania has made only limited progress toward selecting a site. Chem-Nuclear Systems, Inc. (CNSI) has been chosen as the operator-licensee.[70] Currently it is screening the state for potential sites. In early

---

60. The statute directs the Secretary of the Environment to appoint a Low-Level Waste Advisory Committee to counsel the DER "regarding policies and issues related to the implementation" of the Low-Level Radioactive Waste Disposal Act. The committee is to be composed of 23 individuals representing "local government, environmental, health, engineering, business, academic and public interest groups . . . and the General Assembly". Id. § 7130.317(A).

61. Id. § 7130.304.

62. The EQB consists of the Secretaries of Environmental Resources, Health, Commerce, Transportation, Agriculture, Labor and Industry, and Community Affairs. Also sitting on the EQB are the Executive Director of the Fish Commission, Executive Director of the Game Commission, Chairman of the Public Utilities Commission, Executive Director of the State Planning Board, Executive Director of the Pennsylvania Historical and Museum Commission, five members of the Citizens Advisory Council, and four members of the General Assembly. Pa. Stat. Ann. tit. 71, § 180-1.

63. Pa. Stat. Ann. tit. 35, 7130.307(B).

64. Id. § 7130.307(D).

65. Id. § 7130.307(E).

66. Id. § 7130.307(F)(1).

67. Id. § 7103.308(C)(6).

68. Id. § 7130.308(D).

69. Id. § 7130.308(D)(3).

70. Compact Status Report, supra note 16, § 3 at 2.

1993, CNSI expects to release the results of its stage two site screening process showing potential sites for a disposal facility.[71] A Pennsylvania facility is not expected to be operational until late 1996.[72]

Nebraska: Central Interstate Compact

In Nebraska, the developer of the disposal facility initially screens the state and selects three potential sites for the disposal facility.[73] Once the sites are selected, local monitoring committees[74] are established in each proposed site area. These committees are designed to "provide significant input concerning local needs and resources regarding all relevant aspects of the site selection" process.[75] The developer, after taking into account the information provided by the committees, then must name a proposed site from the group of potential sites, leaving only the local monitoring committee for the final site in existence.[76]

The suitability of the proposed site is reviewed by the Nebraska Department of Environmental Control (the DEC), which considers the proposed facility's impact on, among other things, the public health and water supply of the sited area.[77] As part of the review process, the DEC also is required to "provide an opportunity, after public notice, for written comments and . . . hold a public hearing in the county in which the proposed facility is to be located."[78] After the investigation of the proposed site is completed, the DEC is obligated to "issue a written determination of the action to be taken" based upon the information learned during the review period.[79]

Site selection in Nebraska has proven to be anything but simple. Although the developer, U.S. Ecology, made a timely selection of a proposed site (near Butte, in Boyd County), citizens of the area were outraged at the possibility of hosting a nuclear waste facility.[80] In July 1990, U. S. Ecology filed its license application

---

71. In Appalachia, The Radioactive Exchange, Oct. 21, 1992, at 10.

72. Compact Status Report, supra note 16, § 3 at 2.

73. Neb. Rev. Stat. § 81-15,101.01(1)(a) (1990). No mention is made in the Nebraska Low-Level Radioactive Waste Disposal Act of precisely how and by whom the developer is chosen.

74. Id. § 81-15,101.01(1)(b). Each local monitoring committee is to be composed of ten members to "represent the citizens of the proposed site areas and maintain communication with the developer and the department . . . ." Id. Of those ten members, eight must be residents of the affected area. These members are to be appointed by the chief executive of the affected municipality (two members), the governing body of the affected county (two members) and by the Governor (four members). The final two members are to be appointed by the board of directors of the national resources district in the affected area. Id. § 81-15,101.01(3).

75. Whether the local monitoring committees are required to hold public hearings in the proposed areas is unclear. The statute leaves it to the Nebraska Environmental Control Council to delineate the committees' precise functions and duties. Id. § 81-15,101.01.

76. Id. § 81-15,101.01(1)(a).

77. Id. § 81-15,107(2).

78. Id. § 81-15,107(1).

79. Id.

80. In fact, the Chairman of "Save Boyd County," an organization created to stop the development of the facility, went on a 30-day hunger strike in the fall of 1990. Compact Status Report, supra note 16, § 3 at 5-6.

with the DEC. In response to the license application, the DEC has ordered U.S. Ecology to respond to 249 inquiries regarding the environmental impact of the proposed facility on Boyd County.[81]

Work on the technical studies has brought further citizen opposition. The local monitoring committee filed suit to stop the Central Interstate Compact's contract negotiations with U.S. Ecology, alleging that it was given no information about the talks until they were over. However, this suit was dismissed with a ruling that the committee's authority was limited to participation in site characterization and facility construction.[82]

The opposition next turned to the local government. At its 1991 annual meeting, the local township barred the deposit of "offensive materials" within the township, and later clarified its opposition by expressly banning the deposit of radioactive waste.[83] In the meantime, a local citizens' group filed suit, challenging the applicable state and federal regulatory standards that allow the release of some radiation into the environment. The claim was rejected by the Court of Appeals for the Eighth Circuit.[84] The court first found that the statutory challenge was stale, because federal regulations under the Atomic Energy Act had to be challenged within 60 days of adoption.[85] The court then rejected the citizens' claim that they had a fundamental right to an environment free of nonnatural radiation:

> Since the advent of the nuclear age and the enactment of the [Atomic Energy Act] in the early 1950s, our society has chosen to develop and use nuclear power. This decision reflects a balancing of the advantages of nuclear power . . . against its dangers, such as the inherent risk of radiation. The courts are not free to reconsider the wisdom of this decision.[86]

Three days later, the Compact and the developer filed suit to enjoin the township's ban on radioactive waste, alleging it was superseded by the federal and state scheme.[87]

The Central Interstate Compact still is a long way from opening a disposal facility in Boyd County, Nebraska. U.S. Ecology predicts that Nebraska officials will not rule on its license application until at least 1994.[88] In the meantime, with few outlets for public opposition, newspaper accounts report that opponents are considering armed resistance.[89]

California: Southwestern Compact

At one time, California had the least formal statutory site selection process. California's Radiation Control Law directs the state Department of Health Services (the DHS) to develop "[s]iting criteria for

---

81. In the Central States, The Radioactive Exchange, Apr. 15, 1991, at 3.

82. In the Central States, The Radioactive Exchange, July 20, 1992, at 8.

83. Central States, US Ecology File Suit Against Township, The Radioactive Exchange, July 20, 1992, at 2.

84. Concerned Citizens of Nebraska v. U.S. Nuclear Regulatory Comm., 970 F.2d 421 (8th Cir. 1992).

85. Id. at 424-25.

86. Id. at 426.

87. US Ecology File Suit, supra note 82.

88. In The Central States, The Radioactive Exchange, Sept. 21, 1992, at 5.

89. Mike Shields, Nuke waste site foes armed and angry, The Hutchinson News (Kansas), Oct. 1, 1992, at 1-2; Melvin Paul, Wastesite may spark violence, Pilot-Tribune (Blair, Nebraska), Sept. 1, 1992.

potential land burial disposal sites and treatment facilities within the state."[90] With respect to site selection, the statute requires the Governor to direct "the appropriate state agency or agencies . . . to conduct and complete a study which identifies those regions of the state within which it is likely the [siting] criteria . . . could be met."[91]

While the statutory language appears to delegate the siting decision to a state agency, an independent contractor actually has taken over all site selection duties. This is possible because the state agency chosen to identify potential areas may ask for the assistance of "private organizations."[92] Pursuant to this section, the DHS has selected U.S. Ecology to choose a suitable site, using the siting regulations developed by DHS.[93] Once the DHS "determines that the [proposed] site is consistent with the public health and safety," it can ratify the proposed site by issuing a license to receive radioactive materials.[94]

California at one time had made significant progress toward having a regional low-level radioactive waste disposal facility developed by the January 1, 1993, milestone. U.S. Ecology chose a site in the Ward Valley town of Needles to host the regional facility and filed its license application with the DHS for its operator's license.[95] U.S. Ecology and the DHS spent nearly five years and twenty-five million dollars on planning and environmental analysis on the site. On July 22, 1991, the DHS held simultaneous one-day public hearings on the licensing request (pursuant to Cal. Health & Safety Code § 25845) in Needles, Sacramento, and Los Angeles.[96] About one thousand people attended, most of whom were opposed to the site.[97]

A quick decision on licensing, however, was not forthcoming. Citizens' groups filed a lawsuit challenging the Ward Valley site and initiated a letter writing campaign. The groups challenged the adequacy of the one-day public hearing, but the court refused to grant a preliminary injunction requiring DHS to hold additional hearings. Two of the three members of the State Lands Commission responded by blocking the state's purchase of the Ward Valley site, and the State Senate blocked the appointment of the DHS Director. To get the nomination approved, the Director agreed to hold additional adjudicatory hearings on the safety of the Ward Valley site. These hearings were imposed by administrative order, and were expected to delay any approval of the site for at least a year.[98]

---

90. Cal. Health & Safety Code § 25811.5(c) (1992). The Radiation Control Law requires the state Director of Health Services to appoint an advisory committee to aid the DHS in fulfilling its duties under the Act. The advisory committee is to be comprised of experts in the science and health fields. Id. § 25814.

91. Id. § 25811.5(e).

92. Id.

93. Compact Status Report, supra note 16, § 3 at 24.

94. Cal. Health & Safety Code § 25812(a)(2).

95. Compact Status Report, supra note 16, § 3 at 24.

96. Rowdy Crowds Turn Out to Oppose California's LLRW Disposal Site, The Radioactive Exchange, July 31, 1991, at 3.

97. Id.

98. Adjudicatory Hearing to Decide California LLRW Disposal Site, The Radioactive Exchange, Apr. 21, 1992, at 2.

U.S. Ecology then filed suit, claiming that the one-day public hearing was adequate and that the consent of the Director to hold the additional hearings was improperly coerced.[99] The case was assigned to the California Court of Appeals, and, on September 17, 1992, the court stayed the adjudicatory hearings pending its decision.[100] A ruling is expected in November 1992.

Group II Summary

Perhaps the statutorily acknowledged participation of a private developer galvanizes public opposition. For whatever reason, the experience of these states demonstrates the need for meaningful public participation in a review of the siting process. Opposition in Group II states is among the fiercest in the country. California's one-day public hearing could not replace meaningful public participation; the state's acceptance of a full adjudicatory hearing was a significant concession to public involvement in the siting process. When the Nebraska courts neutered the local monitoring committees, the opponents were left without significant input into the process. This has provoked extremists, and does not bode well for ultimate site acceptance.

Group III: Recommendation By Special State Agency Plus Independent Review

Several states follow this two-step site selection framework, with government agencies undertaking the responsibility of statewide screening and site selection. In only one of these states--Illinois--has the siting process proceeded to a full public hearing. The Illinois experience demonstrates the degree of independence required for a critical siting review, and establishes guidelines for how to conduct a public hearing so as to build public acceptance.

Connecticut: Northeast Interstate Compact

The Connecticut Hazardous Waste Management Service,[101] in conjunction with an advisory committee,[102] is to select sites that appear to be suitable for a disposal facility applying a "broad" analysis of the siting criteria established by the legislature.[103] After this initial screening, the Service is to "establish a continuing process of technical refinement of such areas based on more detailed levels of technical analyses . . . ,"[104] culminating in the Service's selection of a proposed site for the disposal facility.[105] The Service

---

99. US Ecology Sues to Block Hearings on California LLRW Disposal Facility, The Radioactive Exchange, Aug. 3, 1992, at 1-2.

100. California Radioactive Materials v. Health & Welfare Agency, No. 3 Civ. C013930 (Cal. App. 3d Dist. Sept. 16, 1992).

101. Decision-making authority within the Service is vested in a ten-person board of directors. Board membership consists of "the Secretary of the Office of Policy and Management or his designee, the Commissions of Health Services, Transportation and Environmental Protection or their designees . . . and six members appointed by the Governor." 1991 Conn. Legis. Serv. P.A. 91-337 (West).

102. The eleven members of the committee are to be selected by the Governor (three members), the Speaker of the House (two members), the President Pro Tempore of the Senate (two members), the Minority Leader of the House (two members), and the Minority Leader of the Senate (two members). Conn. Gen. Stat. § 22a-163u (West 1990).

103. Id. § 22a-163d.

104. Id.

105. Id. § 22a-163d(b).

also selects the operator of the proposed facility (although the selected party must not have "participated in the selection of any proposed site").[106]

Final site approval rests with the Connecticut Siting Council.[107] Once the site and operator are selected, an application for a certificate of public safety and necessity is to be filed with the Siting Council. The applicant must pay $100,000 to the Siting Council, which is distributed to a local project review committee for technical assistance in reviewing the proposal.[108] Within 180 days, the Siting Council is to hold at least one public hearing "in the municipality in which the proposed facility is to be located."[109] Every party at the hearing has the right to present evidence and conduct cross-examination.[110] The Council's decision is to be made after a careful evaluation of the "impact of the proposed low-level radioactive waste facility on the municipality and affected geographic area in which it is to be located in terms of public health, safety and welfare."[111] In addition, the Siting Council is required to "file, with its decision, an opinion stating in full the reasons for its decision."[112]

Connecticut's siting process has not worked out as planned. On June 10, 1991, the Service named three candidate sites to undergo further suitability analysis. The selection of the three candidate sites set off a firestorm of controversy. Public opposition was so strong that the Connecticut legislature appropriated $400,000 for the three affected towns to fight the selection.[113] In May 1992, the state scrapped the whole process.[114] The Service must now present, by February 1, 1993, a new waste management plan with new siting criteria, after public comment and a public hearing.[115] The Service is directed to re-start the siting process for a permanent disposal facility,[116] and to begin to search for a temporary monitored retrievable

---

106. Id.

107. The Connecticut Siting Council is located within the Department of Public Utility Control. It is comprised of (1) the Commissioners of Health Services and Public Safety or their designees; (2) one designee of the Speaker of the House and one designee of the President Pro Tempore of the Senate; and (3) five members of the public, appointed by the Governor. Id. § 16-50. Once a site is selected by the Service, four ad hoc members are appointed to the Siting Council, "three of whom shall be elected from the municipality in which the proposed facility is to be located and one of whom shall be an elected official from a neighboring municipality likely to be most affected by the proposed facility." Id. § 16-50j.

108. Id. § 22a-163p. The members of the committee are to be appointed by the chief elected official of the municipality they represent. Id. § 22a-163p(a).

109. Id. § 22a-163i(a).

110. Id. § 22a-163k(a).

111. Id. § 22a-163l(b).

112. Id. § 22a-163l(a).

113. Kirk Johnson, Connecticut Confronts Being Its Own Nuclear Waste Site, N.Y. Times, Sept. 16, 1991, at B1.

114. Connecticut Scraps Siting Process, Renews Search for LLRW Host, The Radioactive Exchange, May 18, 1992, at 2.

115. 1992 Conn. Pub. Acts 145 § 1 (amending Conn. Gen. Stat. § 22a-163b).

116. Id. § 4.

storage facility.[117] It currently is formulating its new plan and has scheduled public hearings in December 1991,[118] but has indicated that any course of action with substantial public involvement could push back the February 1993 deadline.[119]

Michigan (formerly Midwest Interstate Compact)

The Michigan site selection process begins with the establishment of the Michigan Low-Level Radioactive Waste Authority, an autonomous entity within the Department of Management and Budget.[120] Under the Michigan statute, the Authority is responsible for initiating the site selection process by establishing, in conjunction with an advisory committee,[121] siting criteria for the proposed site.[122] Upon establishing final siting criteria, the Authority is to select three candidate sites to undergo further site characterization,[123] the purpose of which is to determine compliance with the established siting criteria.[124]

The Michigan statute creates an elaborate mechanism for public comment and participation. Central to this mechanism is the establishment of a review board,[125] the main purpose of which is to "mitigate the concerns of the municipality in which each candidate site is located if that municipality is selected as the host site."[126] The review board is directed to hold public hearings in which members of the candidate site community can participate.[127] Upon reviewing the testimony gathered at such hearings and the Authority's site characterization information, the review board has the opportunity to recommend to the Authority one

---

117. Id. § 5.

118. In the Northeast, The Radioactive Exchange, Sept. 21, 1992, at 4.

119. In the Northeast, The Radioactive Exchange, June 15, 1992, at 8.

120. Mich. Comp. Laws Ann. § 333.26203(i) (West 1991).

121. The Siting Criteria Advisory Committee is an independent entity within the Department of Management and Budget. Its members are appointed by the Authority and must have technical knowledge about low-level radioactive waste. Id. § 333.26208(1).

122. Before establishing final siting criteria, the Authority must make a draft version available for public comment and hold a public hearing. Id. § 333.26209(2).

123. Id. § 333.26211.

124. Id. § 333.26212(2).

125. The review board is to be comprised of seven voting members: four appointed by the Governor with the advice and consent of the Senate and three appointed by the governing body of each of the municipalities in which the candidate sites are located. The Governor also is directed to appoint an attorney to serve as a non-voting chairperson. Id. § 333.26213(2)

126. Id. § 333.26213(1).

127. Public participation is to be organized through local advisory committees established in each candidate site municipality. The composition and size of each committee is left to the discretion of the affected municipality's governing body. Id. § 333.26214(1).

of the three sites to host the regional disposal facility.[128] The board's recommendation is only advisory, however; the final power to designate a proposed host site rests with the Authority.[129]

Once the Authority has designated one of the three candidate sites as the proposed site, the Michigan legislature is to act on the Authority's selection. The Authority's selection becomes final only if the legislature fails within 30 days of the Authority's decision either to (a) reject the proposed site, or (b) reject the Authority's proposed site and select one of the other two candidate sites.[130] If the state legislature does not act, the disposal facility site is implicitly approved.

A variety of events have caused the Michigan site selection process to be among the most contentious in the country. Although the Authority's selection of candidate sites went relatively smoothly, it later withdrew its proposed selection, citing wetland concerns.[131] The Authority failed to designate another proposed site for the disposal facility. Because of Michigan's perceived foot-dragging, on July 24, 1991, the Midwest Compact Commission ousted Michigan from the Compact and confirmed Ohio as the next host state.[132] Ohio has turned to a blue ribbon panel of experts to recommend procedures for facility development and siting criteria.[133]

Michigan now is a "go-it-alone" state. Effective January 21, 1992, Michigan's governor issued an executive order transferring "(a)ll the statutory authority, powers, duties, functions and responsibilities" of the Authority to the Director of the Department of Commerce.[134] It appears that the remainder of Michigan's statutory site selection process remains intact. However, the state is considering privatizing its siting process.[135]

---

128. Id. § 333.26213.

129. Id. § 333.26215(i).

130. Id.

131. Michigan's siting criteria has strict rules against siting a proposed facility near a wetlands area. Id. § 333.26210(e). This rule caused concern among the other members of the Midwestern Compact. Upon reviewing Michigan's siting criteria, the members concluded that the strict wetland rules "virtually guaranteed that a site cannot be found" in Michigan. Compact Status Report, supra note 16, § 3, at 12.

132. Michigan Out of Midwest Compact; Ohio Selected as New Host, The Radioactive Exchange, July 31, 1991, at 1.

133. Ohio Legislature Urging Action on LLRW Disposal Regs, The Radioactive Exchange, Sept. 21, 1992 at 2.

134. Mich. Comp. Laws Ann. § 333.26226.

135. In Michigan, The Radioactive Exchange, Sept. 7, 1992, at 7.

Massachusetts

The go-it-alone state of Massachusetts established a Low-Level Radioactive Waste Management Board,[136] located within the Executive Office for Environmental Affairs (although it is not subject to the control of that office).[137]

The Massachusetts site selection process is to begin only when a two-thirds majority of the Board determines that it is necessary to proceed with establishing a disposal facility site.[138] Once the Board decides that a site is necessary, it next performs preliminary site characterization using siting criteria established by the Department of Environmental Protection (the DEP) and selects "at least two, but not more than five, candidate sites that the Board considers best able to satisfy the site selection criteria."[139] The selection of candidate sites is to be accompanied by at least one public meeting to discuss the preliminary characterization report in each candidate community.[140]

If it decides to proceed with detailed characterization of the candidate sites,[141] the Board then develops a detailed site characterization plan in conjunction with community advisory committees established by the local governing bodies in each candidate area.[142] The proposal is followed by a public meeting (discussing the plan) in each candidate community,[143] detailed site characterization,[144] and a public meeting in each community following the issuance of the characterization data.[145] Upon completion of these steps, the Board must select the proposed site.[146]

Independent review under the Massachusetts scheme is provided by an adjudicatory proceeding before the Commissioner of the DEP.[147] In addition to any aggrieved party,[148] the Board, the site community,

---

136. The nine-person Board is appointed by the Governor in accordance with criteria set forth under § 2(b) of the Massachusetts statute, Mass. Gen. Laws Ann. ch. 111H, § 2(b) (West 1990).

137. Id. § 2(a).

138. Id. § 17(a).

139. Id. § 20(c).

140. Id. § 20(g). In order to "encourage and facilitate the participation of interested persons," the Massachusetts statute directs the Board to appoint a full-time participation coordinator. The coordinator is to make recommendations that will insure proper public participation where it is called for under the Act. Id. § 29(a).

141. Id. § 20(i).

142. Id. § 23(a).

143. Id. § 23(b).

144. Id. § 23(c).

145. Id. § 23(d).

146. Id. § 23(g).

147. Id. § 24(c).

148. Id. § 24(a).

and neighboring communities may be parties to the proceeding.[149] Although the Commissioner ultimately can nullify the Board's selection, the statute directs the Commissioner to approve the proposed site if it satisfies the applicable siting criteria.[150] The statute provides for judicial review of the Commissioner's decision by the Massachusetts Supreme Judicial Court.[151]

Massachusetts site selection is beset by two distinct, yet interrelated, problems: budget constraints and governmental inaction. Concern over the state's finances has caused lawmakers to cut back the Board's budget and, hence, its ability to complete its siting obligations. In fact, the Board has failed to initiate the site selection process by conducting the required two-thirds vote.[152] It still is awaiting the promulgation of regulations by the DEP and the Department of Public Health before it determines whether to site a low-level radioactive waste facility in the state.[153] Those regulations are expected to be completed in December 1992.[154] Should such inaction continue, the sited states have warned Massachusetts that it will face a fate similar to that of Michigan--a denial of access to the existing disposal facilities prior to 1993.[155] The present target date for a Massachusetts facility is late 1995.[156]

New York

New York alone among Group III states has created an agency--the New York Low-Level Radioactive Waste Siting Commission[157]--whose sole mission is to site a disposal facility. While other states have created separate state agencies to undertake all aspects of low-level radioactive waste management, not just site selection, the New York regime creates a commission whose sole function is to select a disposal facility site and operator.[158]

New York's overall framework resembles the two-step site selection process seen in other Group III states. Specifically, the Commission is directed to conduct a statewide study of areas potentially suitable for a disposal facility. Once the study is completed, the statute provides for a review of the Commission's

---

149. Id. § 24(b).

150. Id. § 24(c).

151. Id. § 24(e).

152. In New England, The Radioactive Exchange, Dec. 24, 1991, at 14.

153. Id.

154. In New England, The Radioactive Exchange, Sept. 21, 1992, at 4.

155. Id.

156. Compact Status Report, supra note 16, § 4 at 4.

157. The Commission is to be composed of seven individuals appointed by the Governor, including a geologist, a medical doctor, a health physicist, a professional engineer, a social scientist, an environmentalist and a private citizen. N.Y. Envtl. Conserv. Law § 29-0301(i) (McKinney 1991)

158. New York also has an Energy Research and Development Authority which is not involved in the site selection process. It was created to acquire necessary property, as well as to construct, operate and maintain the facility once the site is selected. N.Y. Pub. Auth. Law § 1854-C (McKinney 1991).

findings by a Citizens' Advisory Committee[159] and by a Technical and Scientific Evaluation Panel.[160] Taking into account the recommendations of these bodies, the Commission then must choose a proposed site for the facility.[161] It also is directed to hold "periodic" public hearings during the course of its site selection duties.[162]

Review of the Commission's proposed site is conducted by the Department of Environmental Conservation (the DEC). Through its certification procedures, the DEC is required to undertake an extensive examination of the record established by the Commission.[163] It also is directed to hold public hearings about the Commission's analysis of the facility's environmental impact on the proposed site area.[164] In light of its findings, the DEC must decide whether the proposed site "is in conformance with the applicable siting criteria."[165] If so, it is directed to certify the site, thereby ratifying the Commission's recommendation.[166]

After conducting a statewide study, the Commission named five potential sites (in Allegheny and Cortland Counties) for the disposal facility.[167] Fearing that the proposed facility would constitute a health hazard, citizens of the two counties have staunchly opposed any efforts to site a facility in the areas.[168] The protests led the Commission, at the request of the Governor and legislature, to suspend its field work indefinitely.[169] The Commission now is concentrating on selecting its disposal method before siting a facility.[170]

---

159. The Citizen's Advisory Committee is independent of the Commission. Its members are appointed by the Governor based on specific criteria enumerated in the statute. N.Y. Envtl. Conserv. Law § 29-0501(i).

160. The state Department of Health is directed to appoint the Technical and Scientific Evaluation Panel. The Panel itself has a narrowly defined function: to "assess the natural sources and quality of any specific data the commission relied upon, the nature of assumptions made, and the specific analytical methods, procedures or techniques employed including, modelling and calculations performed." Id. § 29-0303(11).

161. Id. § 29-0303(7).

162. Id. § 29-0303(9).

163. Id. § 29-0105(i).

164. Id.

165. Id.

166. Id.

167. Compact Status Report, supra note 16, § 4 at 7.

168. Billy House, NY Continues Bid to Block Waste Law, Gannet News Service, June 11, 1991.

169. U.S. General Accounting Office, Nuclear Waste: New York's Adherence to Site Selection Procedures is Unclear 4 (Aug. 1992).

170. In New York, The Radioactive Exchange, Nov. 2, 1992, at 7.

Illinois: Central Midwest Compact

Under the Illinois Low-Level Radioactive Waste Management Act, the Illinois Department of Nuclear Safety conducts state-wide studies to enable the Director of the Department to designate a site for a permanent disposal facility.[171] In part because of the potential conflict between the Department's role as licenser and its role as site promoter, the Act also establishes the Illinois Low-Level Radioactive Waste Disposal Facility Siting Commission.[172] The Siting Commission must evaluate the safety and suitability of any site proposed by the Director.[173] The Department can take no final action on any facility license until the proposed site of the facility has been designated by the Siting Commission.[174] The Siting Commission thus provides independent review of the Department's siting proposal.

On January 10, 1991, the Director proposed a site near Martinsville, Illinois. The Siting Commission held a public hearing in Martinsville, developing a record on which to base its determination of safety and suitability.[175] The public hearing was a rigorous review of the siting decision, commencing on June 12, 1991, and covering 72 days.[176] During the public hearing, the Commission heard from over 100 witnesses, including 31 expert witnesses and 67 members of the public offering their expressions of personal opinion. The commissioners, a retired state supreme court justice, a professor of civil engineering from the University of Illinois, and an environmentalist, questioned many of these witnesses, and propounded nearly 200 formal requests for information to the parties. The Commission toured the site and the surrounding area, observing pyrotechnical displays delineating stratigraphic profiles and the surface location of characterization wells, piezometers, and boreholes. It complied a record consisting of 20,539 pages of transcript and over 500 individual exhibits.

The Siting Commission considered the public hearing to be more than a trial or simple administrative proceeding. While the hearing at times resembled an adversarial proceeding, the Commission repeatedly characterized it as a statutory inquiry, the purpose of which was to entertain all relevant and useful information so that the Commission could make the most carefully reasoned decision possible. On October 9, 1992, the Commission held its public deliberation in Martinsville. After more than ten hours of discussing the evidence before a packed audience, the commissioners voted unanimously to reject the Martinsville site.

---

171. Ill. Rev. Stat., ch. 111>, | 241-10.

172. Id. | 241-10.1. The three members of the Siting Commission are appointed by the Governor and confirmed by the Illinois Senate. Id. | 241-10.1(a).

173. Id. | 241-10.1(b).

174. Id.

175. Id.

176. The hearing was conducted entirely in Martinsville, first at the Martinsville High School gymnasium and then at the hall of the local American Legion Post. The summer hearings at the gymnasium were held on weekdays, including evening sessions, and over the Labor Day weekend. The remaining sessions at the American Legion hall were held primarily on evenings and weekends.

The sessions ran long. Weekdays typically began at 8:00 a.m. and ran until 6:00 p.m. or later. Weekend sessions usually covered eight to nine hours each day. These long hours enabled the Siting Commission to cover as much ground as possible with a minimum number of hearing days.

Group III Summary

The siting procedures of these states contain the elements needed to gain public acceptance. In most states, however, these elements have not yet been given a full opportunity to build support. When local opposition flared in Connecticut and New York, the process of public participation in an independent review was derailed. Only Illinois has carried the process all the way through. The lessons of its experience are discussed in more detail in Section III, below.

Group IV: Comprehensive Review With Legislative and Voter Approval

Planned public participation in siting is greatest in New England. In addition to full review by both the licensing agency and the legislature, two go-it-alone states give full authority to local voters to reject a site.

Vermont

The Vermont Low-Level Radioactive Waste Authority has the primary responsibility for siting, while the Vermont Agency of Natural Resources (the ANR) establishes the siting, screening and certification requirements.[177] The Authority first was required to characterize a site next to the Vermont Yankee nuclear power plant, where most of the state's low-level waste is generated.[178] In September 1992, however, the Authority terminated the Yankee site characterization study after significant concerns were raised about the site's suitability.[179]

The Authority then was required to collect data for site screening both in the town of Vernon (where the Yankee plant is located) and the rest of the state to identify potential alternative sites.[180] After initial site screening and public comment,[181] the Authority must select at least three potential alternative sites, including one in Vernon.[182] After the Authority selects one site for proposal, it must submit that site to the ANR to certify whether the site meets the its siting requirements.[183] If the ANR certifies the site, the Authority then must decide, after public comment, whether to characterize the site;[184] if so, it must petition the state legislature for site characterization approval.[185] If the legislature agrees, the Authority must complete site characterization within 18 months of approval.[186]

---

177. Vt. Stat. Ann. tit. 10, § 7002(a)(5) (1991).

178. Id. § 7002(a)(3).

179. In New England, The Radioactive Exchange, Oct. 21, 1991, at 5.

180. Vt. Stat. Ann. tit. 10, § 7002(a)(4).

181. "'Public comment' means ample opportunities for public input, including at least prior availability of a draft decision, policy or rule, two public hearings in different areas of the state, warned at least twice . . . and preparation and distribution of a response summary to all comments received." Id. § 7001(10).

182. Id. § 7002(a)(6)(B).

183. Id. § 7002(a)(7).

184. Id. § 7002(a)(8).

185. Id. § 7002(a)(9).

186. Id. § 7002(a)(10).

Following site characterization, the Authority must determine whether to proceed with the site or to characterize another, more suitable, site.[187] If the Authority determines to proceed with the characterized site, it must complete a social and economic impact study, prepare a report on the strengths and weaknesses of the site, and negotiate any impact fees or other payments with the municipalities where the proposed alternative site is located.[188] The Authority is required to hold at least one public hearing near the site, and obtain the consent of the majority of the voters of the municipality where the proposed site is located.[189]

After the reports are prepared and local municipal approvals are obtained, the Authority must petition the legislature to prepare a draft license for the development of a disposal facility at the site.[190] If the legislature approves the licensing petition, the Authority is required after public comment to submit a draft license application to the ANR for its review.[191] If the ANR gives final approval to the Authority for its license application, the license application is then sent to the U.S. Nuclear Regulatory Commission for approval.[192]

Because the Yankee site characterization work was terminated, the Vermont authority currently is screening the state to identify potential alternative sites.

Maine

Maine's site selection process also is comprehensive. First, the Maine Low-Level Radioactive Waste Authority must recommend a potential site[193] according to the rules and criteria promulgated by the Authority in its low-level radioactive waste management plan.[194] Second, before further consideration of the proposed site, the local voters must give their approval. Specifically, the sited municipality's governing body must hold an election "for the purpose of approving the site."[195] The proposed site must receive approval from 60 percent of the cast ballots.[196] Third, if the local voters approve the site, the Maine Board of Environmental Protection (the BEP) undertakes further review. Before granting a license for the proposed facility, the BEP must hold hearings on the proposed facility, examining all aspects of the proposed site, including the technical feasibility, environmental impact, social impact, and economic impact on the host

---

187. Id.

188. Id. § 7012(f)(1)(2)(3).

189. Id. § 7012(f)(4)(5).

190. Id. § 7002(a)(11). The legislature may sua sponte direct the Authority to prepare a draft license.

191. Id. § 7002(a)(11).

192. Id. § 7002(a)(16).

193. Me. Rev. Stat. Ann. tit. 38, § 1521 (West 1991). Until a prospective site is selected, the decision-making unit of the Authority consists of the State Geologist plus six members appointed by the Governor. Id. § 1512(1)(A). After site selection, two more members are appointed from a list nominated by the local government where the site is located. Id. § 1512(1)(B).

194. Id. § 1527(1).

195. Id. § 1527(3).

196. Id.

municipality.[197] Fourth, legislative approval is required on any license for a proposed site that the BEP has approved.[198] Finally, the license is subject to a statewide referendum, requiring majority approval.[199]

It is difficult to say how well Maine's elaborate site selection process works, siting is still in its early stages. The Authority's statewide screening has narrowed the state to 12 possible sites.[200] Precharacterization studies are expected to be completed by the end of 1992.[201] No facility is expected to be operational before the end of 1995.[202] Some legislators have advocated a delay in the Maine siting process.[203] Because of this delay, it has been suggested that Maine join the Southwestern Compact or form a new compact with Texas.[204] Membership in a compact would have to be approved in a statewide referendum.[205]

Group IV Summary

Maximum public participation has not yet been put to the test. Both these states are in the early stages of the siting process, and have not yet had to involve the public.

Summary of Siting Efforts

The most obvious fact about each of these approaches to siting is that none has produced an approved site. In all of these siting regimens, trust has become the key issue. Where states have forged ahead without a full, independent, and public inquiry into the merits of a low-level radioactive waste siting decision, the rush to judgment has been unavailing. Indeed, the careful and detailed process of a full public inquiry appears inevitable, for without such a review it may be impossible to build a consensus around the decision to site, or not to site, such a facility.

ADVANTAGES OF THE ILLINOIS SITING COMMISSION APPROACH

The experience gained by the Illinois Siting Commission in reviewing the Martinsville proposal can be used by other states. The main lesson from the Martinsville hearings is that a detailed, independent review in which the public is fully involved can result in public acceptance. The Siting Commission held a full public inquiry into the site's safety and suitability--not a one-day, "cram-down" hearing, but a comprehensive, no-holds barred proceeding in which the science was put to critical review, the benefits were fully explored, and the risks were honestly weighed. Other states can tailor their public hearing procedures in the same way.

Several factors are key to this approach. First, the review must be absolutely independent. The reviewing body can have no ties--actual or perceived--to the proponents or opponents of the site, and should

---

197. Id. § 1479.

198. Id.

199. Id. § 1493.

200. In New England, The Radioactive Exchange, Sep. 21, 1992, at 3-4.

201. In Maine, The Radioactive Exchange, Oct. 21, 1992, at 10.

202. Compact Status Report, supra note 16, § 4 at 2.

203. In New England, The Radioactive Exchange, Sept. 21, 1992, at 3-4.

204. Compact Status Report, supra note 16, § 4 at 3.

205. Title 38, § 1494.

not answer to either the executive or legislative branches of government. Separation of powers reduces uncertainty, while built-in conflicts can only undermine confidence in the body with the fiduciary responsibility that is the basis for public trust.[206] In Illinois, the Siting Commission was created to regain trust at the systemic level.[207] It is absolutely independent, and answers (in the words of its members) only to the commissioners' consciences. Its independence won it grudging respect even from those opponents who expected the Siting Commission to approve the Martinsville site.

Second, the hearing must be rigorous. The reviewing panel must be fully committed to a full, open, and complete inquiry in which all views are aired. Its members should be selected from a variety of backgrounds to offer diverse perspectives. They must command respect as impartial arbiters. If not technically proficient themselves, they should have their own team of consultants to assist them in reviewing the data and conclusions presented. In Illinois, the Siting Commission hired its own counsel and technical consultants to help the commissioners focus the public hearing on critical questions. The resulting technical competence of the inquiry was another element in building public trust.

Third, the public must be allowed to freely participate. Representatives of the public must be allowed to challenge the rationale supporting the site. Opponents may be able to finance a team of lawyers and technical consultants on their own. If not, funding should be provided to them, as it was in Martinsville. Only direct participation will ensure a comprehensive review of the evidence and will satisfy opponents that all views have been considered. Involvement of the public, not just their education, is one of the few avenues proven to change beliefs.[208] The additional cost of opponent funding should be more than justified if the siting effort is successful.

Fourth, the inquiry must be open. There can be no hint of a "back-room deal." All proceedings should take place in public, and in a convenient location within a short distance of the site (usually the epicenter of opposition). For the Siting Commission, this meant an extended proceeding in a small town, presenting challenging logistical difficulties. However, it also meant that local citizens could attend the hearing, as their personal schedules and interest dictated, to judge for themselves the basic fairness of the proceeding. Scores of members of the public were able to address the commissioners, and to relate their practical concerns.

Finally, the body sponsoring the site--the very individuals whose conclusions about the site are at issue--must fully support the proceeding. From agency officials to individual scientists, the site proponents must be sufficiently confident in their decisions to withstand public scrutiny. At Martinsville, scientists, engineers and project officials had to undergo sometimes grueling cross-examination. However, it is only in the cauldron of scrutiny that public acceptance can be forged.

All the elements for public acceptance were present in Martinsville, and a foundation was laid for public support of the commission's decision. The decision to reject the site spoke to the technical shortcomings of the Martinsville site, not to the process by which the decision was made.

CONCLUSION

The nature of low-level radioactive waste disposal and the public response to it requires that siting procedures be designed and implemented with the goal of achieving public trust. The best approach for achieving this goal is to bring full public participation into an independent review of the siting proposal. Any site that can stand on its merits can withstand this level of critical scrutiny. Any site that cannot does not

---

206. Bullard, supra note 2, at 714.

207. Id. at 717.

208. Bullard, supra note 2, at 717, quoting Sorenson et al., Impacts of Hazardous Technology: the Psycho-social Effects of Restarting TMI-1, (1987).

deserve, nor will it receive, public support. Other states can benefit from the Illinois experience by similarly structuring the public hearing already contemplated by their siting statute.

Perspectives on the Siting of Low-level Radioactive Waste Disposal Facilities in Illinois

Christine G. Zeman
Giffin, Winning, Cohen & Bodewes, P.C.
P.O. Box 2117
Springfield, IL 62705

Having been a part of the Illinois environmental community since before the "Local Siting Approval Process" became law for Illinois' solid and hazardous waste landfills in the early 1980s[1] and having attended nearly 71 days of hearings before the Illinois Low-Level Radioactive Waste Disposal Facility Siting Commission (Siting Commission) in 1991 on behalf of the City of Martinsville, this author recommends that neither the process established by the Siting Commission, nor the specific law on which it purports to be based,[2] should serve as a blueprint for future siting efforts. While the Illinois Siting Commission process has some merit, its benefits are limited, its cost excessive, and its goals readily achievable through alternative means. Accordingly, policymakers and legislators may wish to consider the advantages, disadvantages, costs, and failures in the Illinois system before adopting a similar scheme.

HISTORICAL PERSPECTIVE

The Illinois Low-Level Radioactive Waste Management Act (Management Act) sets forth the Illinois system for *inter alia*, state monitoring, tracking, or licensing of LLW generators, brokers, transporters, processors and contractors for LLW disposal.[3] Originally, the Illinois Department of Nuclear Safety (DNS or Department) was responsible for characterizing potential LLW disposal sites, selecting alternative sites, and designating that site according to statutory criteria, as well as being responsible for licensing the contractor selected for facility operation.[4] The criteria for site selection have remained essentially the same and have consistently included local government approval, with the existing statute requiring the approval of either the local municipality or county in whose jurisdiction the site is located.[5] Therefore DNS not only had the responsibility to select sites, acquire land, establish technical requirements and regulations, choose contractors for site design, facility development, construction and operation, but was also responsible for ensuring local approval.[6] DNS contracted with Battelle Memorial Institute and Hanson Engineers, Inc., for site characterization and development of reports to establish whether the selected site meets the applicable criteria and regulations.[7] Chem-Nuclear Systems, Inc., was the Department's ultimate choice for development, construction, and operation of the proposed facility once a site had been designated and a license approved.[8]

Because the site had to meet a variety of technical criteria and receive approval of the local governing municipality or county, the Department developed a detailed site screening plan and contacted numerous local governments and organizations; the site therefore had to be both technically and politically acceptable.[9] The Department's activities directed to achieve a politically acceptable site included correspondence to all 102 counties of Illinois advising of the LLW project and inquiring of the county's interest in the project.[10] Meetings were held and officials were lobbied; interested citizens and public officials were invited to visit the Barnwell and French LLW facilities.[11] The Department sent more letters to local governments advising of the potential economic benefits of a LLW disposal facility, including temporary and permanent jobs, local improvements, and financial grants.[12] Meanwhile, geographic information was analyzed and site screening continued, primarily on locations in counties that evidenced an interest and met minimum technical criteria.[13] Ultimately every county rejected the Department's offer or was excluded from consideration due to technical factors.[14]

Site screening and characterization by the contractors did not take place in a vacuum, however, and in the process, the characterization scientists and engineers met local officials; as several sites in Clark County had been identified as initially suitable, Hanson personnel met Clark County's economic development personnel.[15] By the time Clark County was prepared to vote on the LLW site, through Hanson's or Battelle's interaction with the economic development personnel and city officials, the City of Martinsville began to listen and show interest. The City of Martinsville voted in support of county approval generally for such a local site

on the day before that Clark County voted by 4 to 3 to reject it,[16] and thereafter unanimously voted to support the Department's proposed Martinsville Alternative Site (MAS) within 1-1/2 miles of the city's boundaries.[17]

Martinsville first indicated approval for LLW site characterization work in its vicinity in January 1988.[18] Site characterization work began. In the summer of 1989, borings had identified sand bodies in the till and were being further analyzed.[19] By fall of 1989, disagreements over the use of the words "aquifer" and "water-bearing zone" had developed between project personnel; the disagreement was widely reported, concerned groups included the Citizens' Advisory Group that had been formed to follow LLW disposal activities of the Department.[20] By September of 1989, a local geologist/activist issued his own report challenging the preliminary findings of the state's characterization team, and concluding that a hydrologic connection existed between the MAS and city's public wells.[21]

One month later, scientists with Illinois' Geologic and Water Surveys publicly withdrew support for the hydrology report of the state's characterization team, which they had not had a chance to prereview or critique and could not endorse as written.[22] Ultimately these technical disagreements and the manner in which they were handled lead to scrutiny of the state's preliminary findings by the Governor's office and General Assembly. Even earlier, however, in May of 1989, an Illinois Senate Committee sought information on site characterization progress; the Department Director at that time testified that the MAS was not above an aquifer.[23] Thereafter, the Illinois Senate created an Executive Committee to investigate the department's siting activities.[24]

While a lack of public trust in the ability of government to make scientific decisions may be factors in siting of environmental facilities generally, Illinois faced a unique set of facts, including the repeated public announcements by either the state's characterization team or the Department's management that appeared to some, including Illinois Senate leaders, to mischaracterize the facts in favor of site suitability. The Department Director at that time was accused of "overzealousness" in selecting a site "on time" and of "leaning" on the scientists to achieve timely siting of the MAS.[25] The General Assembly, Governor, and NRC also recognized the inherent conflict or difficulties in one Department being solely responsible for regulating, siting, contracting and licensing.[26] As a result, the Siting Commission was created,[27] leaving intact the criteria by which a site was to be judged, including the local approval component, but adding consideration of the facility design to the factors. By the time the Illinois Senate voted for a Commission, however, the Governor had already announced the appointment of former Supreme Court Justice Seymour Simon to act as a hearing officer, apparently without any legislation directing over what he was to preside in what has been characterized as a deal-of-sorts with the Governor.[28] That the Siting Commission was deemed a quick fix to a unique political problem is evidenced by the Siting Commission Chairman's statements that he believed it was due to the actions of one individual, the former Department Director, that lead to his role overseeing site suitability.[29] Unfortunately, following the decision of the Siting Commission on October 9, 1992, which rejected the MAS as unsuitable for the siting of Illinois' LLW disposal facility, Illinois is back to square one after expending over $85 million to reassess and redesign a siting process.[30] At this writing, whether the Illinois LLW Siting Commission will continue to exist, to assess other sites in its present form or any other, is uncertain.[31] Because of serious flaws in the Siting Commission law and process utilized by the Siting Commission, extensive revamping, if not Commission elimination, appears warranted.

LEGAL AND PROCEDURAL CONSIDERATIONS

As the city's pleadings to the Siting Commission state, which are pending at the time of this writing, the process utilized by the Siting Commission was seriously flawed, raising the issues of due process and fundamental fairness; conducting such a hearing with insufficient procedural and substantive standards allows for a completely arbitrary decision, one in which those familiar with the process can have no faith. Even the Commission, throughout the proceedings and in its deliberation, admitted that the very law which it was directed to apply to the Martinsville site was poorly crafted and vague.[32]

The Illinois Low-Level Radioactive Waste Management Act is confusing on crucial issues, including whether the site and facility must each independently meet the various safety factors in the statute and regulations and, if not, what interplay or balance is acceptable, allowable, or best. Neither the Siting

Commission nor the Management Act provided guidance to the applicants prior to the hearing on a host of procedural and substantive issues necessary to adequately prepare a case of this complexity.

The criteria under the Management Act by which a site is to be judged are similar to and based upon the criteria that must be met for a regional pollution control facility in Illinois to be approved by either a county or city before a landfill or other environmental facility can receive a permit from the Illinois Environmental Protection Agency.[33] The local siting approval law for landfills and other regional pollution control facilities (SB 172) was enacted in 1981 in order to give local officials veto authority over siting, so long as the decision was based on the criteria set forth. The goal of technical and political acceptability in siting solid and hazardous waste landfills, incinerators, and LLW disposal facilities is sound. The question is how do we get there and is a Siting Commission the best or most efficient way. The local siting approval law for RPCF's (SB 172) has spawned more litigation in Illinois than a host of other environmental issues and has generated, including inter alia local battles over annexation of the property on which a regional pollution control facility (RPCF) is to be located; contracts between host communities and the proposed RPCF for local improvements; guaranteed jobs, benefits, tip fees. Even prior to the siting hearing,[34] costly proceedings in which a crop of expert witnesses such as hydrogeologists and engineers has developed, including technicians as successful in testifying under extensive cross-examination as they are in permit application work and writing as well as a host of appellate decisions requiring that the hearing be adversarial and fundamentally fair, thankfully providing guidance to the various litigants in these hearings.[35]

The LLW Siting Commission law incorporated some but not all of the procedural requirements of the RPCF local siting approval law. Curiously, the Siting Commission relied only on one or two RPCF Siting cases as precedent, rather than the host of precedent available to properly guide it. But even Illinois' RPCF local siting approval law is subject to frequent legislative amendments to cure its deficiencies; a task force of representatives of manufacturers, local governments, business, industry and environmentalists convened in 1990 and 1991 to restructure the local siting approval process for landfills, with complaints including excessive process costs and that new facilities were not being sited while those that were sited were not necessarily technically superior.[36] Despite the growing criticism of the RPCF local siting approval process, few of the well-established procedural safeguards in the RPCF local siting approval law were incorporated into the LLW Management Act when the Siting Commission was established.

The LLW Management Act's Section 12 criteria are exceedingly broad but also impermissibly vague. The Section 12 criteria of the Management Act provide:

> The site shall meet all of the following criteria with respect to a facility of proposed design: (Emphasis added)

1. The site shall be located so that the public health, safety and welfare will be protected.

2. The site shall be located in a suitable geological and hydrological medium.

3. The site shall be located so as to minimize the possibility of radioactive releases into groundwaters utilized as public water supplies.

4. The site shall be located outside the boundary of the 100-year flood plain as determined by the Department of Transportation.

5. The site shall be located so as to consider the distance necessary for the transportation of low-level wastes and so that the impact on existing traffic flows is minimized.

6. No low-level radioactive waste disposal facility shall be located in or within 1-1/2 miles of the boundaries of any municipality unless approval is given by the governing body of that municipality.

7. No low-level radioactive waste disposal facility shall be located in an area of a county situated more than 1-1/2 miles beyond the boundaries of a municipality unless approval is given by the governing body of that county.[37]

The first factor, directing that public health, safety, and welfare be protected, is vague. For example, its unclear whether the legislature intends for the Siting Commission to go beyond the existing regulations, requiring a site or facility or both to exceed the existing technical regulations and requirements of DNS and the NRC. Its unclear whether the legislature intends for the Siting Commission to investigate the foundation for existing technical regulations and reject those it deems unsafe or inadequate. The Illinois Siting Commission did both reject existing regulations and require the site and facility to exceed these and other standards, citing the general safety criteria in doing so.[38]

Indeed, Chem-Nuclear noted that the Siting Commission "fundamentally ignored the federal and state regulatory system in reaching its decision."[39] For example, it rejected the as low as reasonable achievable (ALARA) principles, risk assessment methodologies, dose limitations, and buffer zone requirements, the foundations of the LLW management system.[40] Rejection of the existing regulatory scheme raises questions of possible preemption by the NRC and whether such a Commission should have reviewed the regulatory system first so that applicants would know the rules by which they would be expected to adhere and could appeal for a review of the adequacy of the Commission's decision on just the sufficiency of the regulatory scheme. The latter suggestion simply creates unnecessary bureaucracy, but it is a logical and legal extension of the Siting Commission's decision.

Further, Section 12 of the Management Act is impermissibly vague in requiring that the site "with respect to a facility of the proposed design" meet the 12(b) criteria. The Act provides no guidance as to how the site or facility are to be factored, balanced, weighed or assessed independently against the criteria, a vagueness that even the Commission acknowledged.[41] This vagueness becomes readily apparent as an obstacle in assessing site and facility factors during characterization, preparation of reports and evidence, and during Commission deliberation. For example, how can one assess the impact of certain geological or hydrogeological "flaws" that the experts testify can be overcome by the facility, without guidance as to the weight that the facility can be given in assessing suitability of the site.[42] Similar problems are also raised in assessing the requirement or goal that waste be "isolated"; guidance must be provided to decide what weight to give facility design.

The Illinois Management Act is impermissibly vague in not setting forth basic procedural safeguards; the minimal procedural rules of the Siting Commission did not provide either the necessary procedural nor substantive guidance required for a 70-plus day-long hearing on such a variety of complex technical issues with so many parties. For example, the Management Act specifically stated that the Administrative Procedure Act, a law regulating the conduct of administrative agencies, was not applicable to the Siting Commission procedures.[43] The problems that develop can be seen in the parties' assumption that the hearing would be conducted as an adversarial proceeding like a trial, as is required for the RPCF Local Siting Approval hearings. Instead, the Commission insisted, despite legislative history and thus intent to the contrary, that it be an "inquiry" like a legislative committee into issues seemingly unrelated to the Section 12 factors.[44] The Commission admitted its inquiry went into "peripheral" issues,[45] wasn't a comprehensive technical review,[46] and rejected portions of the very law it was directed to apply.[47] The Management Act's and Siting Commission's failure to specify procedural and substantive safeguards wastes the legal and scientific resources expended in characterization, in the application and licensing reports, and in the hearing process and therefore is inefficient and reckless, at best.

Therefore, if a Commission Review process is to be utilized, the implementing law must be carefully considered and drafted clearly so that the time, money, and effort expended in planning, bringing in experts to testify, observe, and consult is not wasted.

Enabling legislation for a Commission Review should also require technically qualified commissioners, whether in chemistry, geochemistry, geology, hydrology or medicine. Renown experts would be even better. LLW disposal and facility siting involves exceedingly complex scientific data in a variety of scientific fields;

universal confidence in the decision as well as efficiency in presenting evidence during the hearing process, and in knowing that the data and evidence is understood, requires no less. The city's pleadings, for example, argue that the Siting Commission failed to recognize the inherent uncertainty in the interpretive sciences involved in site characterization. Even the Illinois Pollution Control Board, the quasi-legislative and quasi-adjudicative body that enacts environmental regulations, judges permit appeals and enforcement cases of the Illinois Environmental Protection Agency, by law requires technically qualified members.[48] Yet the scientific issues that the Pollution Control Board generally must address are less complicated and numerous than those at issue in the Siting Commission's proceeding. Further, during the Siting Commission process, the explicit and implicit strategy of opponents of the MAS was to focus on the politics of the characterization process instead of the science itself because of its complexity.[49] But a requirement for technically qualified expert Commissioners raises questions of cost, over and above the millions already expended in the characterization process, as well as duplication of licensing and regulatory efforts.

COST AND STRUCTURAL FACTORS

To date, the costs for site characterization and review in Illinois have reached $85 million.[50] While the costs have not been borne by the general taxpayer, the public can ultimately expect to pay.[51] All costs for the Siting Commission process were essentially from the same source;[52] while the total of probably millions expended in the Siting Commission's hearing process is not yet and may not be readily known because of characterization contracts that may include siting review participation with other characterization activities, it is not insubstantial and includes the following factors, covering the 71 days of hearing and interim legal and technical activities pertaining thereto.

The Management Act requires that two Siting Commissioners each receive $300 per diem and the chair $500 per diem.[53] The Siting Commission is authorized to hire its own contract staff, executive director, and experts.[54] Vouchers for the selected law firm show legal fees paid at the rate up to $230.00 per hour, and that it received hundreds of thousands for its efforts not only for the 10–12 hours the law firm had several attorneys present at hearing but also for the 6-, 10-, and 12-hour days the law firm had more than one attorney researching issues.[55] Lawyers for Battelle, Chem-Nuclear, DNS, the site characterization team, and additional experts were also present throughout the hearing, researching and preparing witnesses prior to and throughout the hearing process. Site characterization scientists as well as consultants expended innumerable hours and expenses in travelling to and from, preparing and sitting throughout the 70 days of hearings.

Other parties were allowed to seek funding from the Compact Commission. The League of Women Voters solicited grant proposals and approved funding so that the public was represented by its particular counsel and scientists. The Concerned Citizens of Clark County, opponents of the site, received $360,000 for its three lawyers and technical consultants, while People for Responsible Opportunity (PRO), a group supporting the siting in Martinsville, received $121,500.[56] The City of Martinsville too received a grant, over $75,000 for its attorneys, consultants and participation in contract negotiations with DNS on its host agreement.[57]

The Martinsville facilities used for the hearings received rent; a contractor assured that the sound system and set up were satisfactory; the contractors and department had offices established near the hearing locations; air-conditioning during the summer cost $18,000 a month.[58] The Commission staff, virtually all the experts, Concerned Citizens lawyers, department personnel and others, including this author, incurred travel and lodging expenses generally at locations outside of the county at issue. At least two court reporters from Chicago were present and produced over 20,000 pages of transcript. While cost should not be a primary factor, policymakers should ensure they know what they are getting before enacting Siting Commission legislation.

The Siting Commission process also brought parties together in unusual roles. For example, the Commission's staff was on contract to the Department and DNS was required by contract to cooperate with it;[59] however, Commission staff's legal bills were scrutinized and approved by nondepartment personnel.[60] The City of Martinsville, while a litigant before the Siting Commission and supportive of a LLW facility so long as it was safe, at times took on an adversarial role to the Department, particularly during negotiations

on its host community agreement. And at the same time it was a litigant before the Siting Commission and in contract negotiations with DNS, the city also sought funding from the Compact Commission to support its participation in such activities. While the League of Women Voters was set up to approve such funding on behalf of the Compact Commission, the Siting Commission Chairman, Seymour Simon, received and commented on all such requests. Therefore, the individual before who the city, PRO and Concerned Citizens were litigating also passed judgment on funding of the parties, as did the Director of the Department, a Compact Commissioner who ultimately approved funding for city participation even as contract negotiations intensified. The City of Martinsville could not have had legal and technical representation throughout the proceedings without such funding. Policymakers should carefully consider and specifically legislate function of each player and the manner in which participation in such proceedings is to be funded.

LOCAL APPROVAL AND CITIZEN PARTICIPATION

The question of the adequacy of the Commission's enabling legislation and the process it utilized begs the question of the Siting Commission's utility, function, purpose, and advisability in the first place. The goals originally sought to be achieved by the siting process in general, finding a technically and politically acceptable site, are valid and desirable.

However, the benefit of the Commission Review process of bringing the science into the open for public scrutiny, acceptability, and debate can readily be met without a Commission, with less delay and expense, and without facing the problems of duplicating licensing and the regulatory process. Many of the efforts of the Department, Chem-Nuclear, and the City of Martinsville were vastly successful but were eclipsed by the events of 1989. For example, the concrete advisory task force created by the Department of Nuclear Safety brought together first-class experts in the field to identify, among other issues, problems that could be caused by Illinois' wet climate and how to achieve greatest durability, from which Chem-Nuclear drew for its concrete design.[61] Perhaps that process could have involved the public, as well. In addition, one must question whether a legal tribunal subjecting scientists to cross-examination that, by the Siting Commission's own admission, went beyond a normal trial-like procedures, is the best method to independently review the science and involve local citizens.

Both the state and city created citizen advisories. The local citizenry attended briefings on the status of site characterization, brought in lecturers from private and public institutions to address different technical issues and answer the questions raised, met the experts and personnel engaged in the project, and toured other low-level waste facilities. Anyone could attend these meetings.

The City of Martinsville also employed a local geologist, a man generally respected for his integrity, education, and experience to monitor and work with the site characterization team and intended operators of the facility. He met with the scientists at the site, attended their meetings, and reviewed their documentation. He asked tough questions and often requested additional work.[62] Not every technical demand was granted, but additional characterization work at the site was performed by the state at his request in part to satisfy his concerns.[63] His involvement and the state's response in turn provided the city residents and city officials with confidence in the work, but also satisfaction in knowing the state and its contractors listened to, involved, and incorporated local concerns. Though the City of Martinsville had its site opponents, not once during the many years of work on the site were there any significant challenges in local elections, with the Mayor none at all. Indeed, during the unsworn public comment portion of the Siting Commission hearing, the Mayor recalls no Martinsville residents addressing the Commission in opposition to the site nor as active members of the Concerned Citizens of Clark County, site opponents.[64] Following the Commission's decision denying site suitability, Martinsville residents and officials voiced their continued support for the site.[65] Policymakers must therefore also consider what component of the public is to be involved and satisfied.

The Siting Commission in its deliberations expressed concern with the local government approval component and implied such factor doomed the technical process from the outset.[66] Yet, the importance of local siting approval is obvious not only from legislative debate and politicians' comments,[67] but so as to avoid the antithesis of democracy, big government and bureaucrats ignoring the wishes of its citizens and ensuring the smooth operation and cooperation between the facility, local government, and its citizens. Local

government had little role in the siting and permitting of landfills in the '70s in Illinois; that system did not work for a variety of reasons and was altered in 1981 when the local siting approval process was initiated. It would be unwise to eliminate the requirement in LLW disposal siting.

Local government approval combined with contractual obligations must remain a part of the siting process for LLW, just as it is now essential for landfills, incinerators, transfer stations and other facilities involving perceived risks. It is imperative that the local government officials and local citizenry have confidence in believing that the operator and state cannot act without significant input from the citizens most impacted by the facility. Toward that end, the City negotiated its wide-ranging Community Agreement.[68] The Community Agreement provided for job guarantees, local hiring and contract preference, substantial oversight and involvement in major facility alterations, local property value protection, and community benefit fees. Greater control and benefits are always desired, but not necessarily justifiable, just like a Siting Commission's quest for more data. Following its execution, the only criticism of the Agreement was that the city either got too much money, or not enough, and that it failed to provide for long-term health monitoring of its citizens.[69] The community benefit fees are now standard provisions for host agreements for a variety of pollution control facilities, even purely private operations that unlike a state-owned operation continues to pay all taxes; such fees enable, inter alia, the improvements necessary for a small community to sustain the growth in business, industry, schools, and residences that a facility could generate. While the benefit fees and safety factors were important factors, the city never forgot the intangible benefits too, including, for example, the impact nuclear scientists and engineers in its community could have on the local science program, having educated themselves and accepted as reasonable the nature of the risk such a facility affords.[70] As noted in its post-hearing motions, the Martinsville city officials were and still are ready to accept the site and facility as safe, especially given the extra protections provided in the Community Agreement, the Siting Commission decision notwithstanding. While some of the contract provisions were deemed necessary in part due to ambiguities and frequent changes in the LLW laws, adding certainty in the law in a variety of areas would generate greater comfort with the system and likelihood for local approval.

REFERENCES

1. Ill.Rev.Stat. 1991, ch. 111-1/2, par. 1039.2 The procedures for local siting approval is for "regional pollution control facilities" and includes transfer stations, incinerators as well as solid and hazardous waste landfills.

   Christine G. Zeman and her firm represented the City of Martinsville, a small rural town in Southeast Illinois, throughout the proceedings to site a low-level radioactive waste disposal facility within the city's jurisdiction. At the time of writing, the city had filed a Motion to Reconsider and Objections to the decision of the Siting Commission, as well as a Motion to Reopen the Record to consider pertinent activities occurring after the Siting Commission's hearing ended in February, 1992. These pleadings serve in part as a basis for the author's comments. No decision on said Motions had occurred at the time of this writing. Ms. Zeman has also represented several clients in siting proceedings under the regional pollution control facility local siting approval law.

2. Ill.Rev.Stat. 1991, ch. 111-1/2, par. 241-1, et seq.

3. Id.

4. Ill.Rev.Stat. 1989, ch. 111-1/2, par. 241-12. Section 12 of the Management Act required the Director of the Department of Nuclear Safety to designate the site for the development and operation of a LLW disposal facility, provided the site meet several criteria. The criteria remained once the Siting Commission procedure was adopted, though additional language was added requiring the Commission to apply the criteria to the site "with respect to a facility of the proposed design." The additional verbiage unfortunately proved exceedingly ambiguous throughout the Siting Commission's proceedings, as admitted by the Siting Commission in its deliberation (See, e.g. page 20466 of the transcript of the Siting Commission's deliberation of October 9, 1992). Such confusing language should obviously be avoided as policymakers and legislators ponder siting procedures and criteria.

5. Ill.Rev.Stat. 1991, ch. 111-1/2, par. 241-12(b)(6) and (7).

6. Transcript of the deliberation of the Siting Commission on October 9, 1992, at page 20089.

7. See, e.g. Volume IV Assessment of Site Compliance of the Alternative Site Investigation Studies ("ASIS Reports") of the Martinsville Alternative Site ("MAS").

8. See, e.g. License Application of Chem-Nuclear Systems, Inc. to the Illinois Department of Nuclear Safety, May 15, 1991.

9. Siting Commission Transcript, p. 20090.

10. Siting Commission Transcript, p. 20092.

11. Siting Commission Transcript, p. 20093-20100.

12. Siting Commission Transcript, p. 20093.

13. Siting Commission Transcript, p. 20094.

14. Siting Commission Transcript, p. 20093-20100.

15. Siting Commission Transcript, p. 20101, 20107, 20111.

16. Siting Commission Transcript, p. 20110.

17. See, resolutions of the City of Martinsville, 91-6-1 adopted June 5, 1991; 91-1-1 adopted January 9, 1991 and February 3, 1988. It should be noted that the Siting Commission spent substantial time hearing evidence and calling for witnesses not originally scheduled to appear on what it termed "How we got to Martinsville." Siting Commission Transcript at p. 20088-20116, stating, in its interpretation of the record, that the site screening plan changed to accommodate "politics" i.e. Martinsville's local approval. Siting Commission Transcript at page 20115. The City objected to the Commission's inquiry and findings as inconsistent with the law and record. See Motion to Reconsider and Objections of the City of Martinsville, especially pp. 8-14. Further, deleting a local approval component as the Siting Commission appears to suggest would be objectionable to the public, local officials and state politicians.

18. Id.

19. Siting Commission Transcript, p. 20125, 20127 and 20136.

20. Siting Commission Transcript, p. 20136.

21. Siting Commission Transcript, p. 20129.

22. Siting Commission Transcript, p. 20133.

23. Siting Commission Transcript, p. 20123.

24. Transcript of proceedings of the 86th General Assembly, Senate transcript, May 18, 1990, p. 20.

25. Transcript of speech in Florida by Seymour Simon Radioactive Exchange LLW Forum, June 11, 1992, p. 18-20, 24.

26. Siting Commission Transcript, p. 20123, 20152-20229; Transcript of proceedings of the 86th General Assembly, Senate Transcript, May 18, 1990 p. 20-21 on Senate Bill 1761.

27. Id.

28. Florida Simon Speech Transcript, p. 19-22.

29. Id.

30. See, e.g. *Back to Square One in Nuke Waste Site Selection*, Waukegan News—Sun, October 19, 1992; comments by DNS Director Tom Ortciger, Compact Commission meeting, November 17, 1992.

31. Id.

32. Siting Commission Transcript, p. 20456, 20466.

33. Ill.Rev.Stat. 1991, ch. 111-1/2, par. 1039.2.

34. See, e.g. *F.A.C.T. v. IPCB*, 198 Ill.App.3d 541, 555 N.E.2d 1178, appeal denied 133 I11.2d 554, 561 N.E.2d 689; Waste Management of Illinois v. IPCB, 175 Ill.App.3d 1023, 530 N.E.2d 682, appeal denied, 125 I11.2d 575, 537 N.E.2d 819.

35. Id.

36. See, e.g. proceedings on HB 4013 in 1990, 86th General Assembly and HB 6 introduced by Representative Kulas in 1991.

37. Ill.Rev.Stat. 1991, ch. 111-1/2, par.241-12(b)(l)-(7).

38. See, e.g. Letter of Julian D'Esposito, Jr. of Mayer, Brown & Platt on behalf of Chem-Nuclear to the Siting Commission dated November 6, 1992.

39. Id.

40. Id.

41. Siting Commission Transcript, p. 20456, 20466.

42. Siting Commission Transcript, pp. 5872-5873, 7389, 7557, 7575, 11975-11976.

43. Ill.Rev.Stat. 1991, ch. 111-1/2, par. 241-10.1(d).

44. Siting Commission Transcript, p. 20453; Transcript of proceedings of the 86th General Assembly, Senate Transcript, May 18, 1990, pp. 20-22 on Senate Bill 1761.

45. Simon's Florida Speech Transcript, p. 26.

46. Siting Commission Transcript, p. 20506.

47. Siting Commission Transcript, p. 20518-20519.

48. Ill.Rev.Stat. 1991, ch. 111-1/2, par. 1005(a).

49. Comments made personally by counsel for Concerned Citizens of Clark County to the author during Siting Commission proceedings. Siting Commission Transcript makes such strategy obvious.

50. See, e.g. *Edgar Vows No Repeat of Nuclear Dump Snafu*, St. Louis Post Dispatch, October 17, 1992.

51. Each Illinois generator of LLW and each Illinois nuclear power reactor are subject to fees per Section 13 of the Management Act, Ill.Rev.Stat. 1991, ch. 111-1/2, par. 241-13(a)-(c) payable to the LLW Facility Development and Operation Fund.

52. Siting Commission Transcript, p. 20528.

53. Ill.Rev.Stat. 1991, ch. 111-1/2, par. 241-10.1.

54. Id.

55. See, Contract Obligation Documents of the State of Illinois, Contract No. 1244 RUDNCK; Invoices for Representation of the Commission from Thomas F. Geselbracht to Department of Nuclear Safety, October 7, 1992, August 19, 1992, July 20, 1992, etc.

56. Seventh Annual Report of the Central Midwest Interstate LLW Compact Commission, July 1, 1991–June 30, 1992.

57. Id.

58. Simon Florida Speech Transcript, p. 9.

59. See Contract Obligation Documents of the State of Illinois, RUDNCK.

60. Letter of Thomas F. Geselbracht to Shawn W. Denney, October 7, 1992.

61. Siting Commission Transcript, p. 17051.

62. Siting Commission Transcript, p. 20133-20134.

63. Id.

64. Comments of Mayor Truman Dean to the author during Siting Commission proceedings.

65. Comments of Mayor Truman Dean and PRO attorney, Perry Baird to the author in weeks following the Siting Commission decision, October 9, 1992.

66. Siting Commission Transcript, p. 20114-20116.

67. See Transcript of Proceedings of the 86th General Assembly, Senate Transcript, May 18, 1990 on Senate Bill 1761 wherein several legislators repeatedly inquire for assurance that the legislation creating the Siting Commission does not eliminate or alter the veto power of the local government, pp. 22-23; See also, Edgar Vows No Repeat of Nuclear Dump Snafu, supra.

68. Community Agreement between DNS and the City of Martinsville.

69. Comments of those in attendance when the Community Agreement was discussed and later adopted.

70. Comments of city officials to the author during deliberations on the Community Agreement.

Licensing and the North Carolina LLW Project

Patrick Watters
Environmental Engineer
North Carolina Division of Radiation Protection
Raleigh, NC

ABSTRACT

The State of North Carolina was selected in September 1986 by the Southeast Compact as the host state for the next low-level radioactive waste disposal site. The current schedule is to have a license issued by 3/15/95 with the facility operational by 1/1/96. The North Carolina Division of Radiation Protection (DRP) is the responsible regulatory agency conducting the license application review for this facility. The product of the review must be a licensing decision that is technically and ethically correct and defensible against legal challenges. This paper outlines the key organizational and policy elements of the DRP that are essential to achieve a defensible licensing decision from the license application review.

INTRODUCTION

The State of North Carolina was selected in September 1986 by the Southeast Compact as the host state for the next low-level radioactive waste disposal site. Two proposed sites have been selected and are currently undergoing characterization studies. The current schedule is to have a license application submitted by 12/31/93, the license issued by 3/15/95, and the facility open by 1/1/96. This is obviously a very ambitious licensing schedule for a project of this magnitude. Even though litigation has so far had little impact on the project, it could have a significant schedule impact in the future.

As the lead regulatory agency, the Division of Radiation Protection recognizes that the final judgment of our regulatory decision may more than likely occur in a courtroom. From our perspective, success will be measured by how well our licensing decision can stand up to both technical and legal challenges. Achieving this requires that the regulatory process be conducted in a manner that not only meets the letter of the relevant laws and statutes but also is technically and ethically defensible. While we cannot predict the level of technical and legal scrutiny that we will face, several fundamental elements can be implemented in the regulatory process to provide a higher degree of confidence that the licensing decision will meet the technical, legal, and ethical tests.

ORGANIZATION

The first and most basic element necessary to develop a defendable licensing decision is to have the organizational structure of the regulatory agencies founded on three principles:

1. The regulatory agencies must have the expertise available either on staff or via hired independent contractors to perform thorough and competent technical reviews of characterization activities and of the license application.

2. They must have sufficient authority and organizational freedom to apply their expertise to review and critique characterization activities and the license application when needed.

3. The State regulatory agencies must be completely independent of the other State agencies involved with promoting the facility. Having the promoter and regulator under the same organizational roof is a potential recipe for conflict and compromise.

North Carolina has two State agencies with the primary responsibilities for the low-level radioactive waste disposal project. One agency is responsible for development of the project while the other has the regulatory role. The development agency is the Low-Level Radioactive Waste Management Authority

(Authority). The regulatory agency is The Division of Radiation Protection (DRP) of the Department of Environment, Health and Natural Resources. Figure 1 illustrates the relationship between the two agencies.

Low-Level Radioactive Waste Management Authority

The Authority was created within the Department of Administration as the State agency responsible for siting, designing, constructing, operating, and closing the disposal facility. The Authority selected Chem-Nuclear Systems Inc. as their primary contractor to carry out these responsibilities. The Authority was given sole responsibility for the site selection process. Siting procedures and criteria were developed based on North Carolina General Statues and appropriate regulations.

Division of Radiation Protection

The DRP is the State agency with lead responsibility for regulatory control of the facility. This regulatory control covers the regulatory aspects of site characterization, license application review, license issuance, construction, operation and closure. The DRP is also responsible for the coordination of all State agencies and their contractors involved in reviewing the site characterization process and the license application. The DRP is completely independent of the Authority and has the freedom to pursue technical issues.

The technical expertise required for the project is provided by DRP, from numerous other North Carolina State agencies and independent contractors. These agencies and contractors are matrixed together through a Coordination Task Force. The Coordination Task Force (CTF) was established in 1989 and is comprised of representatives from those agencies with essential special expertise as well as those with regulatory or permitting responsibilities applicable to the proposed facility. The charter of the CTF is to ensure that reviews and decisions made by State agencies for the proposed facility are conducted in an effective and timely manner.

The CTF has been an excellent vehicle for communication between State agencies and with the Authority and their contractors to resolve concerns and issues. Resolving technical issues early will help to achieve a higher quality license application. The subsequent license application review and licensing decision will therefore be more defendable.

SITE CHARACTERIZATION REVIEW

An equally important element in helping ensure a defendable licensing decision is approving site characterization plans and monitoring of the site characterization process. Successfully defending an affirmative licensing decision is directly proportional to the quality of the license application, which is a function of the quality of the data gathered during site characterization. Monitoring the data collection activities can help achieve a higher quality technical database that will be the foundation of the license application.

The first level of site characterization monitoring was dictated by North Carolina regulations, which required that the characterization plans be reviewed and approved by the DRP. This provided the DRP the opportunity for early input into the development of the characterization process. Secondly, our regulations require that we hold comprehensive review meetings at least every 90 days to review characterization results and to discuss any modifications that may be needed to the plans. These meetings have been conducted for both sites since late 1991 and have served as an excellent means to monitor and direct the focus of characterization activities.

A surveillance system is also being used by DRP and other State agencies to monitor site characterization activities. Over 200 individual surveillances have been conducted by State agencies on the sites since characterization began in August 1991. As with the 90-day comprehensive review meetings, these surveillances have been an excellent vehicle to monitor and direct the focus of characterization.

One significant caveat must be noted regarding regulatory review of the characterization process. The regulator should monitor the characterization process, but they must remain independent and avoid being prescriptive regarding characterization activities or procedures.

PUBLIC PARTICIPATION

Public participation is also an essential component of a defendable licensing decision. The North Carolina site selection criteria and procedures and the licensing criteria and standards were developed with public participation and include specific requirements for public participation throughout the process of characterization and license application review. Public participation is accomplished by having review committees for the proposed sites and the preferred site and by open public meetings.

Site Designation Review Committees

In each county where a candidate site is being characterized, the county commissioners have appointed an 11-member Site Designation Review Committee (SDRC) as provided for in the North Carolina General Statutes. Each SDRC is eligible to receive a technical assistance grant of $50,000 to help defray costs. SDRC representatives are encouraged to participate in meetings and to comment on any aspect of the project. The SDRCs have hired independent consultants to provide technical assistance on characterization activities.

Preferred Site Committee

Upon designation of the preferred site, the commissioners of each county in which the site is located may appoint an 11-member preferred site local advisory committee. This committee reviews the license application, recommends conditions for licensing, and proposes agreements between the Authority, the operator, and the local government. The committee is funded by an application fee of $100,000 paid by the operator. The local government may negotiate with the Authority on any issue except the need for the facility and the Authority's decisions on the site, operator, and technology. Municipalities are prohibited from annexing volunteer sites or sites that have been selected for characterization.

Openness Policy

The Division of Radiation Protection has always had a policy of openness regarding public participation on this project. The public is encouraged to comment on any aspect of the project at any time. To keep the public informed on project developments, two representatives of each affected county receive a copy of all pertinent correspondence between DRP and the Authority or its contractors. The public is invited to attend and freely participate in the monthly Coordination Task Force meetings as well as the Comprehensive (90-day) Review Meetings. In addition, North Carolina General Statutes require a public hearing prior to issuance of a license.

QUALITY ASSURANCE

Developing and implementing an effective quality assurance (QA) program for the regulatory process can be the most important policy action a regulatory agency can use toward establishing a credible and defendable licensing decision. A well-executed QA program will help provide a planned, systematic and well-documented system by which to conduct the regulatory process.

The QA concepts typically used are taken from the criteria given in 10 CFR 50 and NQA-1. These criteria were originally intended for nuclear reactor construction; therefore, it is important to realize that many of the 10 CFR 50 and NQA-1 criteria do not apply to the regulatory review and licensing process. The primary regulatory role will be to review and evaluate characterization and licensing data and information gathered and submitted by the license applicant versus state and federal guidelines. As a result, the principal objectives that a quality assurance program should accomplish are to:

- Ensure that reviews and evaluations performed by the regulatory agencies are conducted thoroughly and efficiently by qualified personnel

- Ensure that these reviews and evaluations are documented to provide clear objective evidence of the results and conclusions that are formulated.

Basic components needed in a regulatory QA program include the following:

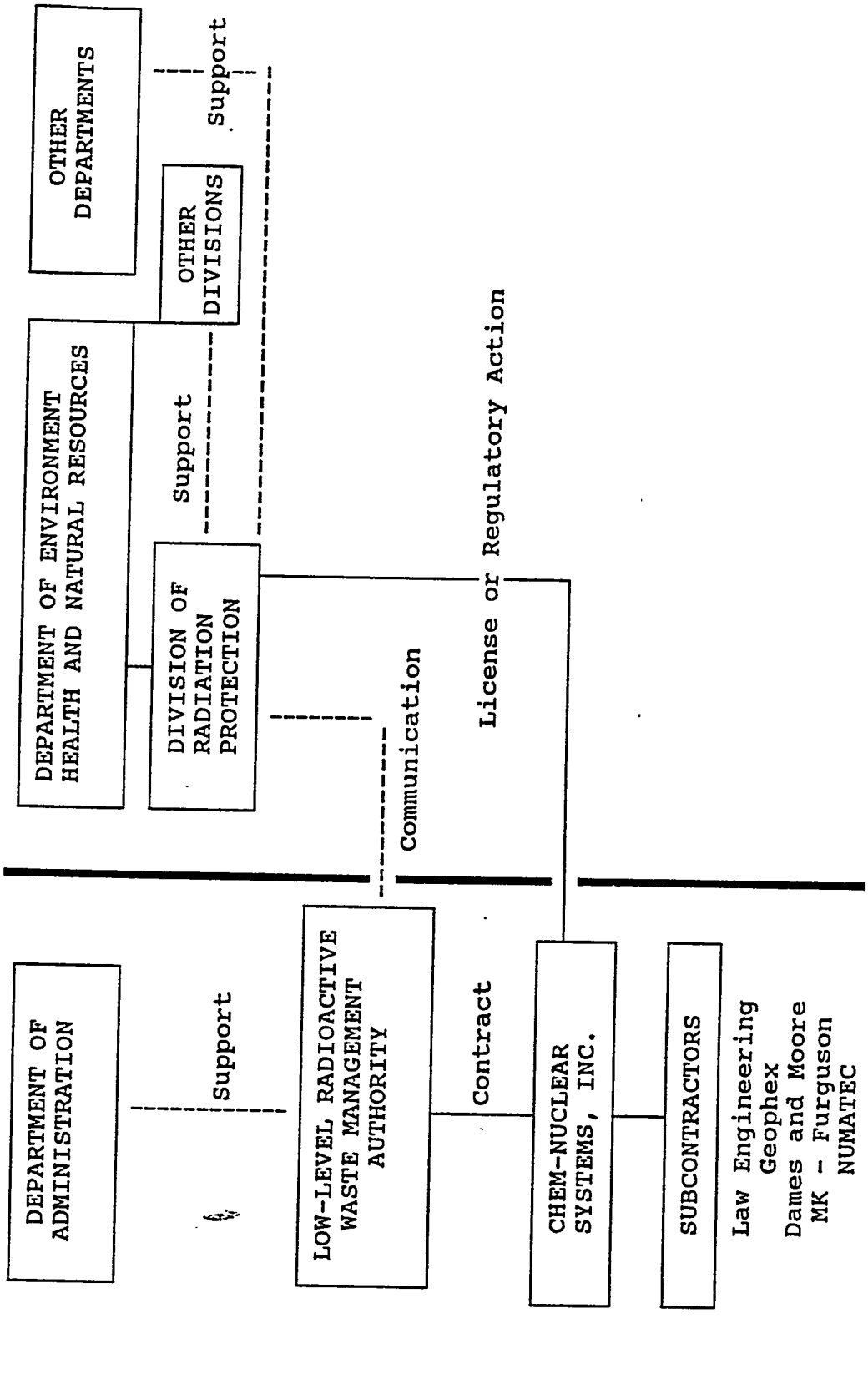
1. Description of the overall QA program (including requirements for key responsibilities, qualification and training requirements, etc.)
2. Document preparation, review and control procedures (includes detailed requirements for the License Application review)
3. Records procedures (storage, retention times, defining of QA and non-QA)
4. Procedures for audits, surveillances and corrective actions (both internal and external).

Other elements such as measuring and test equipment, and purchasing may need to be included in a regulatory QA program depending on the level of responsibilities.

SUMMARY

The concepts expressed here will help to enhance the technical and ethical excellence and legal defensibility of our licensing decision. Licensing a low-level radioactive waste disposal facility is a complex, time consuming, and expensive project with many sensitive social and technical issues. All things nuclear are seemingly subject to scrutiny based on both real and perceived radiological hazards. The time periods of concern associated with radioactive waste disposal are expressed in terms of hundreds or even thousands of years. Some of the studies and analyses conducted for a waste disposal project are often subjective with various degrees of uncertainty. Some of the most important conclusions for these facilities will be based on computer models intended to predict events and consequences many generations into the future. While the scientific and regulatory community cannot provide absolute assurances in an imperfect world, it is important that we take the time to ensure that decisions made for low-level radioactive waste disposal facilities are defendable and based only on sound, ethical scientific investigations conducted with a social conscience.

FIGURE 1
ORGANIZATIONAL RELATIONSHIPS



Who Pays for the Costs of Delay?

Roberta Lovenheim
C. Barrier
Regulatory & Legislative consultants, Inc.
130 E. Main St.
Rochester, NY 14604

I have been asked to deliver a paper on the impact of the costs of delaying the LLW siting process to those licensed to use low-level radioactive materials in their industrial processes, to provide nuclear medicine diagnoses and treatments, to undertake essential biomedical research, to develop new pharmaceuticals, to conduct important academic pursuits, and to provide a safe energy source that does not contribute to global warming or acid rain.

After giving you an overview of the contributory factors to this costly delay, I will cite examples of the impacts and costs. I will conclude with a description of the impact on the licensee and on the general public.

DELAY DEFINED

Let us agree that the "delay" describes the entire period after January 1, 1986. After the sited states first shut down the importation of LLW in 1980, the Low-Level Radioactive Waste Policy Act provided the compromise between the sited states and the 47 states that additional LLW disposal would be on line by January 1, 1986. The failure of the nonsited states to keep those promises resulted in the Amendments Act. The Act added a federally mandated milestone leading to disposal availability in January 1993 and surcharges and penalty surcharges.

THE FLAW IN THE LLRWPAA

Let us first take note that although state governments and Compact Commissions have the responsibility under the Low-Level Radioactive Waste Policy Act Amendments (LLRWPAA) to provide for disposal of LLW, the Act is flawed in that penalties do not accrue to the state and Compact governments in violation of the law or that delay their siting processes. Penalties are imposed on the licensees who use radioactive materials, and who are dependent upon state and Compact governments for action. It is time for us to consider ways to correct this inequity.

It is a fair question to ask that if state governments and Compact Commissions that delay siting safe permanent disposal had to pay damages to generators for costs associated with that delay, would the siting process be stalled as it is now? I suggest that we would see more successful siting outcomes.

COSTLY PENALTIES FOR DELAY

Penalty charges resulting from delay of the siting process accrue to licensees in these ways: (a) substantial penalty surcharges on the costs of available disposal, (b) expensive and extended siting processes for prospective disposal sites, (c) individual generator costs for extended onsite storage, (d) new "privilege-of-being-regulated" taxes, (e) expensive and lengthy litigation, and finally (f) the potential cost of moving to a jurisdiction that is providing safe, environmentally sound, permanent disposal of LLW.

As we analyze the costs of delaying LLW siting process, it is useful to picture a practical unit of cost. For this discussion, the unit of cost will be measured as the average investigator-initiated grant awarded by the National Institutes of Health for biomedical research, last year approximately $125,000 of direct costs for

the research.[a] We can in this way examine our distribution of resources in the context of the AIDS epidemic, the emerging tuberculosis crisis, the need for progress on cancer, diabetes, Alzheimer's, and other diseases of great concern to our nation. Resources expended by licensees on penalty surcharges, special access fees, extended onsite storage, and other costs not directly related to the safety and health considerations of permanent LLW disposal are diverting limited funds from important continuing biomedical research, medical diagnosis and treatment, and job opportunities in the health care and biotech industry, one of the few growth areas of our sagging economy. This is waste of a different character, and one we need to be mindful of during this, the final decade of our century. This is a cost of delay borne by an important portion of the generator community.

Now let us examine the costs of delay in the units of cost just defined. The LLW siting process nationwide has cost since 1986 as much as 10,000,000 average grants awarded by NIH through 1991. Each year of delay increases this number by another 1,500 average grants. From 1986 through the end of 1993, New York State generators alone will spend resources for surcharges, access fees, and penalty surcharges that would have funded 700 average biomedical research grants awarded by NIH.

We must recognize that the cost of delay of the LLW siting process is measurable in diverted valuable resources and has a direct negative effect on public health and safety.

The irony in using the NIH-grant-unit of cost model is that the costs of delay built into current disposal costs reduce the value of the grant received for important biomedical research. The biomedical research community is the community of licensees most affected by the delay in permanent disposal.

PROGRESS ON PERMANENT DISPOSAL IS DELAYED

It has now been twelve years since Congress passed the Low-Level Waste Policy Act of 1980, which made each state responsible for the disposal of low-level waste generated within its borders. To date, no new state or compact disposal sites have opened. In the site closest to being operational, the Ward Valley site in California, development has been brought to a standstill. While a license application was submitted in late 1989, and public hearings were held in July 1991, final approval of the site has been delayed for close to a year in part because of a legal battle to decide whether the state's Department of Health has the authority to conduct prelicensing adjudicatory hearings.

Unfortunately, this scenario is not uncommon. The history of low-level waste site development in this country is more a history of delay and litigation than of actual site development. This delay in siting has many causes.

WHAT CAUSES DELAYS?

Delays arise because of perceived lack of public acceptance and overlapping regulatory jurisdictions, whether through legislation or simple use of influence. Some obstacles to speedy site development are the result of the bureaucratic delays common to any enterprise regulated by government and are compounded when several agencies on the state and federal level are regulating the same effort simultaneously.

Because this is an issue that causes strong constituent response, politicians often think that opposing site development is a stance beneficial to their incumbency. That attitude can cause lawsuits on both the local and state level to block siting, especially if a site is selected in the incumbent's district. Finally, companies, institutions, and states have been embroiled in many lawsuits to determine who has the right to regulate whom and how, and, of course, whose fault it is that sites are not available already.

---

a. After the NIH determines that a research project is worthy, it is still a long way from being funded. Last year only 12% of worthy projects were fundable. This was due to the depletion of funds from the Federal budget because of these difficult economic times.

GENERATORS ARE AND HAVE BEEN RESPONSIBLE FOR THEIR LLW

Licensees have always been and continue to be responsible for management of their LLW. Governmental responsibility for the licensing and regulation of the management of LLW was established in the belief that it better protect the public interest against private interests. Licensees, while financially supporting the whole siting process, have consented this to model, because it provided an appropriate focus and regulatory structure for the long-term protection of the public health and safety. However, licensees are not specialists in long-term waste management, they are experts in biomedical research, biotechnology, nuclear medicine, or a specialized industrial process or technology. The facilities they work in, including hospitals, academic institutions, pharmaceutical companies, electric power stations, and other industry, have been located on sites that are appropriate for the beneficial services they provide. These have not been placed on sites that are suitable for long-term management of low-level radioactive waste.

Among the responsibilities licensees must willingly undertake is to meet federal, state, and local laws and regulations on management of LLW until it can be shipped for disposal. And governmental responsibility for the siting process in their state or compact region is among the requirements they, too, must adhere to. And, as a result of anticipated loss of access to low-level radioactive waste disposal, generators have had to adapt by closing businesses, not expanding businesses in the U.S., denying needed medical diagnosis and treatment, and reducing plans for biomedical research activities. This economic impact cannot be overstated.

LITIGATION COSTS ADD TO THE COST OF DELAYS

Litigation costs—both the costs of being defendant or plaintiff and the costs incurred by interested parties in filing amicus briefs—make up a substantial part of the national expense of developing sites. Experience places the briefing costs of a typical case at $50,000 minimum. The total cost of the New York State case that was heard in the Supreme Court was upwards of two million dollars, including private attorney's fees and the cost of the involvement of state and federal officials.

A representative of U.S. Ecology estimates that the costs of litigation over the Ward Valley site will reach at least half a million dollars for his company alone. And that estimate does not include the ongoing operational costs during the impasse, such as environmental monitoring and loan payments, which they must continue to pay while the site produces no revenue. Including those costs, U.S. Ecology says it is costing them about three-quarters of a million dollars a month to stand still while the site is delayed. And California is no closer to having a functioning site than it was last December, when things ground to a halt.

While not all sites are being privately developed, and consequently interest payments are not a universal concern, with nine or ten lawsuits in the past few years in the federal courts alone, and more than 20 petitioners and respondents involved, those litigation costs amount to many millions of dollars. In the New York case alone, there were four amicus briefs filed by 19 states and territories and the Council of State Governments for the petitioners, and three states intervened on behalf of the respondents.

There are other costs to licensees when lawsuits are initiated. Because lawsuits delay the siting process, generators have to find alternative means of disposing the waste they produce, or temporary storage options must be pursued.

In New York State, where there are about 400 generators, the cost of storage can be conservatively estimated to be at least $45,000,000. One generator in Ohio, Centerior Corporation, has built two storage facilities at a cost of three million dollars each to guard against further litigious delays. The Wall Street Journal reported a few weeks ago that a storage facility is being built in Indiana at a cost of $10 million. Some onsite storage facilities at nonutility sites in Connecticut cost as much as $1 million.

Freezer space is an essential feature of storage of biomedical waste. Since freezers take up an enormous amount of room, Yale University purchased a bakery to use for freezer storage space. Albany Medical College plans to convert patient care space and an old emergency room, for its needed freezer space. (I will discuss these plans later in this paper.)

In Michigan, where many generators are filing 10 CFR 20.302 permit applications for alternative onsite disposal, a Michrad Board member related that the research department of a large "chemical corporation" informed the state that they would have to move their research activities if prompt consideration were not given to their application. The result is, research departments at three facilities in Michigan are moving, including more than 100 jobs. And this story is not unusual.

LITIGATION IS A LINCHPIN IN THE STRATEGY OF DELAY

Opponents to the LLW siting process have been practicing a consistent strategy of delay, hoping to shut down the use of radioactive materials. In addition to these grave problems, the licensees that use radioactive material have had to deal with the reluctance of politicians and bureaucrats to move more quickly in the face of more lawsuits—and, therefore, such an intolerable situation is created for many generators that more lawsuits result. In July 1992, the regents of the University of Michigan filed suit against the several state agencies asking the court to, among other things, issue a writ of Mandamus "compelling" them "to locate, construct, and operate a LLW disposal site." Michigan's waste is currently being stored by generators on site as the result of a decision by the Sixth Circuit Court of Appeals, which stated that states do not have to accept Michigan's waste for disposal. If anyone here remembers the Barney Miller episode that resulted from the storage of biomedical wastes on site in Manhattan when generators were cut off from disposal sites in 1980, you will get some idea of the sort of litigious problems hospitals and other licensees may have to face when people start to realize they have a site located, not just in their county, but in the hospital next door. New York State alone would have nearly 400 such sites without access to Barnwell starting January 1, 1993, and without a site available by June 30, 1994.

ACCESS COSTS ARE THIRTY TIMES WHAT THEY WERE IN 1986

Even if generators can temporarily ship out of state for disposal, every delay increases surcharge costs and therefore increases disposal costs. The total cost in surcharges alone to NYS generators from 1986-1993 will have been slightly over 69 million dollars, having risen from $\$10/ft^3$ in 1986 to $\$277/ft^3$ starting in 1993. When you consider that in most cases money for storage or disposal has to come out of a generator's general operating budget, and has to be subtracted from monies available for things such as medical research, it becomes clear that the cost of delays has a value that dollars alone cannot adequately describe. When limited economic resources are used for aspects of waste disposal that provide no improvement in public health and safety, these funds are wasted.

Many hospitals and medical research facilities have found that monies earmarked for research or medical treatment must increasingly go to storage and disposal costs. While hospitals can, in most cases, ultimately pass along part of the cost of disposal to third-party payers or to patients receiving treatment, research facilities are largely dependent on fixed grants for funding and cannot compensate for the added costs of dealing with waste. Unfortunately, some generators are so squeezed for space that they have to contemplate using space currently devoted to other operations, including patient care, to store their wastes. For example, Albany Medical College, in Albany, NY, estimated that for 1993-1996 that they will need 10,000 ft^3 of storage space, including 5,000 ft^3 of freezer space for animal carcasses. (Those animals, by the way, now cost approximately as much to dispose of as they do to purchase and keep alive). The renovation costs for this project were estimated at over $100,000 in 1991, and to find the space, AMC is considering using patient care space.

This is by no means an unusual situation—Albany Medical College is one of NYS's smaller biomedical generators, producing only 608 ft^3 in 1991, according to the NYSERDA report for that year. A leading New York City cancer center produced 2,503 ft^3 of LLW last year according to the same report (which was, by the way, more waste volume than two New York nuclear power stations produced). The combined waste volume of two other NYC hospitals and research centers also outstripped the volume produced by either of those New York power stations. In a city where space is incredibly tight and incredibly expensive, one can imagine that the costs of onsite storage would be astronomical even if space could be found.

Other costs for temporary storage due to delay include financial reserves for decontamination and decommissioning, Department of Health, Department of Labor, and Building Code requirements, and the cost of siting storage facilities in potentially unwilling neighborhoods. These financial constraints must ultimately act to curtail research; although, while the amount of the average NIH grant has doubled since 1970, the cost of disposal of minimally radioactive animal carcasses is now 22 times what it was 22 years ago.

THE IMPACT OF DELAY ON AVAILABILITY OF ISOTOPES

We now rely heavily upon imported isotopes for biomedical research, pharmaceutical development, and nuclear medicine. There have been numerous reports of shortage of isotopes. In March 1991, hospitals in the Buffalo, NY, area had to stop nuclear medical procedures for several days because Atomic Energy of Canada, Ltd., which is the only source of some critical isotopes that many U.S. institutions use, could not ship the needed isotopes. Nine hundred patients in the Buffalo area could not be given tests critical for correct diagnoses and treatment, like organ scans, stress tests for heart patients and dosage tests for patients receiving cancer treatment. Whereas much of the isotopic material used by hospitals has a short half-life, it also has a short shelf life and the supply needs to be replenished frequently.

According to the October 1992 issue of *Scientific American*, a threatened strike at Nordion International in Ontario would have also jeopardized the supply of molybdenum 99, which is used to generate technetium 99 that is then used to diagnose diseases including cancer, AIDS, and heart disease. Now that the delayed siting process in NYS has resulted in the major American supplier of isotopes closing down, eliminating over 100 jobs, we are dependent on an unreliable, single source of isotopes—that fact alone is a threat to public safety and health.

WHO PAYS FOR THE COSTS OF DELAY?

Who pays for the costs of delay? We all do. We lose when biomedical research must be curtailed because government has not succeeded in its mission to finish siting permanent disposal facilities for LLW. We lose when nuclear medicine diagnostic and treatment procedures must be delayed or transferred to other institutions. We lose when delays result in higher electricity rates, when isotope shortages increase for all research and diagnostic purposes, or when jobs are moved to Canada or Europe because the U.S. political system has paralyzed itself over the assignment of conducting appropriate environmental screening and establishing safe, permanent disposal facilities. We must solve this crisis in leadership before our national crisis over LLW disposal abridges public health and safety and reduces our quality of life.

Dealing with Radioactive Waste without Access to Disposal

Walter T. MacRae, P.E.
American Electric Power Service Corporation

Low-level radioactive waste is generated in a variety of ways. Though the waste generators in the State of Michigan lost their access to disposal two years ago, waste has continued to be generated, and we have to deal with the storage of that waste. For the most part this has meant storage, but this has also included accelerated waste minimization programs and the elimination of some practices that generate low-level radioactive waste. The purpose of this paper is to answer four questions. First, what is being done at the Indiana Michigan Power Company's Donald C. Cook Nuclear Plant? Second, what is being done by the State of Michigan? What is it going to cost waste generators? And, finally, what is in the future?

The Indiana Michigan Power Company's Donald C. Cook Nuclear Plant is a two-unit facility that produces about 8,000 ft^3 of low-level radioactive waste per year. Since November 1990, the plant has been unable to dispose of its waste. In response to this need, (originally in response to a future need), the Radioactive Material Building was built. It was completed on April 1, 1992. It is designed to hold 80,000 ft^3 of waste. We will have about 10 years worth of storage before it needs to be expanded. The building has four functionally distinct areas. They are the cell area, the truck bay, the dry activated waste (DAW) area and the service area.

The cell area is used to hold the more highly radioactive waste. Typically, the water processing wastes, resins and filters, will be stored here in high-integrity containers (HICs). There are 12 cells. Each can hold five HICs. We tried to design flexibility into the design, so items other than HICs can be stored here. This area is intended for any of the highest dose containers. The exterior walls are 30 inches of poured concrete. The internal cell walls are 12 inches thick. Each cell has a 24-inch-thick cover on it.

The material is moved in and out of the cell area using a crane. This crane can be operated in the cell area and truck bay, or it can be controlled from a remote console in the service area. There are five cameras to aid in using the crane from the remote console. There are nine HICs in storage, and most of them have been put in place using the remote console.

The building was designed for expansion. There are removable block walls in the cell area. This opening can be used for expansion. The building was designed with the ability of doubling the cell area if needed.

The next area is the truck bay. The truck bay is large enough to hold a full cab and trailer. There is a dock in the truck bay that allows access to the truck from two sides. There will be a ramp that will allow a forklift to drive onto the truck to help unload boxes of DAW.

The DAW will be stored in a large open room. The waste will be stored in this area using a fork lift. The waste is stored in this area in boxes. In the entire building, provisions were made to be able to double the size of the building. This included leaving spare conduits and flanged drain lines. Archways in the DAW area were built into the walls and then filled with concrete. Future expansion will be through those archways. The walls to this section are 12 inches thick. The thickness is a structural requirement rather than a shielding one. More shielding was provided than needed, but it was readily accepted.

The final area is the service area. It contains the remote console for the crane, general office space, the necessary equipment rooms and a restroom.

We have also been concerned about waste form and the periodic inspection of the waste. Criteria and programs have been developed to insure the waste will remain as safe as possible, and, hopefully, the waste will be in a form that will meet the regulations for transportation and burial in the distant future. We will store compacted DAW in IP-2 boxes, and dewatered resins and filters in HICs. The transportation rules have been on the verge of changing for many years. The new rules will incorporate the international requirements

for containers. Therefore, to preclude the possibility of repackaging the waste, it will be put into IP-2 containers. The more difficult choice was the form for the resins. Many options for waste forms of resin type waste have been discussed. We will put the resins and filters into HICs, and dewater them. In that form, it is acceptable for burial today, and if the rules change, it will be in the easiest form to rework into the form required by the regulations.

To ensure that the waste remains intact, a periodic inspection program was developed. The inspection program has three required surveillance cycles. First, there is a monthly requirement to survey to meet the radiation protection requirements. At a minimum frequency of once a month, all areas at the plant are required to be surveyed for radiation dose rates and contamination levels. This is especially important in the Radioactive Material Building; it can be an indicator of a problem in the facility. Second, there is a quarterly requirement to inspect the packages. They are inspected to determine if any are degrading. Third, are the weekly inspections of the mixed waste. To meet the requirements of Tile 40, the hazardous waste must be inspected weekly. Therefore, the mixed waste, waste that is both hazardous and radioactive, is inspected weekly.

The Radioactive Material Building meets the requirements for the interim storage of hazardous waste. It meets the requirements for spill control, fire protection, communication and other needs. In addition, to fully control the material, it is required that each barrel of mixed waste be placed in a corrosion resistant overpack, and be placed on a spill containment skid.

Along with the technical issues on the storage of waste are the regulatory issues. Specifically important to us are the issue of the receipt back of waste from offsite waste processors, and the five-year "rule." Even though all the technical issues can easily be met, the regulatory issues can become confounding, especially given the influence of political issues on the enforcement of regulations.

Offsite processors are used by many power reactors as an economic means of dealing with the radioactive waste. Offsite processors can achieve better volume reduction, and remove nonradioactive material from the waste stream. When burial was available, it was not a problem. The waste would be sent to the processor. They would do their magic, and send the resulting waste to the burial site. However, without access to disposal, the waste needs to be returned to the waste generator. This created some regulatory concerns, because the NRC believes that the waste generators with 10 CFR Part 50 licenses did not have the authority to receive their waste back. To fix the problem the NRC developed new rules to allow that practice. The new rule was issued on October 21, 1992, and it gave specific authority to power plants per 10 CFR 50, to receive back waste processed offsite. The rule will become effective on November 20, 1992.

The other pressing regulatory issue is the five-year "rule." I put the word rule in quotations because it is not a regulation, but it may be perceived to be one. The five-year issue was first mentioned in Generic Letter 81-38. It is also the typical period for a 10 CFR Part 30 license. What it means is that was could only be stored onsite without an amendment to the license or without a new Part 30 license for five years. It is my opinion that the Cook Plant can store the waste onsite as long as the 10 CFR Part 50 license is in place. This assumes that the storage of waste does not create an unreviewed safety question and is documented in a 10 CFR 50.59 review. This issued must be resolved by the NRC now, while it can still be approached rationally. It cannot wait until the issue becomes a crisis, and is forced to become a political issue.

That summarizes what the we are doing at the Cook Plant, and it highlights the issues of concern in dealing with the radioactive waste without disposal. We got into this mess because of the lack progress by the State of Michigan, and we will only get out of it if Michigan proceeds. Therefore, it is important to review what the State of Michigan is doing.

Because of a few issues, Michigan has been unable to move forward. First was the unexpected defeat of Governor Blanchard, second was its troubled relationship with the Midwest Compact, and third was the loss of access. Finally, after the U.S. Supreme Court ruling on the Low-level Waste Policy Act, Michigan has decided to move forward albeit very slowly. So what is Michigan doing?

They are trying to meet their financial repayment obligations to the Midwest compact. They have included the repayment of the Midwest Compact in their 1993 budget. Even though we are now in Michigan's 1993 fiscal year, they have not yet resolved the budget. And it is expected that the budget arguments will last into next year. But, the Governor has personally supported the repayment of the compact.

The State has also publicly acknowledged that they have a legal responsibility to dispose of the waste generated in Michigan. This occurred after the Supreme Court Ruling. Before then, they were unwilling to take a position that the ruling may have let them get out of. Since that did not happen, they have accepted their fate.

As part of their expulsion from the Midwest compact, it was often cited that their siting criteria were too strict. They are establishing a Policy Advisory Board to review siting a disposal facility and to review storage issues, and then to report those issues back to the Governor. Finally, they have been working to meet with the representative form South Carolina to explore getting access back for generators.

The storage of waste is not cheap. The last time we permanently stored our waste (disposal), the costs were less than it will cost us to store the same waste. At the Cook Plant, the cost to store all the waste generated for the next ten years is about $\$130/ft^3$. This includes all the cost needed to store the waste, and includes all the capital, operational and maintenance costs. It does not include the final disposal cost. For nonutility generators, if a central facility was developed for them, their cost for a facility able to store ten years of waste would be about $\$300/ft^3$. There are two reasons for the big difference between the sites. First, is the economy of scale. The more waste designed for the lower the total cost per unit. Second, are the licensing costs. A new facility would require new licensing studies, emergency plans, environmental monitoring, and other items. Most of these are in place for an existing facility.

The final storage cost will be the disposal cost. It will not go down, so we may be looking at a future cost of more than $\$1000/ft^3$. At the 1993 rates, it will cost the Cook Plant more than $5 million to dispose of the waste we have on site now. Work is already in progress to establish an escrow fund similar to the one established for decommissioning, so that if disposal ever becomes available the financial shock will not be too great.

The future for Michigan waste generators is not bright, but it is not fatal. The power plants and universities are in the best position. They can develop enough storage to last them a long time. Power plants can store their waste until the end of life of the plant. The waste will become a problem when the plants need to be decommissioned. Hospitals will not stop treatments, but will limit the amount of research being done. The small industrial users will be the hardest hit. Most will either stop using the material, move their operations to another state or go out of business.

The victims of the mess in Michigan and the mess throughout the country are hard to specifically point out, but they will be the people for whom no new products will be developed to improve the quality of their lives. The largest impact will be on research. Either the research will not get done, or because of costs, less will be done. Universities will have to charge the additional costs to the research grants, leaving less money for research. Hospitals may forfeit their research to ensure that they have the space and the money to handle the radioactive wastes from treatment. There are a variety of medical, agricultural, industrial and engineering research projects going on that radioactive material is essential to. In Michigan research is being done on AIDS, fetal heart drugs, disease resistant crops and other topics. The lost of this research will lower the potential quality of life for all of us.

Current and Future Economic Impacts of Onsite Storage A National Perspective

Janis D. Stelluto
NELRAD, an New England association of the medical, research, university, industrial, and utility communities
Boston, MA 02118

INTRODUCTION

Since *no one* seems willing to assume responsibility for disposal of low-level radioactive waste, *everyone* gets to have some stored nearby . . . at the research laboratory, at universities and medical centers, engineering companies, . . . in neighborhoods, in communities.

States and regions that do not have reasonable assurance that disposal capacity will be available when currently operating facilities close have stated the policy that LLW will be stored on site until new capacity is secured. That leaves all states and regions, except the Northwest and Rocky Mountain Compact regions, with such a policy. Impacts from that policy have already been experienced in Michigan and are anticipated in other states—economic impacts, health and safety impacts, and management impacts.

Products and services that rely on having radioactive materials available are clearly in demand: scientists require radioactive labeled compounds for definitive studies as they investigate both the origins and possible treatments for disease—AIDS, Alzheimer's and cancer; cardiologists rely on thallium studies to track heart disease and circulatory disorders; engineers count on their radioactive source devices to test the integrity of welds on bridges, building frames, and transformer towers. . . . These uses of radioactive materials lead to waste byproducts that also have some radioactive component.

Waste managers from companies and institutions with LLW cringe when they are asked about their attitude toward the official state or compact policy of onsite storage. They express grave concern over the uncertainty that lies ahead. They are accustomed to an orderly process, set by uniform standards and guidelines, and that level of order is clearly missing in regulatory guidance for onsite storage. Both Nuclear Regulatory Commission and state guidance rely on individual evaluation of individual licensee plans for waste storage. Licensees are advised that they will be informed if their plans for storage are not adequate. Standards for evaluation have not been established and licensees are uncertain about agency expectations.

Beyond the commonality of uncertainty, few generalizations about the impacts of onsite storage can be made. There is no universe of data; there are no averages to extrapolate from. LLW management is as unique and tailored to company or institution management policy as the products and services that they deliver. Material and information gathered for this paper are anecdotal; managers have talked freely and candidly with me, all with the understanding that company and institution names would not be used.

Behavior patterns do emerge; some trends are evident; concern for responsibility runs deep; and we can probably count on less and less LLW as time goes on.

Waste managers anticipate reassigning and adding employees for LLW management, without knowing the rules of the policy. Waste will be packaged under current regulations for disposal in currently operating facilities, or according to proposed regulations for facilities to be developed sometime in the future, with no certainty that regulations will be the same when the waste is finally shipped for disposal. Space will be secured for LLW storage—space that otherwise might be used for research or computers and equipment, open space, or patient, student or employee parking—for an uncertain period of time. All those provisions translate to economic impact as budgets are examined, assigning more money to LLW management to meet uncertain requirements for unknown periods of time. *Uncertainty* is the recurring state of mind, compounded by the South Carolina/Southeast Compact Policy that may allow continued use of the Barnwell disposal facility for an uncertain length of time.

LLW MANAGEMENT AND DISPOSAL

History of LLW Management

To assess the probable impacts of onsite storage, we might review the practices and evolution of LLW management over the past 12 years. Waste management has become a science in its own right, a profitable business with incentive to advance it further. Each step in the management process has a tradeoff, and, as the history shows, improvements in waste form are a result of hands-on management, trading off advances in management for employment costs and accompanying health and safety precautions as more people and processes are involved.

In the "old days," that is the late '70s and early '80s, before the high cost of disposal and consciousness raising, LLW management was relatively simple: when material in a laboratory or plant had reached the end of its intended use and was called WASTE, it went to an onsite LLW preparation area where it was "packaged" and held until enough accumulated to truck for disposal.

As the cost of disposal increased after the 1980 LLW Policy Act, with more management at the disposal facilities, new costs charged to disposal, and normal increases over time, there was incentive to ship less waste—cost avoidance through disposal avoidance. Waste management then introduced methods of volume reduction, adding steps to achieve less volume: LLW sorting and segregating; material reclamation and recycling, where appropriate; physical reduction by compaction or incineration, where permitted; and finally packaging and shipping for disposal by a new level of safety standard. This in-house volume reduction required equipment and operations employees, trading off disposal costs with the onsite management and associated costs.

The next step was waste minimization, where management in the laboratory and plant controlled the amount of waste generated, requiring less of both treatment and disposal. However, with less waste, it is held longer in order to have a full load for shipping, or it may be sent to a broker where waste from several licensees is held to accumulate for shipping for disposal, in both cases trading reduced volume for additional handling and employee contact.

Through the '80s and into the '90s disposal costs continued to be driven higher by surcharges and waste management operations, and licensee incentive for disposal avoidance increased. That led to a new order of waste minimization and a new industry of volume reduction by contract, whereby licensees ship waste for supercompaction or incineration before being shipped for disposal. Thus far, the cost of waste volume reduction is less than the cost of disposal, and licensees show a preference for more reduction and less disposal.

Onsite Storage of LLW

But, alas, disposal capacity availability will come to an end. Companies and institutions that depend on having radioactive materials available are preparing for a new generation of waste management: "storage at the point of origin."

Waste management practices of the '90s—onsite management and treatment and volume reduction by contract—will continue; however, neither will be able to truck the sorted and reduced and stabilized waste form for disposal. Instead, it will remain at, or be returned to, the point of origin, to be stored for an uncertain period of time until disposal capacity is available. When LLW is returned, more hands-on management is required to unload, place in storage, and then provide careful watch over the waste until sometime in the future when it will be shipped for disposal.

To a licensee, planning and preparation for the inevitable onsite storage has begun; however, many of those plans have been suspended as contracts for continued disposal at Barnwell are negotiated. Several companies with campus settings and real estate are preparing space to accommodate onsite storage. In one case, building plans for an underground parking garage now include a LLW storage area; in another, empty

basement space has been roped off and secured for LLW storage. Existing storage-for-decay facilities are planned for expansion with necessary provisions for "interim, longer-term storage."

University and hospital campuses, with less real estate, more participatory management, and more general population access, find similar provision more difficult. On blueprint paper, a proposal to store LLW in a library basement appeared to be responsible planning; faculty objections have scuttled the suggestion. Nearly all plans include waste minimization through operations management; many include volume reduction equipment, with costs varying from a few thousand dollars to well over $100,000 for a state-of-the-art compactor. The most costly and most difficult storage to provide for appears to be freezer space, necessary for tissue waste, which is a predictable byproduct of life science and molecular biology research.

Each step adds costs. Each operation and equipment purchase adds cost. Meticulous recordkeeping of each operation adds costs. A midwestern university medical center reported in 1987 that they had already expanded their LLW program from a two-person operation to a program with 12 employees and a budget of $650,000. As companies and institutions plan to accumulate stored waste, they will require license amendments to increase their radioactive materials possession limits; license applications and review impose costs of both personnel time and money. At the same time, with increased possession limits, the NRC requirement for trust funds or set-aside funds for financial assurance for proper decommissioning will require greater amounts of dedicated money, resulting in higher costs to customers, or reduced services, or more conservative projects.

Onsite storage has already begun in Michigan, which two years ago was denied access to existing disposal facilities. More than 50 licensees in the state are already storing LLW at the point of origin. Michigan experience affirms that there are no averages and generalizations in the LLW issue. There are as many reactions to the onsite storage policy as there are licensees in the state. At one of the universities, preparations for storage began several years ago, providing warehouse space that is now an "interim" storage facility; other licensees prepare space for a few months at a time. The cost of providing space and management services ranges from $2000 to $20,000, annually, to the extreme case of a utility investing $10 million to provide storage capacity for 80,000 cubic feet of waste, a projected ten-year accumulation. Public reaction to the new practices appears to be relatively calm; however, licensees, once viewed as providers of services, employers, or sites of advanced research and social benefit, have in a year's time, become "LLW generators and storers."

WASTE AWARENESS AND AVOIDANCE

Waste awareness that aims for waste avoidance has become the norm. One university that has already reached an admirable plateau of LLW minimization, has announced plans to allow radionuclide use by permit only after January 1, 1993. The policy recommends use of substitutes whenever possible—short-lived radionuclides, fluorescents if effective, or substitute projects if defensible. When permits are granted for projects that will use longer-lived radionuclides and will result in LLW, the individual laboratory or researcher will have to pay $17,000 for each barrel of waste. That amount was arrived in the following way:

$ space + $ safety provisions + [management(x years)]
+ $ projected cost of disposal = $17,000/55 gallon drum.

"How so cheap?" A supportive university administration calculated the cost of retrofitting existing space to meet "onsite" storage requirements to be only $50-60,000 for the expected one hundred drums over 12 years, rather than the $1,000,000 that might realistically be expected if all known requirements for "onsite" storage were included in the charge, or if a new building or land acquisition were necessary.

Requirements for onsite storage include the following:

Protection from the elements

Security provisions

Fire protection

Plumbing and utilities

Provisions for natural disaster

Recordkeeping

Personnel

Waste packaged and ready for disposal

Provision for routine monitoring and inspection

Freezer space for tissue waste.

The impact of such provisions varies from institution to institution, depending to some degree on how the costs are charged. Until recently, in most institutions, waste management has been charged to general administrative overhead, costs subtracted from appropriations and grants before the money reaches the project. In those circumstances the institution passes responsibility for cost-containment to the waste management program, which in turn promotes programs of waste avoidance. In other cases, and becoming more common, the project or the individual researcher is charged with the project overhead, including waste management. The result really is the same: waste minimization, or avoidance, in order to maintain ultimate funds for the research project itself.

We have heard a great deal about overhead costs in universities in the last years; these are the kinds of issues and requirements that make up that overhead, known to reach 80% of certain project costs. Grantors appear to be catching on; at one university, National Institute of Health grants have required that overhead be reduced from 52% of the total grant allocation to 24%.

The economic tenet "There is no free lunch," or "There are no decisions without trade-offs," applies to waste avoidance. We have to ask, "what are the real costs? Where will services be cut to meet those overhead reduction requirements? Are projects denied to avoid waste storage costs—costs that include more than dollars: space, employee assignment, and perceived good neighbor policy?"

I did not discover any instances where a project had actually been rejected because of its waste implications. However, in safety management they talk of "opportunities lost," pointing out that we cannot know the projects that were not proposed or developed that might have been if waste were not so costly or inconvenient to manage on site.

ADVANTAGES OF STORAGE

Not all licensees consider the prospect of onsite storage a disaster—either as a management or economic issue. In fact, some licensees with small amounts of waste and narrow profit margins count on storage for some economic relief, as they may avoid the increasingly high cost of disposal. A few larger companies, with greater volume of LLW, existing space, and a history of "storing for decay" have invested in preparing for storage and hope to see return on that investment.

The South Carolina/Southeast Compact offer for continued disposal at the Barnwell facility may set a new benchmark for measuring this economic impact. Access privileges are currently offered at $220 per cubic foot surcharge—before disposal, handling or transportation charges, which may total $100-$150. If storage can be provided at less than $2700 per drum of LLW, it may appeal to some licensees as a least-cost or return-on-investment option.

ONSITE STORAGE AVOIDANCE

For the most part, licensees concur on a strong preference for "onsite storage avoidance," even in the cases where it comes with considerable potential cost-saving. Potential problems in LLW management are far less likely in facilities of permanent emplacement with sole responsibility for LLW management than in temporary quarters where there are employees with varied responsibilities. The "inadvertent intruder," controlled against in NRC regulation, is far less likely at a disposal facility than at a licensee location, where storage space may have served another purpose in the past.

Historically, responsible LLW management has included safe disposal at a properly managed disposal facility, and with the record of sound performance, most companies and institutions will elect to dispose of LLW as soon as practical, leaving long-term surveillance to disposal facility operations, thereby reserving their own company/institution resources for their primary service or product.

SUMMARY

Current policy that depends on low-level radioactive waste storage and preparation for storage have an impact on the LLW situation. Some of the impact can be described as economic; much of it is in management, which will, in turn, affect the business side and overall economics. Radioactive materials users are preparing for the time when disposal capacity will not be available.

Not all licensees anticipate additional cost. In fact, many will avoid the need for storage by avoiding LLW in the first place, with the bonus of potentially less cost. The impacts and tradeoffs of this waste avoidance policy have not been measured yet.

However, responsible LLW management includes long-term maintenance and surveillance in properly and safely operated disposal facilities. The policy on ONSITE STORAGE AVOIDANCE favored by most licensees should become a national LLW program goal. That program must recognize the economic and health and safety impacts of onsite storage and work for a national, responsible LLW disposal policy.

REFERENCES

The information used to prepare this paper was assembled from personal interviews with institution and company waste management and radiation safety personnel throughout the country. The nature of the information defies specific quotations and citation. Data have been aggregated and generalized, to the extent practical, and then disaggregated in order to draw conclusions.

Defusing Hysteria: How Institutional Generators of LLW Can Make Allies, Not Adversaries, of Their Residential Neighbors

Christopher Collins
Former Chair, Manhattan Community Board 8
New York City, NY

COMMUNITY PLANNING BOARDS IN NEW YORK CITY

Because of its size and complexity, the government of the City of New York consists of more than its Mayor and 51-member City Council. At its most localized level, New York is divided into 59 Community Planning Boards, commonly referred to as Community Boards (CBs). Created by the City Charter, Community Boards consist of 50 unpaid members appointed to two-year terms by the president of each borough (the equivalent of a county executive). Community Boards have no final decision-making authority but are required by law to adopt advisory opinions on such varied topics as the city budget, zoning changes, landmarks designations and franchises for cable television and other uses of the city streets. In addition to those matters for which the City Charter requires some specific Community Board action, each CB monitors the delivery of municipal services within its borders and has a broad mandate to protect and enhance the quality of life for its constituents. Although members of the Community Board serve without compensation, each board has an annual budget of approximately $118,000 plus a rent allowance from which it hires full and part-time staff and purchases supplies necessary to carry out its functions. In addition to the mandated functions of Community Boards, they also serve as neighborhood "sounding boards" and provide direct constituent service to assist individuals in dealing with the sometimes imposing maze of the city bureaucracy.

Most Community Boards operate with a committee system pursuant to parliamentary procedure and/or Robert's Rules of Order -- in essence, like a "mini-legislature." It is not uncommon for Community Board members to give up six to eight evenings per month to attend committee and full board meetings.

Although these boards are not dispositive of most of the issues that come before them, in many communities appointment to the Community Board is a much sought-after honor, and most boards command the attention of area elected officials. Why? Because Community Board members are usually the most active and committed civic activists with strong ties to their communities. They are tenant leaders, senior citizen activists, PTA officers, block association leaders and often, future City Council or State Assembly members.

From July 1990 until June 1992, I served as Chair of Community Board 8 in Manhattan, which encompasses the Upper East Side from 59th Street to 96th Street, from 5th Avenue to the East River. It was in this capacity that I first had the opportunity to learn of the myriad issues associated with LLW.

The area of Community Board 8 is less than 3 square miles but has a population of close to 220,000 people. It is also home to 12 medical or research institutions that generate low-level radioactive waste.

NONREACTOR LLW IN NEW YORK

According to reports filed with the New York State Energy Research and Development Authority (NYSERDA) for calendar year 1991, approximately 51% of all the nonreactor LLW produced in New York State comes from New York City. Given the number of medical, biomedical and other research facilities in the city, this percentage is hardly surprising. However, as one examines the next levels of concentration, it becomes clear that one community has an extraordinary concentration of LLW generation within its borders. Generators in the Borough of Manhattan produce approximately 41% of the statewide total and generators within the confines of Community Board 8 produce nearly 21% of the statewide total.

Under federal statute, New York, like all other states, will be responsible for the management and disposal of all LLW generated within its borders as of January 1, 1993. While New York has disposed of LLW

at Richland, Washington, Beatty, Nevada, and Barnwell, South Carolina, in the past, only the Barnwell site may be available after January 1, 1993, (and that site will be available only until July 1994). Given that 44,015 ft^3 of New York LLW (39.9%) of the total) in 1991 was shipped to the sites about to be closed, the need for alternatives becomes readily apparent.

New York State's response to changes in federal law has included the enactment of the Low-Level Radioactive Waste Management Act of 1986, which assigned several aspects of LLW management to a variety of state agencies. NYSERDA will ultimately be responsible for the actual operation of an in-state disposal facility if such a management choice is made. However, the initial decisions regarding site selection and disposal methods are now under review by a special commission and must be approved by the State Department of Environmental Conservation.

Additionally, NYSERDA has created a review panel that is studying the issue of onsite storage. This panel consists of a wide variety of interested parties who meet regularly and seek input from all sources in their effort to fully and fairly assess the ability of generators to store on site. The City of New York is represented on this study review panel by the Department of Health's Bureau of Radiological Health. As Chair of Community Board 8, I met with members of the study review panel in May 1992 and the Community Board hopes to have further input as the panel prepares its recommendations.

THE ROCKEFELLER UNIVERSITY CASE

In 1988, The Rockefeller University, located on York Avenue in Manhattan (Community Board 8), petitioned the Nuclear Regulatory Commission to amend its regulations to permit Rockefeller to dispose of solid biomedical waste (paper, glass and plastic trash) through onsite incineration. Technically, Rockefeller sought NRC classification of such materials containing small amounts of hydrogen-3 and carbon-14 as "below regulatory concern." In a companion petition, Rockefeller sought NRC action to expand the list of radioactive isotopes for which unregulated disposal would be permitted. Such action by the NRC would clear the way for Rockefeller to dispose of certain animal tissue without regulation. The petitions also sought to make such regulatory changes a matter of compatability for which compliance by all jurisdictions would be required.

In July 1990, the NRC published its policy concerning Below Regulatory Concern (BRC) under which the Rockefeller petitions could have been considered. However, in June of 1991, the NRC placed a moratorium on the implementation of its BRC policy, effectively halting action on the Rockefeller petitions.

The files of Community Board 8 do not contain any record of being notified of either the Rockefeller petitions when filed in 1988 nor of the actions taken by the NRC regarding BRC or the petitions.

Sometime in the fall of 1991, a series of rumors -- the source of which remains unknown -- swept the Community Board 8 area. The word on the street was that Rockefeller had petitioned the NRC for permission to incinerate LLW on its campus on York Avenue. As large as New York is, the spread of such rumors often makes it seem like a small town. Needless to say, my phones began to ring off the hook.

Not knowing how the rumors began, whether they were true or not, or how and by whom LLW was regulated in New York City, I knew I had my work cut out for me. I instructed the CB staff to inquire of Rockefeller whether such petitions had been filed. I also sought technical assistance and advice from the NYC Health Department's Bureau of Radiological Health. Finally, I instructed the appropriate committee chairs to plan for a public hearing on the matter and to invite Rockefeller University, the NYC Health Department, and our state and local elected officials.

A Community Board public hearing was scheduled for February 5, 1992, in an auditorium at New York Hospital (just down the street from Rockefeller). Almost a week before this hearing, I had learned the facts surrounding the filing of the Rockefeller petitions as well as the NRC's moratorium on BRC, and was thus relatively certain that Rockefeller would not be incinerating LLW at any time soon.

Nevertheless, knowing that a moratorium can be lifted and that Rockefeller's petitions were technically still before the NRC, I felt compelled to go ahead with the hearing -- to "clear the air" -- so to speak. Not only did I think that our constituents deserved a full explanation of the issues involved, I also thought it only fair that Rockefeller -- a distinguished and respected institution -- be given the opportunity to explain its plans fully, openly, and fairly. I seriously thought that Rockefeller would welcome the opportunity to educate the public, explain its position, and show its desire to be a responsive institutional neighbor.

Shocked is too mild a word to describe my reaction to learning that a representative of Rockefeller informed my committee chair that he felt no obligation to attend our hearing because "it would serve no purpose." I then called the university myself and explained that our intent was to educate the public and dispel the rumors -- not to vilify the university. That approach also failed. The Rockefeller representative stated that "there's no point in coming because the Community Board will oppose us on this no matter what we do." Finally, I asked our local State Assemblyman to intervene and request the university's attendance -- but to no avail. We decided to go ahead with the hearing and make certain that everyone in attendance, including the press, knew that the university had refused to attend.

On February 5, 1992, more than 350 area residents crowded into the auditorium for our public hearing. The public listened intently as government officials and environmental activists gave us as much relevant information as they could. When the time came for questions and comments from the public, the mood of the hearing became evident. These people were angry -- not hysterical yet -- but very mad. More than one speaker decried the university's refusal to attend as arrogant, disdainful, even dumb.

Following that hearing, a series of meetings with officials at Rockefeller were finally arranged, but not before at least five elected officials intervened on our behalf and not before the local press excoriated the university for its arrogant treatment of our community. By that time the local school board had come out against the university as had two other Community Boards in Manhattan. The general feeling among Community Board members was that this institution had seriously -- and needlessly -- destroyed any hope of having a cooperative relationship with the community.

Fortunately for all involved, the new President of Rockefeller University came forward and admitted a major public relations gaffe. More importantly, the university realized that it needed community input and support in addressing the issue of managing or disposing of LLW.

In a clear and strong message to our community, the new President of Rockefeller had the NRC petitions withdrawn. He also committed the university to regular attendance at the monthly meetings of Community Board 8. With the seemingly simple leadership and common sense of one person, a three-month battle between an aroused community and a major institution came to an end.

RECOMMENDATIONS

But was it all really necessary? Aren't the benefits of a comprehensive public education and outreach program apparent to generators of LLW? Generators in all states and localities are facing similar problems and will ultimately have to "sell" at least one community on some approach to LLW management. Doesn't it make sense to plan ahead and try to develop some allies early on in the process? I think that the following steps will go a long way toward gaining public trust and, perhaps even support, as generators of LLW meet the challenges ahead:

1. Begin by getting to know your community and its leaders. Find out who the major players are and introduce yourself. Identify civic organizations with which you may have some common ground on issues separate and apart from LLW. Attend meetings and public hearings.

2. If you are a medical, educational, or research facility, sponsor a community forum at which the clinical and research benefits of your work are made clear.

3. Find an articulate spokesperson to "translate" scientific and technical jargon into words and concepts that the average citizen can understand. Be sure to differentiate between and among the varying types and levels of radiation and the relative risks and benefits of each.

4. Be candid! When reaching out to the public, be sure to advise them of all existing methods of management and disposal and the pros and cons of each.

5. Make sure you are on the mailing lists of community and civic organizations and make sure they're on yours.

6. Get to know your elected officials. Don't wait until legislation absolutely vital to your interests is before his or her committee.

7. Debunk the myths! Believe it or not, most people -- even community activists -- will react more cooperatively when you give them the facts.

8. Finally, do all the above in a proactive, not reactive, manner. Don't wait for the rumors to fly. And, above all, don't ignore your neighbors!

Storage and Public Acceptance[a]

Mary R. English
Energy, Environment and Resources Center
327 South Stadium, University of Tennessee
Knoxville, TN 37996

ABSTRACT

The readiness of community members to accept storage of low-level radioactive waste in their midst will depend upon two sets of factors. The first set concerns the nature of the proposed storage arrangement: where it falls on a spectrum of possibilities ranging from onsite storage to a dedicated, centralized facility. The second set concerns the nature of the proposed host community: whether the community is predisposed to be hostile or receptive to a storage facility by virtue of attitudes concerning, for example, the risks of the proposed storage arrangement, the benefits of the storage arrangement and the nuclear industry in general, and the competence and integrity of scientists and risk managers. In this paper, these two sets of factors and their interrelationships are discussed.

INTRODUCTION

States that are out of compliance with the milestones set by the 1985 Low-Level Radioactive Waste Policy Amendments Act have already had to face the problem of storage. For many other states, the problem of storage looms on the horizon. Most do not expect to have their own disposal facilities until 1996 at the earliest; in July 1994, when the Chem-Nuclear facility in Barnwell County, South Carolina, is closed to all but Southeast Compact members, they will be two years or more away from having disposal capacity. Storage is becoming an increasingly critical issue, but it is not altogether clear how it should be undertaken. The term "storage" can have several meanings.

TYPES OF STORAGE

Centralized storage. Storage is not a single concept; it is a spectrum of possibilities. At one end of the spectrum is the centralized storage option: all LLW from a state or compact region would be sent to a centralized, dedicated facility where it would be stored until disposal capacity was available. While such a facility would be intended as an interim, not a final, solution, it might have some technical similarities with LLW disposal facilities, especially given the trend toward retrievability in disposal facilities. (In a few states, in fact, retrievability has become such a byword that disposal is being called storage.)

The centralized, dedicated facility could be the most secure, failsafe storage option, but it would necessitate finding a host community for the facility -- an enterprise that could be nearly as difficult as finding one for a disposal facility. In addition, as with a disposal facility, complicated substantive and procedural issues (e.g., siting criteria, compensation to the host community, allocation of liability among generators) would have to be worked out. Thus, developing a centralized storage facility would take time -- three to four years, according to one estimate.[1] And the costs of LLW storage could be considerable -- for example, the Connecticut Hazardous Waste Management Service has estimated that it would cost between $15 million and $20 million to develop and operate a centralized storage facility for five years.[2]

Onsite storage. At the other end of the spectrum, storage is a "holding pattern"; a stopgap measure until better solutions can be found. This type of storage takes place on site, at the point of LLW generation.

---

a. This paper was presented on November 20, 1992 in Phoenix, AZ at the Fourteenth Annual Department of Energy Low-Level Radioactive Waste Management Conference. Parts of the paper are drawn from Mary R. English, *Siting Low-Level Radioactive Waste Disposal Facilities: The Public Policy Dilemma* (New York: Quorum Books, 1992).

Onsite storage is more immediately feasible and avoids some of the costs and social problems of siting and building a dedicated storage facility: the generator has an existing operation, and members of the surrounding community are likely to be unaware of modifications in that operation to allow for increased LLW storage (although perhaps they should be told). However, onsite storage also may be the least safe option, especially for small LLW generators. Small generators such as hospitals and universities are not professional radioactive waste managers, and without elaborate training programs and security measures, onsite storage runs the risk of radiological exposure to workers and inadvertent intruders. Nor is onsite storage necessarily cheap: it may require specially constructed or retrofitted space with monitoring systems, dedicated exhaust systems, refrigerated storage for biological wastes such as animal carcasses, etc. And even then, it may be difficult to make the storage area secure against hazards such as fires.

Larger generators such as nuclear power plants are more likely to have the money, technically suitable space, and trained personnel for extended onsite LLW storage, but they too can encounter problems. For example, future waste volumes need to be estimated to allow for adequate storage space, especially if modular approaches are not used. In addition, future waste form and packaging requirements need to be anticipated so that waste is stored in the most appropriate and efficient manner. (These requirements also affect the amount of storage space effectively available.) Onsite storage thus is constrained by considerations that can limit the quantity, type, and duration of LLW storage.

Other options. In the middle of the spectrum of storage possibilities are a number of alternatives, each with its own technical, legal, and social pros and cons. One option is to have the LLW from nuclear power plants stored on site but have nonutility wastes stored away from their points of generation, at a dedicated facility. This avoids some but not all of the problems discussed above. While the technical and social difficulties of siting a dedicated storage facility are likely to be much less if utility waste is excluded, the per unit costs of storage are likely to be extremely high: for example, the Connecticut Hazardous Waste Management Service estimates that a large proportion of the costs of developing and operating a centralized storage facility would be fixed costs that would not vary greatly with the size of the facility.[3] A second alternative is to have nonutility wastes stored at one or more nuclear power plants, rather than building a dedicated facility for them. This avoids the problems of siting and paying for a special storage facility, but utilities are disinclined to take on this responsibility, partly because of the liability problems involved. In addition, such arrangements currently are discouraged by the Nuclear Regulatory Commission. A third alternative is to store nonutility waste at facilities provided by LLW brokers (companies that collect and ship waste for disposal). Brokers may be amenable to this idea, but under current regulations, they can only store wastes for a short period. In the long run, if wastes were accumulated at a broker facility for several years, problems concerning space, safety, and public acceptance could also crop up.

FACTORS AFFECTING PUBLIC ACCEPTANCE

The term "public acceptance" encompasses several types of acceptance that together help to determine the political viability of a proposed LLW storage approach. While the attitudes of the public at large in the state or region are involved, of particular importance are the views of stakeholder groups: first, special interest or public interest groups such LLW generator associations and statewide environmental groups; and second, communities in which LLW may be stored. The following discussion focuses on the latter. If storage is acceptable to the potentially affected communities, then public acceptance is less likely to be a problem.

Although a "community" can be difficult to define and its views are never uniform, some generalizations can be made about factors that may predispose community members to be receptive to radioactive waste management facilities.

Prior familiarity and involvement. The most important determinant of community acceptance is, in most instances, the prior familiarity and involvement of the community in the nuclear industry. Five examples are given below, but there are others as well.

One example is Oak Ridge, Tennessee, home of Oak Ridge Reservation, which is the part of the nuclear weapons complex of the U.S. Department of Energy, as well as home of the commercial radioactive waste

processing facilities operated by Quadrex and Scientific Ecology Group and of the defunct Clinch River Breeder Reactor for nuclear fuels reprocessing. In 1985, Oak Ridge officials expressed their willingness to consider hosting DOE's monitored retrievable storage facility for high-level waste. Another example is Barnwell County, South Carolina, home of the Savannah River Site (another part of DOE's weapons complex) as well as Chem-Nuclear's commercial LLW disposal facility and the defunct Allied General Nuclear Services facility for nuclear fuel reprocessing. For several years, Barnwell County officials have urged that Chem-Nuclear's LLW disposal facility remain open. Officials in that region have also proposed that the old reprocessing site be used for DOE's monitored retrievable storage facility. A third example is Fall River County, South Dakota, home of uranium mining operations. In 1985, a majority of the county voted in favor of locating a commercial LLW disposal facility within the county. A fourth example is Benton County, home of the DOE's Hanford Reservation and of US Ecology's commercial LLW disposal facility. Benton County officials have been eager to increase the benefits derived from these operations, but not necessarily to shut them down. A fifth example is Ashford, New York, home of the now-closed Western New York Nuclear Service Center. Local officials have expressed interest in hosting the new LLW disposal facility for New York.

Economics. Clearly, economic benefits -- jobs and special payments -- have been a prime consideration in each of these cases. For example, about 10 percent of Barnwell County's workforce is employed at the Savannah River Site; about 2 percent at Chem-Nuclear. And the Savannah River Site now provides Barnwell County with about $1.7 million annually in payments in lieu of taxes, while special payments to the county due to Chem-Nuclear's disposal operation amount to slightly more than $1 million annually. But economics is not the sole explanation, for other communities have turned down economically attractive offers. Economic persuasion may be necessary, but it is often not sufficient. It appears that communities such as those cited above have, over time, acquired cultural characteristics that make them more likely to accept facilities associated with the nuclear industry, including facilities for radioactive waste storage.

Risk. One acquired cultural characteristic concerns risk. Cultural contexts, with the values they inculcate, help to shape answers to such fundamental questions as "Is this a risk?" "How bad is it?" "Can and will it be managed?" And these answers inevitably differ, especially across cultures. As Mary Douglas and Aaron Wildavsky have noted, risk is a product of a particular social context: people select their awareness of certain dangers to conform to a specific way of life.[4] If a person is part of a particular geographic or organizational culture, he or she will be predisposed to take certain kinds of risks while avoiding others.

Despite a growing awareness of serious environmental problems caused by the US weapons complex, the level of concern is generally not high in many of the communities near weapons facilities -- counterexamples such as Fernald, Ohio, not withstanding. There are different explanations for this. One is that "you don't bite the hand that feeds you." Another, related explanation is that you tend to rationalize if you want the benefits of something that may harm you. A third is that familiarity dispels fears. What counts as a risk in some communities is quite different from what counts as a risk in communities such as Oak Ridge, Barnwell County, etc., especially if the risk is related to the nuclear industry.

Have the people in these communities been lulled into a false sense of security, or have they come to realize that the real dangers of their nuclear operations are insignificant? Although this question is interesting, it is moot; instead, the central question is how people -- risk analysts and managers as well as laypeople -- define risk. In a practical sense, those definitions and their cultural contexts are what count.

Societal benefits. All risks are socially constructed, but technological risks (manmade risks posed by relatively new technologies) are especially likely to have conflicting constructions. People disagree, not only on whether the technology poses a substantial risk, but on whether that risk is worth taking. A second cultural characteristic thus concerns evaluations of the societal benefits of the technology.

Because the defense and nuclear power industries are by far the biggest sources of radioactive waste, arguments about radioactive waste management often become entwined with arguments about national defense and nuclear power. For example, proponents of nuclear power argue that nuclear power is clean, it's needed, and it has had a good safety record in this country; opponents argue nuclear power is uneconomical and inherently unsafe and that measures such as solar energy and energy conservation should be supported instead.

Disagreement arises over the benefits of technologies such as nuclear power because of differences in people's visions of what the world is and should be. It has been proposed that, with respect to technological risk, people can be categorized into three types: "sponsors," "guardians," and "preservationists."[5] Sponsors wholeheartedly favor new technology; they are convinced of its benefits and are optimistic about society's ability to manage its risks. They want the world that new technology makes possible. Guardians are less enthusiastic about technological change and are considerably more skeptical about whether its risks will be well-managed; they think that it should be undertaken cautiously and with many safeguards. Preservationists go further: they are deeply suspicious of both new technology and those who profess to manage its risks. For them, the benefits count for little against the hazards of the technology and the changes in life it will bring. Communities where a number of people have dedicated their working lives to realizing a technology will be likely to believe in the benefits of that technology; with respect to that technology, and possibly others, they are more likely to be sponsors than preservationists.

Trust in and deference to authority. A third cultural characteristic concerns trust in and deference to those in positions of authority, especially the authority of technical expertise. If a community and its local economy have been dominated by one company or industry, the attitudes of employees and their families and friends will in many instances be affected. They are likely to feel loyalty to the company and pride in their own work and the work of others they know (unless the company is notoriously bad, and perhaps even then). They are also likely to respect and trust the company's top management and senior staff; to see them as performing their jobs with competence and integrity.

Residents in communities such as Oak Ridge, Barnwell County, etc., are thus more predisposed to accept the actions and activities of the nuclear industry that has been in their midst for two generations. As various respondents in a 1990 study of Barnwell County commented: "I have confidence in the management of the local [Chem-Nuclear] site and trust local management decisions to keep the site as safe as possible." "I think [Chem-Nuclear] has been good for Barnwell County and [has] some super nice people in high positions." "If all other wastes were handled with the regulations on LLW the whole world would be in much better condition."[6] In contrast, a retired structural engineer in a candidate area for a LLW facility in New York commented, "How do we know they could keep this thing from leaking? How can they be sure it won't crack? There's nothing they could do to make us feel really safe if they went ahead and built it."[7] And as another candidate area resident noted, "This is the same government that gave us a collapsing Thruway bridge."[8]

A reinforcing process; a potential source of conflict. Within a particular cultural context, values and norms can reinforce each other. What is valued in one social sphere as particularly desirable (e.g., patriotism in support of the nation's defense effort) becomes a norm (e.g., not participating in demonstrations against a weapons facility), while what is valued in another sphere as particularly desirable (e.g., maintaining a clean environment) becomes a norm (e.g., supporting demonstrations and legal activity to force rapid defense facility cleanups). The norm in turn helps to strengthen and further inculcate the value by giving it a behavioral standard against which it can be measured. But, while certain values and norms may prevail within a particular geographic locale or a particular organizational culture, they may diverge within a larger context, laying the ground for conflict. For example, Tennessee opposed the monitored retrievable storage facility under consideration for Oak Ridge; South Carolina opposed allowing the Chem-Nuclear facility in Barnwell County to remain open indefinitely; South Dakota voted against allowing a LLW facility to be developed in Fall River County. It thus cannot be assumed that community acceptance of a nuclear waste facility will lead to state acceptance, unless the state has its own compelling reasons for favoring the facility -- as it may, with LLW storage.

CONCLUSION

For states in compacts, decisions about storage are complicated by questions about interstate responsibility: e.g., should the host state take responsibility for the region's waste; should some other centralized, regional solution be sought; or should each state determine how best to manage its waste until the region has disposal capacity? But even without these complications, individual states are faced with hard decisions concerning interim LLW management measures.

A key issue with storage is time. Storage is supposed to be temporary, until disposal capacity becomes available. But the difficulties of establishing a new disposal facility are great, as is the reluctance of states with current or planned facilities to take outsiders' waste on a permanent basis. Approaches such as onsite storage may be workable for a few years at most; approaches such as centralized, dedicated facilities take longer to realize but are able to absorb extended delays in the availability of permanent disposal capacity. That is both an advantage and a disadvantage of dedicated facilities: because they are better able to accommodate delays, they may dilute the political will to move toward permanent solutions. The temptation may be even greater to get waste into storage and then forget it.

Expected time horizons thus play an important role in determining which storage options are both practical and philosophically acceptable. Similarly, federal and state regulatory policies help to determine which storage options are available. But in addition, states should consider which options will have the greatest likelihood of public acceptance, including, especially, the acceptance of affected communities.

The prospects for rapid development of disposal sites look dimmer than ever. In the next few years, the need to turn to centralized, dedicated storage facilities may become much more compelling than it is at present. But if a centralized storage approach is adopted, the pitfalls of siting a permanent disposal facility should be avoided if at all possible. Permanent disposal facilities, with their exacting technical requirements driven by 500-year time horizons, are locationally constrained. They thus are perhaps unavoidably controversial. But with temporary storage facilities, where time horizons are relatively short, such controversy can and should be minimized.

REFERENCES

1. Connecticut Hazardous Waste Management Service, Draft Plan for Developing a Centralized, Temporary Low-Level Radioactive Waste Storage Facility in Connecticut, November 1992, p. 6.

2. Ibid.

3. Ibid.

4. Mary Douglas and Aaron Wildavsky, Risk and Culture: An Essay on the Selection of Technical and Environmental Dangers (Los Angeles: University of California Press, 1982).

5. Michael Elliott, "Coping with Conflicting Perceptions of Risk in Hazardous Waste Facility Siting Disputes," (Ph.D. Dissertation, Massachusetts Institute of Technology, Department of Urban and Regional Planning, Cambridge, MA, 1984).

6. Anonymous quotes in Mary English with Matthew Murray, The Economic and Social Impacts of Chem-Nuclear's LLW Disposal Facility on Barnwell County, South Carolina, report to the U.S. Department of Energy (Knoxville, TN: Energy, Environment, and Resources Center, University of Tennessee, 1991).

7. Joseph Frank, Charleston, NY, as quoted in The New York Times, February 28, 1989.

8. Jean Veeder, Fultonville, NY, as quoted in The New York Times, February 28, 1989.

Interim Storage of Low-Level Radioactive Waste

Robert A. Nelson
U.S. Nuclear Regulatory Commission
Office of Nuclear Material Safety and Safeguards
Division of Low-Level Waste Management and Decommissioning
Washington, DC 20555

INTRODUCTION

The Low-Level Radioactive Waste Policy Amendments Act of 1985 (LLRWPAA) establishes a series of milestones, penalties, and incentives to ensure that regional compacts and States make adequate progress toward being able to manage their low-level radioactive waste by 1993. However, new LLW disposal facilities are not expected to be operational by January 1, 1993, and the compact commissions that control the existing LLW disposal sites are expected to either close or set conditions on receiving LLW from outside their regional compacts on January 1, 1993. Therefore, some licensees who generate LLW may be forced to store their LLW on site until disposal capacity is available, unless other arrangements for storage or disposal can be made. LLW disposal facilities, accessible by all States, may not be available until 1999 or later. This paper describes the current LLW disposal and storage situation and discusses: (a) storage concerns, (b) storage in the State of Michigan, (c) Nuclear Regulatory Commission storage regulations and guidance, (d) procedures for increasing storage capacity, and (e) recent NRC rulemakings concerning LLW storage.

CURRENT SITUATION

Status of Currently Operating LLW Disposal Facilities

The LLW disposal facility in Beatty, Nevada, will close on December 31, 1992. Although originally scheduled to close on that date as well, the South Carolina legislature has authorized the LLW disposal facility at Barnwell, South Carolina, to remain open until January 1, 1996, subject to various conditions. However, under both State law and a Southeast Compact Commission agreement, the Barnwell facility will close permanently to out-of-region waste on July 1, 1994. The facility will accept out-of-region waste before that date if the importation of such waste is approved by the Southeast Compact Commission. The Southeast Compact Commission has stated that compact regions and unaffiliated States that have access to the Barnwell facility on December 31, 1992, pursuant to their status of compliance with the LLRWPAA, are eligible to contract with the Southeast Compact Commission for access to the facility, for generator's in their respective regions or States. Currently, this means that the States of Michigan, Rhode Island, and New Hampshire, the District of Columbia, and Puerto Rico will be denied access.

Although the facility in Richland, Washington, will remain open indefinitely, it will cease accepting LLW from other than the Northwest and Rocky Mountain Compacts effective January 1, 1993.

Status of Compacts and New LLW Disposal Facility Development

Forty-two States have formed nine compacts as authorized by Congress pursuant to the LLRWPAA. Seven compacts (31 States) plan to develop eight disposal facilities, and two compacts (11 States) will be served by the existing facility in Richland, Washington. In addition, five States not affiliated with compacts (unaffiliated States) intend to develop their own disposal facilities. New Hampshire, Rhode Island, the District of Columbia, and Puerto Rico are not planning to develop a LLW disposal facility and are at various stages of securing access for disposal of their waste. The remaining State—Michigan—was expelled from the Midwest Compact on July 24, 1991, and has not announced plans to manage or dispose of its LLW. The LLW compact status is shown on the Figure 1. The status of new LLW disposal facility development follows.

Actual and Forecast Dates for Completing
Steps in LLW Disposal Facility Development

Compact/Host State	Select Site	Submit License Application	Operate Facility
Appalachian/PA	Late 1994	Late 1994	Mid 1997
Central/NB	Dec 1989	Jul 1990	Unscheduled
Central Midwest/IL	Oct 1992	Dec 1991	—
Midwest/OH	Unscheduled	Unscheduled	Unscheduled
Northeast/CT & NJ	Unscheduled	Unscheduled	Unscheduled
Southeast/NC	1994	Mid 1995	Late 1997
Southwest/CA	End 1993	Dec 1993	Jan 1996
	Mar 1988	Dec 1989	Jul 1994
Unaffiliated States			
Maine	1993	Jan 1994	End 1996
Massachusetts	Jun 1994	Nov 1994	Late 1996
New York	Unscheduled	Unscheduled	Unscheduled
Texas	Aug 1991	Mar 1992	Jun 1996
Vermont	Feb 1994	1996	1999

Note: The following states do not have a site under development—District of Columbia, Michigan, New Hampshire, Puerto Rico, and Rhode Island. The States are the sources of the forecast dates.

On October 9, 1992, the Illinois Low-Level Radioactive Waste Disposal Facility Siting Commission voted unanimously to reject the LLW disposal site proposed by the Illinois Department of Nuclear Safety (IDNS). The Siting Commission found that the site, with a facility of the proposed design, does not meet all the criteria set forth in Illinois law. In support of this decision, the Governor directed the IDNS to stop all efforts to locate a facility at the selected site. A license application had been submitted in May 1991. This application had been found to be complete for review purposes in December 1991. The facility had been scheduled for operation early in 1995.

Because no new LLW disposal facilities have been developed and the compact commissions that control the existing LLW disposal sites are expected to either close their sites or set conditions on receiving LLW from outside their regional compacts, some licensees who generate LLW will be forced to store their LLW on site. The LLW disposal facility at Barnwell, South Carolina, is expected to close to out-of-region generators on July 1, 1994, which will result in more widespread storage. NRC staff estimates that approximately 900 LLW generators (including 48 power reactors), which would normally dispose of their LLW, will be faced with onsite storage after this date.

LLW STORAGE CONCERNS

Although LLW can be safely stored, NRC believes that the protection of the public health and safety and the environment is enhanced by disposal, rather than by long-term, indefinite storage of waste. Disposal of waste in a limited number of facilities, licensed under the requirements of Part 61 to Title 10 of the Code of Federal Regulations (10 CFR 61) or compatible Agreement State regulations, will provide better protection of the public health and safety and the environment than long-term, indefinite storage. Stored waste packages need to maintain sufficient integrity to prevent dispersal of the waste during storage, transport, and handling, up to and including emplacement for disposal. Because of the variability of certain storage environments, waste packages may suffer degradation over the extended storage period. Among the ways in which a storage environment can cause waste package degradation are temperature fluctuations (in heated facilities in areas with cold winters) and corrosive atmospheres (e.g., industrial and marine atmospheres as well as acid

deposition). Other waste package concerns during storage include external and internal corrosion, radiolytic generation of gases (predominantly hydrogen) and corrosive substances, radiation-induced embrittlement of polyethylene containers, and biodegradation of institutional wastes. These processes may accelerate internal corrosion and failure of common storage containers, even if the waste is stabilized before storage. Waste form degradation could result in spills or releases during handling for disposal if the degradation goes undetected. In addition, waste package deterioration before disposal will require repackaging of the LLW and cleanup of any spills. As a result, workers will be potentially exposed to additional doses of radiation. The NRC contractor document, *Extended Storage of Low-Level Radioactive Waste: Potential Problem Areas*, NUREG/CR-4062, provides a detailed discussion of these concerns.[a]

Storage also involves a number of activities that could increase radiation doses to the public. First, storage of LLW will result in potential increased worker exposures, from unloading the waste from storage, for disposal. Second, waste forms may need to be repackaged or otherwise processed again as a result of waste form failure or to meet waste acceptance criteria for a new disposal facility, once one becomes available. This additional handling by workers will also cause increased exposures. The site-specific conditions at a new disposal facility may necessitate these new waste form criteria and these criteria may not be known when LLW is placed into storage. Third, radiation surveys and inspections of LLW in storage will result in potential additional doses to those involved in performing these activities.

LLW STORAGE IN THE STATE OF MICHIGAN

On November 11, 1990, access to the three LLW disposal facilities was denied to generators in the State of Michigan. There are approximately 600 NRC material licensees, four power reactor licensees, and three nonpower reactor licensees in the State of Michigan. However, many of the material licensees store only for decay. Approximately 50 material licensees and all but one of the reactor licensees generate LLW that would normally be shipped for disposal. Until LLW disposal facility access was denied, Michigan generators disposed of approximately 30,000 ft^3 of LLW in 1990. Of this total, approximately 91% was generated by utilities.

Licensees have indicated that by minimizing waste generation with administrative controls and by using volume reduction equipment, such as compactors, they expect that their existing storage capacity would be adequate over the next three to five years. NRC has identified no cases where existing and projected storage practices are inadequate.[b]

The Michigan Low-Level Radioactive Waste Authority recently conducted a telephone survey of its LLW generators. The response to this survey indicates that approximately 36,000 ft^3 of LLW is currently in storage. This amount is expected to grow to approximately 87,000 ft^3 by 1995.[c]

---

a. Copies of NUREGS may be purchased from the Superintendent of Documents, U.S. Government Printing Office, P.O. Box 37082, Washington, DC 20013-7082. Copies are also available from the National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161. A copy is also available for inspection and/or copying at the NRC Public Document Room, 2120 L Street NW. (Lower Level), Washington, DC.

b. SECY-92-245, "Low-Level Radioactive Waste Storage in the State of Michigan," July 15, 1992.

c. Taylor, William, "Experience in the State of Michigan," Presentation to Department of Energy Temporary Storage Workshop, Columbus, OH, November 6, 1992.

LLW STORAGE REGULATIONS AND GUIDANCE

The accompanying table identifies the principal NRC regulations governing the storage of LLW.

Principal NRC Regulations Applicable to LLW Storage

10 CFR 20	
20.1	Purpose
20.101	Radiation Dose standards for Individuals in Restricted Areas
20.103	Exposure of Individuals to Concentrations of Radioactive Materials in Air in Restricted Areas
20.105	Permissible Levels of Radiation in Unrestricted Areas
20.106	Radioactivity in Effluents to Unrestricted Areas
20.203	Caution Signs, Labels, Signals, and Controls
20.204	Same: Exceptions
20.207	Storage and Control of Licensed Materials in Unrestricted Areas
20.311	Transfer for Disposal and Manifests
10 CFR 35	
35.92	Decay in Storage
10 CFR 50	
50.34a	Design Objectives for Equipment to Control releases of Radioactive Material in Effluents - Nuclear Power Reactors
50.36a	Technical Specifications on Effluents from Nuclear Power Reactors
50.54	License Conditions
Appendix A	General Design Criteria for Nuclear Power Plants
Criteria 60	Control of Releases of Radioactive Material to the Environment
Criteria 63	Monitoring Fuel and Waste Storage
Criteria 64	Monitoring Radioactivity Releases
Appendix I	Numerical Guides for Design Objectives and Limiting Conditions for Operation to Meet the Criterion "As Low As Reasonably Achievable" for Radioactive Material in Light-Water-Cooled Nuclear Power Reactor Effluents

These regulatory requirements are implemented and interpreted in a series of Generic Letters, Information Notices, Regulatory Guides, Standard Review Plan sections, and Circulars.

Applicable Licensing-Framework Documents for Onsite LLW Storage

Type	No.	Title
Generic Letter	81-38	"Interim Storage of Utility Licensee-Generated Low-Level Radioactive Waste at Reactor Sites"
Generic Letter	85-14	"Commercial Storage at Power Reactor Sites of Low-Level Radioactive Waste Not Generated by the Utility"
Information Notice	89-13	"Alternative Waste Management Procedures in Case of Denial of Access to Low-Level Waste Disposal Sites"
Information Notice	90-09	"Extended Interim Storage of Low-Level Radioactive Waste by Fuel Cycle and Materials Licensees"

Regulatory Guide	1.143	"Design Guidance for Radioactive Waste Management Systems, Structures, and Components Installed in Light-Water-Cooled Nuclear Power Plants"
Standard Review Plan (NUREG-0800)	Sec. 11.4	"Solid Waste Management Systems"
Inspection and Enforcement Circular	80-18	"10 CFR 50.59 Evaluations for Changes to Radioactive Waste Management Systems"

Included in Standard Review Plan Section 11.4 are:

- Branch Technical Position ETSB 11-3, "Design Guidance for Solid Radioactive Waste Management Systems Installed in Light-Water-Cooled Nuclear Power Reactor Plants"
- Appendix 11.4A, "Design Guidance for Temporary On-Site Storage of Low Level Radioactive Waste."

In January 1992, the Commission directed the staff to assess the need for additional guidance or licensing requirements to supplement the existing regulatory framework for LLW storage and to inform the Commission when significant needs are identified. The Agreement States were consulted and input was received from the Regional Offices. No significant need for additional storage guidance was identified by the Agreement States that responded. Three regions identified a need for additional guidance. In response to these requests, NRC staff is drafting an information notice to provide guidance for licensees that request "for storage only" of sealed sources, pending transfer to an authorized recipient and termination of their license. In October 1992, the staff reported to the Commission that, aside from the regional items, there is no significant need for additional LLW storage guidance or licensing requirements.

However, NRC will continue to closely monitor the LLW storage situation in conjunction with a continuing assessment of its guidance and licensing requirements. Additional guidance and licensing requirements will be developed, as the situation dictates, to ensure the continued protection of the public health and safety and the environment.

INCREASES IN STORAGE CAPACITY

Power Reactor Licensees

Generic Letter 81-38 provides guidance for proposed increases in storage capacity for LLW generated by normal reactor operation and maintenance at power reactor sites. The safety of the proposal must be evaluated by the licensee under the provisions of 10 CFR 50, "Domestic Licensing of Production and Utilization Facilities," Section 59, "Changes tests, and experiments." If (a) the existing license conditions or technical specifications do not prohibit increased storage, (b) no unreviewed safety question exists, and (c) the proposed increased storage capacity does not exceed the generated waste projected for five years, the licensee may provide the added capacity, document the 50.59 evaluation and report it to the Commission annually or as specified in the license. If an unreviewed safety question exists, authority for the increased capacity should be requested pursuant to 10 CFR 30, "Rules of General Applicability to Domestic Licensing of Byproduct Material," accompanied by an environmental evaluation. The application should also be accompanied by a showing that the storage provisions will not affect the safety of reactor operations and will not foreclose alternatives for disposal of the wastes.

If it is determined that the storage provisions could impact on the safety of reactor operations or an existing license condition or technical specification limit on the amount of waste storage, a change in the conditions of the reactor facility license may be necessary.

For proposed increases in storage capacity for more than five years (long-term), the application and review procedures will be pursuant to 10 CFR 30 with consideration of container integrity and retrievability, volume reduction, influence on state planning for disposal, and implications of de facto disposal.

The generic letter is accompanied by radiological safety guidance for the design and operation of interim contingency LLW storage facilities.

To date reactor licensees have used the 10 CFR 50.59 evaluation process for changes to their facility operations, thereby obviating the need for license amendment requests. In the future, most licensees are expected to continue to use the 50.59 process for additional storage capacity.

Materials Licensees

Information Notice 90-09 provides guidance to fuel cycle and materials licensees on information needed in license amendment requests to authorize extended interim storage of LLW at licensed operations. Not all licensees who will need to store LLW on site will need amendments to their licenses to do so. However, if the possession limits specified in a license need to be increased to allow storage, or if the terms and conditions of a license otherwise need to be modified, a licensee will need to apply for a license amendment. Information needed in an amendment request includes:

- Identification of the waste to be stored
- Plans for final disposal
- Physical description of the storage area
- Packaging and container integrity
- Radiation protection
- Training
- Financial assurance, and
- Emergency preparedness.

The information notice identifies the information requirements in each of these areas.

Similar to Part 50 licensees, there are no statutory or regulatory requirements that would limit the length of time that LLW could be stored. As a matter of policy, NRC's approval of requests for storage will generally be for a period of time no greater than five years.

NRC has received a total of 14 requests for license amendments allowing storage of LLW. All of these have been submitted by materials licensees. The NRC has received no requests for new licenses to store LLW.

RECENT NRC RULEMAKINGS

Onsite Storage of LLW after December 31, 1995

The NRC staff, at the Commission's direction, has drafted a proposed rulemaking containing the procedures and criteria applicable to the onsite storage of LLW after January 1, 1996. The proposed rule was forwarded to the Commission for consideration and approval on May 8, 1992.

If the proposed rule were adopted, onsite storage of LLW will not be permitted after January 1, 1996 (other than reasonable short-term storage necessary for decay, or for collection or consolidation for shipment

offsite, in the case where the licensee has access to an operating LLW disposal facility), unless the licensee can document that it has exhausted other reasonable waste management options. In addition, reactor licensees would have to document that onsite storage activities would be consistent with, and not compromise, the safe operation of the licensee's activities, nor decrease the level of safety provided by applicable regulatory requirements. The proposed rule would make these requirements standard license conditions for every license issued for reactor, materials, fuel cycle, and independent spent fuel storage licensees. The rulemaking would amend 10 CFR Parts 30, 40, 50, 70, and 72. The licensee would not be required to make a formal submittal to NRC, to show compliance with these conditions. The proposed rule would require that all relevant documentation of the steps taken to satisfy the requirements of this rulemaking be maintained by the licensee, and be made available to NRC, for inspection.

This proposed rule would supplement, but not supersede, the existing regulations and guidance applicable to storage of LLW, and the conditions in themselves would not authorize onsite storage. The existing regulatory and licensing framework will continue to be applicable.

The proposed rule is currently being reviewed in light of the recent United States Supreme Court decision in *New York v. United States.*

Receipt Back of LLW by Power Reactors

The NRC is amending its regulations governing the conditions of licenses for production and utilization facilities to allow a reactor licensee to receive back byproduct and special nuclear material that is produced by the operating reactor after that waste has been sent off site to be reduced in volume by compaction or incineration. At the time when most operating licenses were issued, the Commission expected that low-level radioactive waste would be promptly treated and sent off site for disposal. Therefore, operating licenses did not authorize the licensees for power reactors to receive byproduct or special nuclear material except in the form of sealed sources for special purposes, for analysis or calibration, or in the form of fuel for use in the reactor. Accordingly, while a reactor licensee may send its LLW off site for treatment, the licensee treating the waste may not return it to the generating licensee because the latter lacks authority to receive it. This rulemaking will allow this receipt back to occur.

This minor amendment does not represent any change in Commission regulatory policy regarding radioactive waste. This amendment will further enhance licensees' options to reduce the volume of waste by using services performed off site and permitting the return of the treated waste to the generators. The amendment is intended to ensure that licensees will have adequate *short-term* onsite capacity for self-generated LLW until permanent disposal capacity is available.

The final rule was published in the *Federal Register* on October 21, 1992, and will be effective 30 days after that date.

SUMMARY

The States have been slow to develop new LLW disposal facilities as measured by the milestones established by the LLRWPAA. This situation will require many generators to store their LLW on site until new disposal capacity is available. Although LLW can be safely stored, NRC believes that the protection of the public health and safety and the environment is enhanced by disposal, rather than by long term, indefinite storage of waste. Because of the public health and safety concerns associated with an increased reliance on LLW storage and to support the goals of the LLRWPAA, NRC is considering a proposed rulemaking to establish criteria and procedures applicable to onsite storage of LLW after January 1, 1996.

Recognizing that interim storage of LLW may be required because of delays in developing new disposal capacity, NRC has developed guidance and licensing procedures for storage of LLW. Additionally, the NRC has approved and published a final rulemaking that will permit power reactor licensees to receive back LLW after processing off site. NRC is continuing to assess the need for additional guidance or licensing requirements to supplement the existing regulatory framework for storage of LLW.

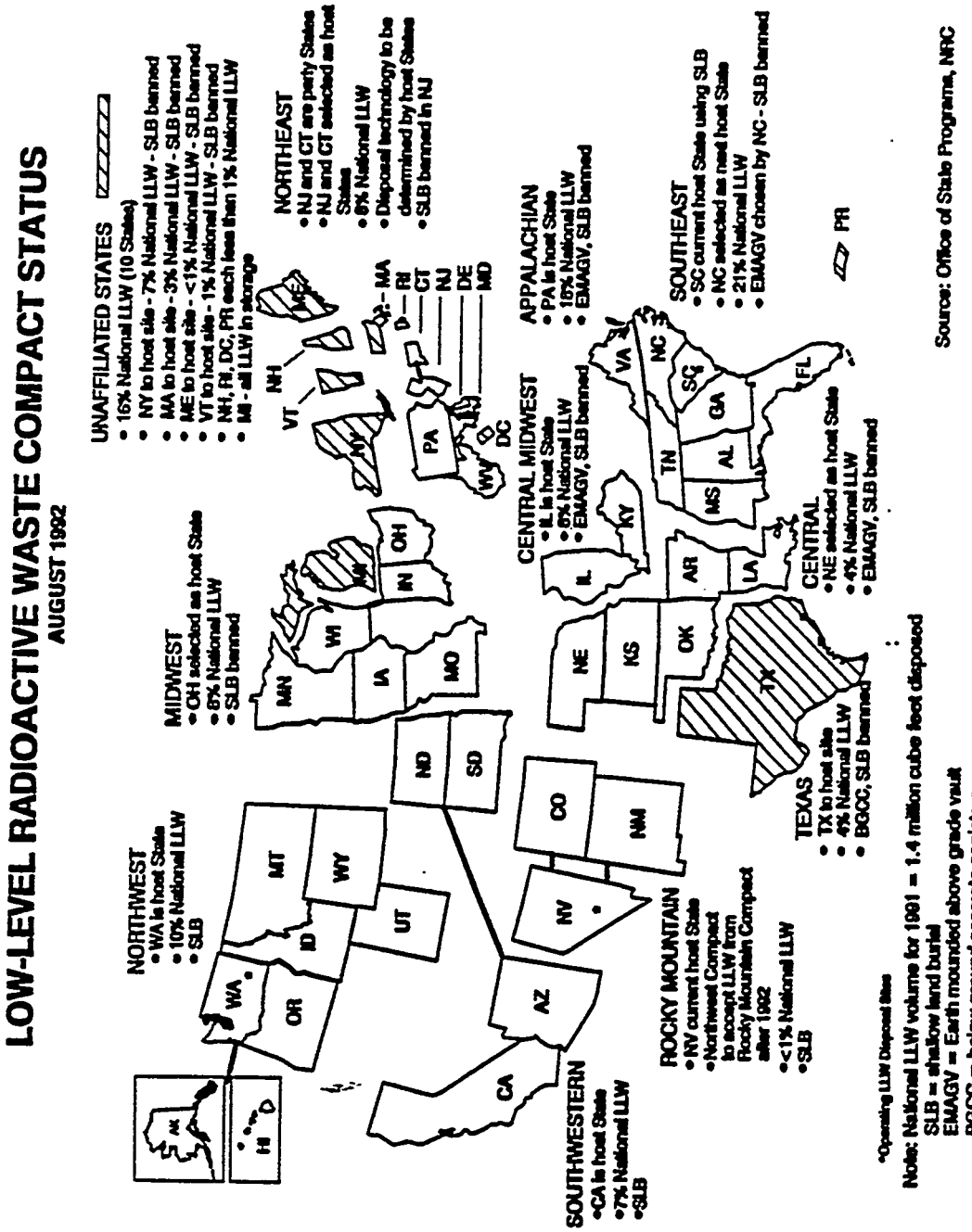


Figure 1. Low-level radioactive waste compact status.