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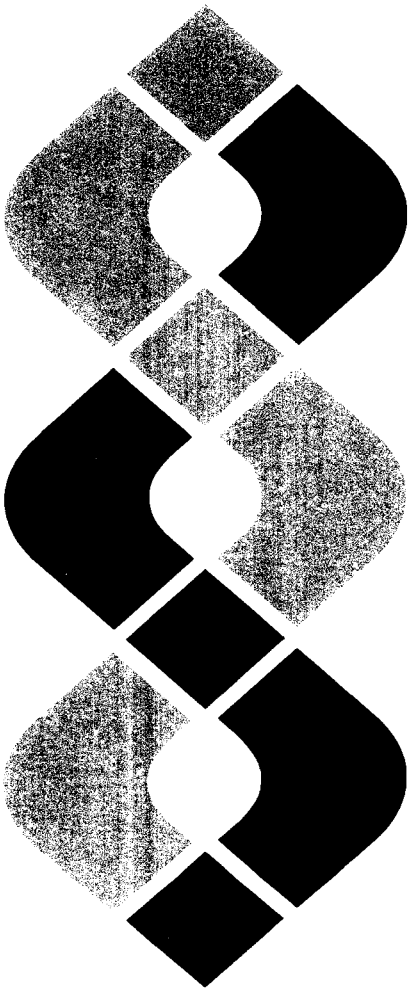
Pacific Northwest Laboratory Annual Report for 1978 to the DOE Assistant Secretary for Environment

Part 5 Environmental Assessment, Control, Health and Safety February 1979



Prepared for the U.S. Department of Energy
under Contract EY-76-C-06-1830

Pacific Northwest Laboratory
Operated for the U.S. Department of Energy
by Battelle Memorial Institute

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Pacific Northwest Laboratory Annual Report for 1978 to the DOE Assistant Secretary for Environment

Part 5 Environmental Assessment, Control, Health and Safety

W. J. Bair and Staff Members
of Pacific Northwest Laboratory

February 1979

Prepared for
the U.S. Department of Energy
under Contract EY-76-C-06-1830

Pacific Northwest Laboratory
Richland, Washington 99352

PREFACE

The 1978 Annual Report from Pacific Northwest Laboratory (PNL) to the DOE Assistant Secretary for Environment is the first report covering a full year's work under the Department of Energy since it came into existence on October 1, 1977. Most of the research conducted during this period and described in this report was begun under the Energy Research and Development Administration or its predecessor agency, the Atomic Energy Commission. However, several new projects have enhanced the PNL emphasis on environment, health and safety research in the area of synthetic fuels. Preliminary reports on these efforts are spread throughout the five parts of this annual report.

The five parts of the report are oriented to particular segments of our program. Parts 1-4 report on research performed for the DOE Office of Health and Environmental Research. Part 5 reports progress on all other research performed for the Assistant Secretary for Environment including the Office of Technology Impacts and the Office of Environmental Compliance and Overview.

Each part consists of project reports authored by scientists from several PNL research departments, reflecting the interdisciplinary nature of the research effort. Parts 1-4 are organized primarily by energy technology, although it is recognized that much of the research performed at PNL is applicable to more than one energy technology.

The parts of the 1978 Annual Report are:

Part 1: Biomedical Sciences		
	Program Manager - W. R. Wiley	D. L. Felton, Editor
Part 2: Ecological Sciences		
	Program Manager - B. E. Vaughan	B. E. Vaughan, Report Coordinator
		C. H. Connally, Editor
Part 3: Atmospheric Sciences		
	Program Manager - C. L. Simpson	R. L. Drake, Report Coordinator
		P. R. Partch/C. M. Gilchrist, Editors
Part 4: Physical Sciences		
	Program Manager - J. M. Nielsen	J. M. Nielsen, Report Coordinator
		J. S. Burlison, Editor

Part 5: Environmental Assessment, Control,
Health and Safety.

Program Managers - N. E. Carter
D. B. Cearlock
D. L. Hessel
S. Marks — W. J. Bair, Report Coordinator
C. M. Unruh — R. W. Baalman, Editor

Activities of the scientists whose work is described in this annual report are broader in scope than the articles indicate. PNL staff have responded to numerous requests from DOE during the year for planning, for service on various task groups, and for special assistance.

Credit for this annual report goes to many scientists who performed the research and wrote the individual project reports, to the program managers who directed the research and coordinated the technical progress reports, to the editors who edited the individual project reports and assembled the five parts, and to Dr. Ray Baalman, editor in chief, who directed the total effort.

W. J. Bair, Manager
S. Marks, Associate Manager
Environment, Health and Safety Research Program

Previous Reports in this Series:

Annual Report for

1951	W-25021, HW-25709
1952	HW-27814, HW-28636
1953	HW-30437, HW-30464
1954	HW-30306, HW-33128, HW-35905, HW-35917
1955	HW-39558, HW-41315, HW-41500
1956	HW-47500
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1958	HW-59500
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1960	HW-69500, HW-70050
1961	HW-72500, HW-73337
1962	HW-76000, HW-77609
1963	HW-80500, HW-81746
1964	BNWL-122
1965	BNWL-280, BNWL-235, Vol. 1-4, BNWL-36I
1966	BNWL-480, Vol. 1, BNWL-481, Vol. 2, Pt 1-4
1967	BNWL-714, Vol. 1, BNWL-715, Vol. 2, Pt 1-4
1968	BNWL-1050, Vol. 1, Pt. 1-2, BNWL-1051, Vol. 2, Pt. 1-3
1969	BNWL-1306, Vol. 1, Pt. 1-2, BNWL-1307, Vol. 2, Pt. 1-3
1970	BNWL-1550, Vol. 1, Pt. 1-2, BNWL-1551, Vol. 2, Pt. 1-2
1971	BNWL-1650, Vol. 1, Pt. 1-2, BNWL-1651, Vol. 2, Pt. 1-2
1972	BNWL-1750, Vol. 1, Pt. 1-2, BNWL-1751, Vol. 2, Pt. 1-2
1973	BNWL-1850, Pt. 1-4
1974	BNWL-1950, Pt. 1-4
1975	BNWL-2000, Pt. 1-4
1976	BNWL-2100, Pt. 1-5
1977	PNL-2500, Pt. 1-5

FOREWORD

Part 5 of the 1978 Annual Report to the DOE Assistant Secretary for the Environment presents Pacific Northwest Laboratory's progress on work performed for the Office of Technology Impacts, the Office of Environmental Compliance and Overview and the reports on Human Health Studies performed for the Office of Health and Environmental Research. The report is in four sections, introduced by blue divider pages, corresponding to the program elements: Technology Impacts, Environmental Control Engineering, Operational and Environmental Compliance and Human Health Studies.

In each section, articles describe progress made during FY 1978 on individual projects, as identified by Schedule 189 tables. Authors of these articles represent a broad spectrum of capabilities derived from various segments of the laboratory and reflecting the interdisciplinary nature of the work.

Most of the program elements reported in this part of the Annual Report are relatively new to the Laboratory. We believe that significant progress was made in all of these areas; however, we expect this part of our program to continue evolving to meet newly identified requirements of the Department of Energy.

For additional information on any of the projects reported in this Part, contact the authors of the articles.

CONTENTS

1.0 Technology Impacts

TECHNOLOGY OVERVIEW

- **Policy Analysis**
- **Technology Assessment**
- **Environmental Impacts**
- **Regional Assessment**

The Integrated Overview Program, funded by the DOE Office of Technology Impacts, is a mechanism by which health, environmental, social, economic, and institutional factors are combined into a form useful for energy planning and decision making. This program selectively combines information about effects of alternative energy technologies (such as waste releases, land and water use, and social effects) to produce broad-based assessments of the advantages and disadvantages of energy and conservation policy options. As a corollary, needs for further research, development, and technology transfer are identified.

The Office of Technology Impacts is organized into four divisions which are named after their respective roles as listed above. The program at the Pacific Northwest Laboratory (PNL) is similarly divided.

Projects conducted for the Division of Policy Analysis are typically aimed at reviews of specific policy actions outside of DOE which are expected to affect DOE programs. Technology Assessment projects focus on respective energy production technologies. These projects evaluate the readiness of these technologies for commercial application and the likely consequences of their deployment under appropriate national energy and environmental policy assumptions.

The projects of the Division of Environmental Impacts are designed to improve analytical methodologies; facilitate the collection, storage, and transmission of energy and environmental information; and project gross national and regional environmental effects associated with national policy options. Regional Assessment considers in some detail the consequences of various national energy policy alternatives as represented by scenarios in which a portfolio of energy technologies is considered to be deployed in the region. At PNL these assessments are directed at the four Pacific Northwest states—Alaska, Washington, Oregon and Idaho. The regional work includes characterization of the region as it is now, identification and assessment of regional issues, and possible approaches to mitigation of regional problems interfering with implementation of national policy.

• Bullets indicate 189 titles.

• Policy Analysis

Work in Policy Analysis was aimed at providing assistance to DOE in its informal and formal reviews of "Proposed Guidance on Dose Limits for Persons Exposed to Transuranium Elements in the General Environment."

D. A. Waite, G. A. Stoetzel, D. L. Hessel

The principal Policy Analysis effort at PNL during FY 1978 was analysis of potential costs of application of the Environmental Protection Agency's "Proposed Guidance on Limits for Persons Exposed to Transuranium Elements in the General Environment" (EPA, 1977). The work included the development of detailed cost estimates for application of the Guidance under a variety of possible site conditions. It also entailed conducting and coordinating among the laboratories reviews of several of the Guidance drafts.

DOE transmitted to EPA a formal review, including the PNL cost estimate report, on March 3, 1978. The letter of transmittal to Dr. William A. Mills was signed by Dr. Bruce Wachholz, and the PNL report was included as part of DOE's official response to EPA's proposed guidance in the letter.

REFERENCE

EPA, 1977. U. S. Environmental Protection Agency Office of Radiation Programs. Proposed Guidance on Dose Limits for Persons Exposed to Transuranium Elements in the General Environment - Federal Register Notice.

• Technology Assessment

Work in Technology Assessment focused on impacts of increased use of coal, enhanced recovery of oil, oil shale conversion to oil, and changes in radiation standards. It also provided major inputs to DOE's formulation of plans for developing several technologies in environmentally acceptable ways and to the agency's evaluation of the environmental feasibility of commercialized application of these technologies.

National Coal Utilization Assessment

J. B. Burnham, and D. L. Hessel

The National Coal Utilization Assessment (NCUA) was conducted to consider the potential consequences in the United States of implementing an increased coal consumption policy. The policy was defined in accordance with the President's National Energy Plan (NEP), and the time frame considered was the present through 1990. Results obtained are specific to the scenario studied and are not necessarily representative of the likely real future. They are of value, however, as guides for further national energy planning.

The NCUA was conducted as a cooperative effort involving DOE headquarters, six DOE national laboratories, and several private contractors. PNL's primary roles included estimates of long-range air transport of sulfur oxides from coal burning in the western United States and analysis of specific effects in the Pacific Northwest.

Long-Range Air Transport of Sulfur Oxides

W. F. Sandusky, W. J. Eadie, D. R. Drewes

Air quality impacts resulting from both industrial and utility coal use in the western United States for 1985 and 1990 were estimated by use of a computer simulation diffusion model. Utility emissions considered that best available control technology (BACT) was used, while industrial emissions considered either BACT or state implementation plan (SIP) regulations applied depending on start-up date of the source.

Long-range impacts of sulfur were the main point of interest. Much of the SO_2 emitted transforms to sulfate aerosols, which can have adverse health effects. A regional transport, transformation, and removal model has been applied to estimate the sulfur impacts of both industrial and utility coal use in the western United States. Figures 1.1 and 1.2 show resulting incremental SO_2 concentrations for the 1985 coal-use scenario.

The maximum incremental SO_2 concentrations on the figures are 12 and 8 $\mu g/m^3$ for industrial and utility emissions. Thus, the prevention of significant deterioration (PSD) limits, as outlined in the Clean Air Act Amendments of 1977, for Class II areas are not exceeded. The western United States, however, contains a large amount of land area designated mandatory Class I (Figure 1.3) where allowable SO_2 increments are limited to 2 $\mu g/m^3$. Therefore, coal use may be constrained in the southern California area for industrial sources and the Four Corners area for utility sources.

Regional-scale sulfate concentrations are smaller than SO_2 concentrations. Maximum predicted incremental concentrations for both industrial and utility emissions are 0.8 $\mu g/m^3$. No PSD limits for sulfates have been established, although some states (e.g., Montana and North Dakota) have established their own air quality standards for sulfates, allowing a maximum annual average concentration of 4 $\mu g/m^3$. Therefore, based on this analysis, incremental sulfate concentrations would not limit industrial or utility coal use.

Several assessments were repeated to test the sensitivity of different model inputs. In particular, the effects of varying the deposition velocity by terrain type and increasing the transformation rate of SO_2 to sulfate were studied. Only the latter test provided significant results in which the maximum predicted sulfate concentration increased by 50%.

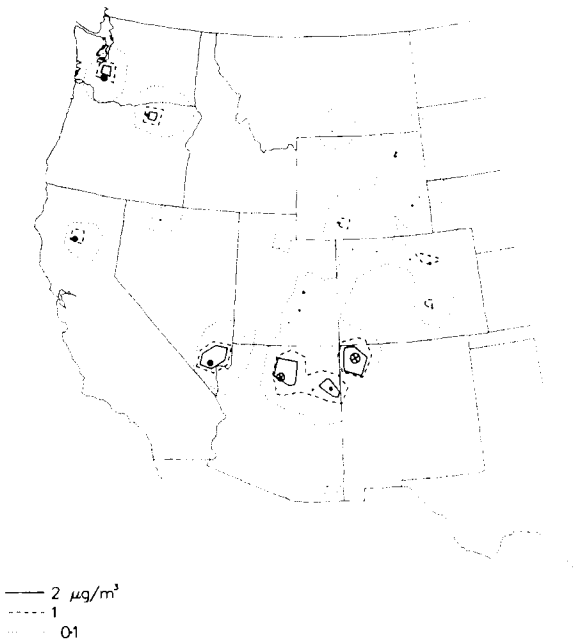


FIGURE 1.1. Incremental SO_2 Air Concentrations for the 1985 Utility Coal-Use Scenario.

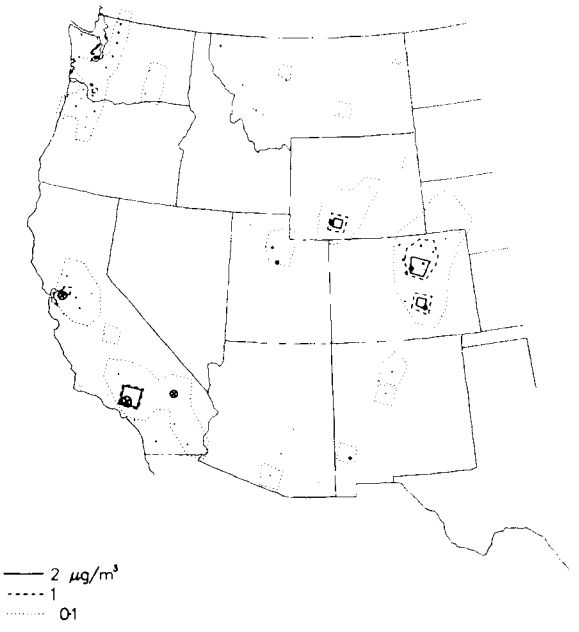


FIGURE 1.2. Incremental SO_2 Air Concentrations for the 1985 Industrial Coal-Use Scenario.

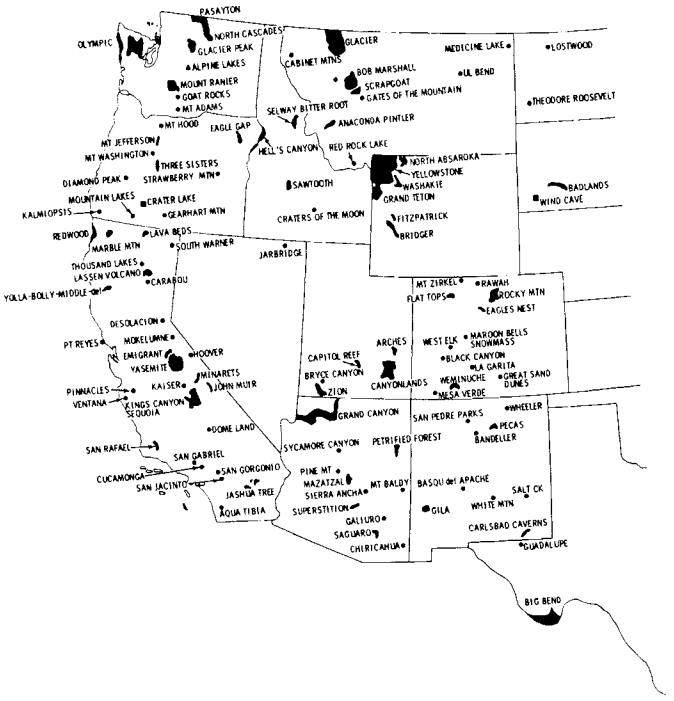


FIGURE 1.3. Mandatory Class I Areas in the Western U.S.

NCUA Impacts in Pacific Northwest Region

J. B. Burnham and D. L. Hessel

In general, the future as defined for the NCUA studies would have little impact on the Pacific Northwest Region. Most of the electricity used in the region comes from hydroelectric plants. Projections of added steam capacity from coal, nuclear, and oil/gas for 1985 are almost identical with existing utility plans; some increase over planned capacity is projected for 1990. There are only two coal mines operating in the region -- one in Centralia, Washington; one in Healy, Alaska. Water availability and quality in the region would not be expected to present serious constraints.

Socioeconomic Impacts of Potential Coal Development at Beluga, Alaska

M. E. Olsen, J. E. Trimble, C. Cluett

Considerable attention has been focused in recent years on the possibility of mining coal in the Beluga area on the west side of

Cook Inlet in Alaska, either to operate on-site electricity generators or for export. The possibility of such development was considered specifically as part of the National Coal Utilization Assessment. The purpose of this study, which was conducted jointly by Battelle's Human Affairs Research Centers (HARC) and CH2M HILL in collaboration with the Alaska Division of Energy and Power Development, was to assess the potential socio-economic impacts of coal development at Beluga.

Three alternative development scenarios were constructed, representing different levels of coal mining activity and hence different sized populations in the area. The first two scenarios assumed that all the workers would live in permanent work camps, whereas the third scenario assumed a larger population living in a more normal community. The study analyzes three sets of socio-economic impacts that might result from the alternative scenarios: (1) impacts on the surounding region, particularly its labor force, its market for coal, and its level and distribution of public revenues; (2) physical, economic, and social requirements of a new settlement in the Beluga area, either a work camp or a full community; (3) psychological, social, and cultural effects of coal development on the residents of the nearby native village of Tyonek. The study also examines the decision-making framework within which development at Beluga would occur, including various governmental jurisdictions and responsibilities, the interests of native organizations, environmental concerns, community service needs, and social planning. The final chapter of the study proposes several topics for further social research on energy development in the Cook Inlet region of Alaska.

Oil, Gas, and Oil Shale Assessment

D. L. Brenchley and D. L. Hessel

During FY 1978, several projects were undertaken as a first phase of an assessment of oil, gas, and oil shale technologies for use in the United States. This phase will be followed in FY 1979 by more comprehensive assessments of enhanced oil and gas recovery and of shale oil production.

Tertiary Oil Processes Technology Characterization - C. A. Geffen

This effort on characterizing the technology and environmental impacts of tertiary oil recovery during FY 1978 resulted in a published report entitled, "Tertiary Oil Recovery: Potential Application and Constraints," by C. A. Geffen. This report describes the technology of tertiary oil recovery methods and identifies potential economic and environmental constraints to future commercial application. Oil recoverable by tertiary techniques represents a domestic resource of between 11 and 42 billion bbl. Estimates of additional oil supplies from tertiary methods by the year 2000 range from 1 to 8 million bbl/day, depending on the price of oil and the rate of technological development.

The principal constraints to large-scale application of tertiary methods at the present time include environmental, economic and technological concerns. Regulatory action associated with the Clean Air Act Amendments of 1977 currently delays the expansion of thermal recovery operations in California and may discourage future projects. The high production costs of tertiary projects also hamper process implementation. Further test- ing and research are necessary to develop the technology of tertiary recovery methods and prove these techniques successful on a field-wide scale.

To enable tertiary oil recovery to play a significant role in augmenting domestic energy supplies, further research and development are necessary. More accurate methods of determining reservoir structure and residual oil saturations are required, as well as means for assuring the technical feasibility and success of a tertiary method in different reservoir types. Technical process limitations must also be resolved. The severity of potential environmental impacts and constraints identified in this report should be determined. These concerns include the air pollutant emissions from steam generation in thermal processes; acceptable methods of brine disposal; damage resulting from runoff or accidental discharge of oil-rich chemicals into surface waters; the impacts of fluid injection on deep aquifers and the prevailing geological structure; and an adequate supply of high-quality fresh water.

Environmental Impacts of Outer Continental Shelf Petroleum Development in the Pacific Northwest and Alaska - P. J. Mellinger

Significant changes in the patterns of the nation's production and consumption of energy are likely to occur during the remainder of this century. The potential environmental impact of these changes will vary in effect and importance from region to region, and from site to site within regions. Mitigating strategies aimed at reducing adverse impacts may be implemented more efficiently and effectively when Federal, state and local officials understand the magnitude and significance of these changes.

The scope of this task was to: (1) describe the development of petroleum reserves on the Oregon, Washington and Alaskan outer continental shelves (OCS); (2) characterize the technology applicable to OCS development; (3) identify the routine discharges to the marine and estuarine environment resulting from the petroleum resource development of the OCS; and (4) discuss any possible ecological impact from these routine discharges.

Components of the routine discharges to the marine environment from OCS development include metals in produced water, drilling muds, and borehole cuttings and chemicals in drilling mud. Large numbers of hydrocarbons and oils are discharged to the oceans from ships' bilges and produced water and to the atmosphere as combustion products from ships and platform power generation sources and as evaporation products from offshore and land-based storage tanks. These discharged hydrocarbons and oils may either dissolve, suspend or settle in the ocean.

Offshore technologies do exist to assure that the concentrations of discharged pollutants to the oceans and atmosphere are kept to a level that complies with regulatory limits.

Where sufficient effluent data exist, we conclude that long-term ecological effects from routine discharges have not been identified and appear not to occur. However, no environmental data gathered to date are sensitive enough to test a scientific hypothesis of the nature or magnitude of impact that would occur to a site-specific population or ecosystem from this type of release. Short-term effects are localized and short-lived and are, therefore, ecologically insignificant.

Ground-Water Pollution from Oil Shale Development -- Possible Impacts of Recent Federal Legislation on In-Situ Retorting - J. R. Raymond

Recent legislation has been promulgated to provide greater protection of ground-water resources. This legislation includes the Safe Drinking Water Act (P.L. 93-523), the Resource Conservation and Recovery Act (P.L. 94-580), and the Toxic Substances Control Act (P.L. 94-469). The objectives of this project are to identify the extent to which regulations, as proposed or expected, would constrain the oil shale industry and to identify aspects of oil shale technology or geohydrologic site conditions under which regulatory controls may be advisable to protect ground-water supplies.

Technical process alternatives of in-situ and other oil shale technologies were identified that may be affected by proposed injection control program regulations or by other provisions of the legislation. Technical process alternatives that might pose a threat to ground-water supplies were identified.

Control regulations, including those proposed by EPA, and possible state implementation regulations were reviewed and an evaluation was made regarding how these regulations might constrain or otherwise affect oil shale development and prevent (or fail to prevent) potential problems.

We intend to identify major data gaps or further research needed to more definitively or quantitatively assess the aspects of oil shale developments relating to ground-water quality.

Costs of Changing Radiation Standards

C. L. McDonald, L. E. Erickson, S. C. Schulte

This project assessed the costs that have been incurred by utilities and mining/milling operators to comply with new radiation standards. Causes of the changes in reactor costs as well as the impacts and costs of selected "typical and important" radiation standards for reactors and mining/milling were investigated. A framework for generating complete and consistent estimates of compliance costs was developed and methods of cost estimating were reviewed. This work can be used as a guide for evaluating and developing cost estimates. The way that estimated compliance costs are used in developing standards seems to be more significant in many cases than the magnitude of the estimated cost. Thus, the use of cost-benefit analysis in establishing selected radiation standards was critically reviewed. The results indicate that improvements in methods of valuing benefits and making cost-benefit trade-offs are possible.

Reactor capital costs have increased from $218/kW in 1969 to $1100/kW in 1978 using constant 1978 dollars. About $140/kW of this increase can be directly associated with regulatory requirements with approximately $70/kW directly attributable to environmental regulations. The remaining $700/kW increase in capital cost is due to general inflation, higher interest and escalation rates, and longer schedules. Some of the $255/kW schedule-related costs may be, but are not clearly, a result of regulatory requirements. Table 1.1 shows the sources of changes in estimated costs.

TABLE 1.1. Sources of Increases in Estimated Costs for Nuclear Power Reactors: 1969-1978 (1100 MWe).

Source	Cost, 1978 dollars
Contingency (20% vs. 7%)	$36/kW
Escalation During Construction	
10% Rate vs. 7% Rate	$90/kW
Interest During Construction	
10% Rate vs. 6.5% Rate	$76/kW
Regulatory Compliance Costs	$140/kW
Direct and Indirect Cost Increases Plus Increased Interest, Escalation and Contingency	
Longer Construction Schedule	
(Interest and Escalation During Construction)	
10 years vs. 6 years	$255/kW
Construction Inflation: 1969-1978	$204/kW
1969 Estimated Cost	$218/kW

Schedule-related costs have, in general, been seriously overestimated or underestimated by not considering the effects of the schedule change on system capacity. If power from the reactor can be sold, then the interest and escalation costs of a longer schedule seriously understates the cost of delay. On the other hand, if the capacity is not needed until a certain date, say 1990, then it makes little difference whether it takes 8 years or 12 years to build the reactor, provided that additional delays do not occur once construction commences.

Operating cost impacts incurred to date appear to be small and of little concern, in part because operating costs are a small part of the cost of nuclear-generated electricity. There are concerns, however, that some proposed regulatory actions (e.g., the reduction of occupational doses) could significantly increase costs. Increases in reactor downtime would result in major costs because of the value of lost power.

Many industry people seem to be more concerned with the noneconomic impacts than the cost impacts. Major concerns include: the distraction of senior management from their planning and innovator roles; difficulties of attracting and keeping good help; uncertainty about the future of regulatory requirements; and the problems of inconsistent, contradictory, and overlapping requirements of the various Federal and state regulatory agencies.

Discussions with Federal and state officials and uranium mining and milling representatives led to the identification of 21 radiation regulations or regulatory guides that result in direct costs for the uranium mining/milling industry. With a mining/milling operation of 2500 tons/day, 13 of these standards result in costs estimated to be at least $1 million. Of the 13, three standards (the NRC Branch Position on Uranium Mill Tailings Management and Regulatory Guide 3.11; State Bonding for Decommissioning and Tailing Disposal; and the Resource Conservation and Recovery Act of 1976) could measurably affect the cost of uranium. Compliance costs for any one of these standards are estimated to be somewhere between $0.40 and $2.50/ton of ore (about $30 million over a productive lifetime of 30 years).

Major concerns of the uranium mining/milling industry include: (1) their ability, within the framework of their contracts, to pass on to their customers costs of regulatory compliance; (2) NRC branch positions having the force of regulation without the public scrutiny required of regulations; (3) the proliferation of agencies with differing requirements and overlapping jurisdictions; (4) uncoordinated and/or conflicting positions taken by different government agencies; and (5) burdensome and time-consuming legal procedures for challenging standards.

Environmental Development Plans and Readiness Documents

D. L. Hessel

As part of its assignment to assess energy technologies, the Division of Technology Assessment (DTA) has been preparing a series of environmental development plans (EDPs) and environmental readiness documents (ERDs) to be used by DOE policy offices in designating energy technologies for research and development efforts. The EDPs, developed jointly by DTA and the technical program offices, define environmental concerns and needed research programs to deal with these concerns. The ERDs are evaluations by the Office of the Assistant Secretary for Environment of the readiness of the respective technologies for commercial application.

During FY 1978, PNL assisted in the preparation of EDPs and/or ERDs for coal gasification, coal liquefaction, shale oil production, nuclear waste management, and fusion technologies. While the level of staff labor applied to these efforts was small, the impact of the resulting documents on the designation of technologies for commercialization has been substantial.

• Environmental Impacts

Work conducted in the Environmental Impacts area included cooperative interlaboratory efforts to improve information transfer and shared use of computerized models. These efforts were designed to facilitate cooperative research programs carried on in two or more national laboratories at the same time. In addition to these efforts, a research project was undertaken to compare health risks associated with various energy technologies.

Interlaboratory Working Group on Data Exchange

P. J. Dionne

During FY 1978, PNL staff cooperated in the first phase of a program to create a data exchange standard which would facilitate the transfer of data among the various national laboratories.

After the exchange standard was incorporated into computer programs, it was used to send several tapes of meteorological data to the Savannah River Laboratory. The exchange standard was also used to read several reels of tape containing output from the Strategic Environmental Assessment System (SEAS) model.

A Geographic Exchange Standard Subcommittee was formed by the Interlaboratory Working Group on Data Exchange (IWGDE). The subcommittee was to create a standard for exchanging geographic (map) data and associated thematic data using the parent standard. An example of geographic data is county boundaries. Associated thematic data might be population by county. The subcommittee created a rough draft Geographic Exchange Standard and Primer. That rough draft and its first revision have been circulated throughout the IWGDE for comment. PNL will publish Revision 2 as a working paper shortly after the beginning of FY 1979.

Development of Level 2 of the parent exchange standard was one of the important subjects discussed at the two IWGDE meetings. The Level 2 implementation has been designed and is expected to be coded during FY 1979. Another subject discussed at the meetings was the creation of a set of reference data bases residing at various national laboratories and available upon request.

Information Coordination Focal Point

P. J. Dionne

The Information Coordination Focal Point (ICFP) program has been established for the purpose of gathering and disseminating information about the data bases, models and graphics packages that are used in support of DOE environmental research activities.

The ICFP is a point-of-contact for those within or outside of the DOE community who wish to communicate with specific researchers about their data. To that end, the ICFP activities at PNL during FY 1978 included: (1) designing a questionnaire for the purpose of surveying PNL's environmental research programs and listing candidate data bases, models and graphics packages; (2) creating a bibliographic data base for storing the above information; (3) transmitting that data base to the Oak Ridge National Laboratory (ORNL) for incorporation into a DOE-wide publication; (4) designing an interactive retrieval system for perusing the PNL data base; (5) writing a document for distribution within PNL; (6) filling out Federal Energy Inventory questionnaires; and (7) supporting the Regional Assessment Data Book activity.

Review of Comparative Health Risks of Energy Technologies

B. J. McClanahan

This project was undertaken to create a basis for comparing energy production technologies on the basis of health risks. It consisted of reviewing publications in the literature that contain estimates of these risks. The reviews entailed a critical assessment of the quality of the data supporting the estimates, the methodologies used

in developing the data, and the assumptions critical to use of the data. The literature was found to contain only very limited estimates. It does not appear that estimates adequate to support credible comparisons of technologies on the basis of health risks are available.

• Regional Assessments

Studies in Regional Assessment during FY 1978 focused largely on aspects of water resource use in the Pacific Northwest -- Alaska, Washington, Oregon, and Idaho. Some efforts were also devoted to the development of social impact assessment methodologies. Finally, a Data Book was created to present information essential to regional analyses of energy-environmental problems and opportunities.

Trade-off between Irrigation and Hydroelectric Power Generation in the Pacific Northwest

A. E. Davis

A trade-off exists between use of surface water for irrigation and its use for hydrogeneration. Only part of the water withdrawn from the Columbia and Snake Rivers and their tributaries for irrigation of crops returns to the rivers. To the extent that it does not, less water is available to run turbines at downstream generating sites. Thus, kilowatt-hours must be foregone if food is to be produced on land irrigated from surface water sources.

The objective of this task is to estimate the total impact of projected levels of future irrigated agriculture development on the Northwest's hydrogeneration system. This total impact consists of both the foregone generating capability at downstream dams and the direct use of electric power for pumping irrigation water and applying it to crops. The research effort to accomplish this objective was completed during FY 1978; its conclusions are summarized below.

In 1974, irrigated area in the Northwest was 7.6 million acres. By the year 2020, the states of Oregon, Washington, and Idaho expect a total of 11.4 million acres in irrigation development. It is estimated that if this level of development is reached, the following impacts will result:

- For irrigation purposes, 43 million acre feet of surface water will be diverted annually by the year 2020.
- Of these 43 million acre feet, 22 million acre feet will return, directly or indirectly, to surface sources. Depletion of surface sources in the region will total 21 million acre feet annually.
- Electrical energy use for pumping and application of irrigation water will total 10.3 MW-hr annually.
- Lost hydrogenerating capability resulting from the 21 million acre feet of depletion will total 17.0 million MW-hr annually.
- The total amount of electrical energy that must be traded off in order for irrigated agriculture to reach the projected level of 11.4 million acres by 2020 is approximately 27 million MW-hr.

Social Impact Methodology Evaluation

C. H. Sawyer, M. R. Greene,
C. Cluett, D. W. Wiley

This project was initiated with the purpose of developing and evaluating methods of monitoring the social and economic impacts of energy development. The focus of the project was twofold. The first purpose was the development of a monitoring system to be used in the measurement and assessment of social and economic impacts associated with the construction of a nuclear power plant in Washington State. The work on this task focused primarily on the identification of key social and economic impact indicators and their organization into a workable measurement system. A comprehensive baseline of social and economic conditions in Skagit County was developed in anticipation of the development of a nuclear energy facility there. Although the prospect of plant construction is in doubt, the work under this project in Skagit County has led to the development of a monitoring framework and guidelines that are applicable at other sites and for other forms of energy development.

The second purpose of this project originally was the evaluation of strategies to

assess and manage social and economic impacts at selected western energy sites. Work in FY 1978 was to focus on the development of a framework for assessing methods to monitor social and economic impacts at these sites. This focus was subsequently expanded to encompass a more general review of problems in social and economic impact assessment and management. A report is being prepared that will present a critical review of current procedures used to forecast, manage, and monitor local social and economic impacts associated with energy development. It will identify components of the impact assessment and management process that are judged to be deficient. It will also argue that such deficiencies can lead to energy-related decisions that not only produce unnecessarily high costs to society but also tend to overlook the equitable distribution of these costs. The report will develop a framework to provide a set of criteria for evaluating public policy and procedures in the assessment and management process. This report will also include several sets of recommendations directed toward the improvement of forecasting, management and monitoring strategies and toward the identificaton of needed basic research in this area.

Implications of Hydropeaking on Columbia River Water Quality

W. H. Walters and S. M. Brown

The purpose of this research was to evaluate the possible changes in water quality from increased bank-line erosion resulting from future hydropeaking operations on the Columbia River. The concern is that the extreme daily water surface fluctuations required for hydropeaking may cause an increase in bank caving or possible land sliding along reservoir perimeters. If this type of erosion were to increase in frequency, prolonged reduction of water clarity (i.e., increased turbidity) would result from suspension of fine sedimentary materials (clay and silt).

The Chief Joseph and Hanford reaches of the upper Columbia River were selected for the study on the basis of available data. Projected hydropeaking ranges for the mid-1980s were evaluated with respect to present reservoir or river water surface conditions. Other primary considerations were river reach geology and the presence of irrigation on the upper slopes.

Two Columbia River tributaries were selected for study since reservoir pondage can impose a backwater effect on tributary rivers and creeks. Any increases in reservoir operating elevation and/or frequency could extend the backwater effect further upstream. This can result in the periodic or permanent inundation of river bank materials which were previously dry under normal streamflow conditions. The two tributaries selected were the Okanogan and Methow rivers.

The final results of this study indicate that hydropeaking at projected mid-1980 levels may not cause any significant long-term changes in turbidity levels. However, if any changes were to occur in the extent or frequency of bank erosion, it would be difficult to separate the increase in erosion that is due to hydropeaking from that caused by seepage forces from upslope irrigation. Irrigation of lands adjacent to the Columbia River has caused the ground-water table to rise in certain areas. The seepage of ground water through the steep, bluffed river banks causes local instabilities and sloughing. The tributaries were found to be fairly stable streams except during extreme (unusual) flood events that would not be related to hydropeaking. Some minor bank erosion problems could occur on tributaries to the Columbia River as a result of reduced vegetation along the bank lines as a result of periodic inundation.

Environment Data Book -- Pacific Northwest Region

G. L. Wilfert and H. McCartney

PNL has completed a draft report characterizing the Northwest (Alaska, Idaho, Oregon and Washington) in terms of energy, environment and institution factors. Similar draft reports have been prepared by other national laboratories for other regions of the United States. Each of these reports has a common outline and format. Together, the six reports characterize all 50 states in over 100 various energy, environment and institutional parameters. During early FY 1979, the draft reports will undergo extensive review within DOE. The report will then be modified and updated. A final report will be printed at the end of FY 1979.

2.0 Environmental Control Engineering

ENVIRONMENTAL CONTROL ENGINEERING

- **Assessment of Environmental Technology for Coal Gas Separation**
- **Energy Material Transport, 1977-2000**
- **Dry/Wet Cooling Towers**
- **LNG Safety and Control**
- **Burning of Oil Spills**
- **LPG Research Assessment**
- **Treatment of Oil Shale**
- **Geothermal Liquid Waste Disposal**
- **Compressed Air Energy Storage**
- **Energy Conserving Industrial Waste Treatment**
- **Analysis of Nuclear Fuel Cycles**
- **Transportation Safety Study**
- **Decommissioning of Retired Facilities at Hanford: Planning**
- **Characterization of Hanford 300 Area Burial Grounds**
- **Decontamination and Decommissioning of Hanford Facilities: Technology**
- **Assistance for Nationwide Decommissioning Planning for DOE Nuclear Facilities**
- **Asphalt Emulsion Sealing of Uranium Tailings**

The objective of the overall Environmental Control Engineering Program is to assure that the environmental control capability for each DOE energy technology is complete, practical, cost effective, and available in a timely manner as the energy source is developed. Program activities are oriented to identifying control technology status and needs for emerging energy systems, then developing methods and equipment for meeting these needs.

PNL's effort in this program is growing rapidly. During 1978 we conducted studies in support of both nonnuclear and nuclear technologies, with programs in oil shale, oil, coal, gas, energy materials transport, geothermal and compressed air energy, and nuclear fuel cycle analysis.

• Assessment of Environmental Control Technologies for Koppers-Totzek, Texaco, and Winkler Coal Gasification Systems

Commercial coal conversion processes employing Koppers-Totzek (K-T), Texaco, and Winkler gasifiers were reviewed to determine the availability of environmental control technologies for meeting current release standards. Information on material and energy flows in the conversion processes was obtained from manufacturers of the gasifiers and from the literature. Technologies for control of releases to air, land, and water are commercially available and are adequate for meeting current environmental release standards. The behavior of trace elements in the coal feed has not been adequately characterized. A draft final report defines areas where improvements of technology would benefit the conversion processes. Construction of a demonstration plant employing these technologies for ammonia production is recommended.

Data Search on Gasifiers to Generate Synthesis Gases

L. K. Mudge and L. J. Sealock

Data on material and energy flows in commercial plants that use Winkler, Texaco, or Koppers-Totzek gasifiers to generate synthesis gas were sought by contacting manufacturers of these gasifiers and by search of the literature. The objectives of the study were: (1) to determine if environmental control technologies in commercial use are adequate relative to existing and proposed standards, (2) to identify areas where improved control technologies are needed, and (3) to rank research and development programs in terms of their potential benefit.

The draft final report prepared in FY 1977 on this project was revised to include the Texaco and pressurized K-T gasification systems. The project is now completed. No further activities are planned.

• Energy Material Transport, Now Through 2000

The objectives of this project are twofold: (1) to assess potential problems that may inhibit the safe and environmentally acceptable development of nuclear and fossil energy material transportation systems in the period now to the year 2000; and (2) to recommend research, development and other necessary action to mitigate the adverse impact of these problems. Effort in FY 1978 addressed the domestic transportation of coal, nuclear fuel cycle materials, petroleum, natural gas and synfuels. Results of the studies on coal, nuclear fuel cycle, and natural gas systems were published.

Energy Material Transport, Now Through 2000: System Characteristics and Potential Problems

J. G. DeSteese, G. W. Dawson, C. R. Schuller

A primary goal of this project is to provide information to government and industry that will help in evaluating future program objectives and priorities related to potential problems in energy material transportation. Final task reports containing system characterization and potential problem assessments of domestic coal and natural gas transportation were completed and published in FY 1978. Summary reviews of problems in the transportation of nuclear fuel cycle materials and coal were also published. The final task reports on nuclear fuel cycle and petroleum transportation are being prepared for publication. Other tasks in progress address specific problems in more detail. These problems include selected regulatory and legal concerns, coal sludge transportation, nuclear transportation logistics and synfuel transportation.

The FY-1977 characterizations of fossil and nuclear energy transportation systems were updated in FY 1978. The identification and ranking of potential problems were based on these system characterizations and on analysis of current system trends, issues and controversies. Additional information was gained from contacts with experts in government and in the transportation industries.

Problems were ranked on the basis of their potential severity and immediacy; they fell into three categories:

1. serious concerns that require action now to avoid greater potential impact in the next decade,
2. moderate concerns requiring moderate action to avoid greater potential impact later in the century,
3. latent concerns which may change as conditions evolve but appear to be under control at present.

Over 180 problem issues were reviewed in the four primary energy material transportation systems.

Analysis eliminated many trivial issues and identified 50 potential problems that fall in the three classes above; see Table 2.1.

A recommendation was made that if these problems are not receiving adequate attention in other related programs, they should be addressed according to their seriousness. Where possible, estimates of the level of effort and timing, and suggestions for the scope and responsible agency for each project should be included in these studies.

A continuing effort is planned to maintain the capability of providing early warning and assessment of problems that may affect energy material transportation in the balance of the century. Other efforts planned for FY 1979 will address specific potential problems already identified, with emphasis on the nuclear fuel cycle and coal transportation.

TABLE 2.1. Potential Problem Areas in the Primary Energy Material Transportation Systems.

Transportation System	Priority Class 1 Near-Term Concerns	Priority Class 2 Longer-Term Concerns	Priority Class 3 Latent Concerns
Nuclear Fuel Cycle	Reasonable Radiation and Safety Standards Acceptable Risk Policy Railroad Attitudes Cargo Security Accident Response Cask Integrity Relationships Public Acceptance Representation in Planning and Decision-Making State and Local Regulation	Labor Attitudes Slow Action on Problems and Policies	Standardization of Hardware and Procedures Intervenor Action
Coal	Public Acceptance Frozen Coal Slurry Pipeline Impacts Sludge Removal	Unit Train Rates Liquid Fuel Slurries Congested Waterways	Eminent Domain for Slurry Pipelines Railroad Abandonment Policy Sabotage Potential Diesel Fuel Dependence Competition for Barges at Harvest Time Requirements for Scrubbers
Petroleum	Effects of Marine Oil Pollution Oil Spill Trajectories Training of Waterway Personnel Emergency Distribution Planning Pipeline Sabotage Waterway Congestion Deepwater Port Licensing	Environmental Impacts of Pipelines Tanker Size/Safety Relationships Petroleum Industry Reorganization Preemption Federal Right of Eminent Domain Oil Spill Liability and Compensation	Safety of Unit Oil Trains Effectiveness of Vessel Traffic Services Loss of Crucial Pipeline Links Double Bottoms for Tankers Distribution Efficiency
Natural Gas	Pipeline Compatability with New Fuels Emergency Distribution Planning	Effects of Natural Disasters	Pipeline Corrosion Deterioration of Older Systems Third-Party Damage

• Environment-Multiresource Environmental Research and Development Dry/Wet Cooling Towers

The objective of this project is to evaluate environmental effects of dry/wet cooling for thermal power plants and to develop systems that can be applied to conserve water resources, increase power-plant siting flexibility and give efficient power-plant performance at lower costs than for those now available. PNL also plans to study the application of the dry cooling concept to advanced systems of energy generation.

Dry/Wet Cooling Tower Project

R. T. Allemann

Dry cooling of thermal power plants -- heat from the power cycle is released directly to the air -- has been used in a few isolated instances throughout the world for the past 15 years. Very few installations are dry cooled in the United States although the method is being given increased consideration for new, large power stations. Dry cooling is a more costly option than once-through or evaporative cooling, but there are a few locations now, and there will be far more in the future, at which once-through and all-wet evaporative cooling towers cannot be used because of the increased competition for existing water supplies among growing populations, agriculture and industry. The competition for water may change agricultural economics, and thereby the environment, in some parts of the United States. Earlier studies at the Pacific Northwest Laboratory have shown that considerable incentives exist for development of an advanced dry/wet cooling system that makes use of ammonia as an intermediate heat transport medium. This system provides augmented cooling by evaporation of a relatively small amount of water. A test of the advanced system is being planned.

One aspect of that test is the environmental impact of corrosion and deposition on large-scale dry cooling systems for power plants, particularly on those systems made of aluminum. Work is also planned to evaluate the possible use of this new dry cooling concept in advanced systems of energy generation, since such a concept would be a logical extension to use in current power-plant systems. An advanced concept dry-cooling tower test facility is shown in Figure 2.1.

This work was funded and begun late in the fiscal year. A report, "Analyses and Experimental Results From the PNL Augmented Dry Cooling Surface Test Program," was completed, edited and published.

Further work will study the economic effects of water transfer from agriculture to plant cooling, the environmental constraints on the use of aluminum, and the incentives for dry cooling of advanced energy systems.

Studies are being done to evaluate material corrosion/deposition, and environmental effects of future cooling systems of this type.

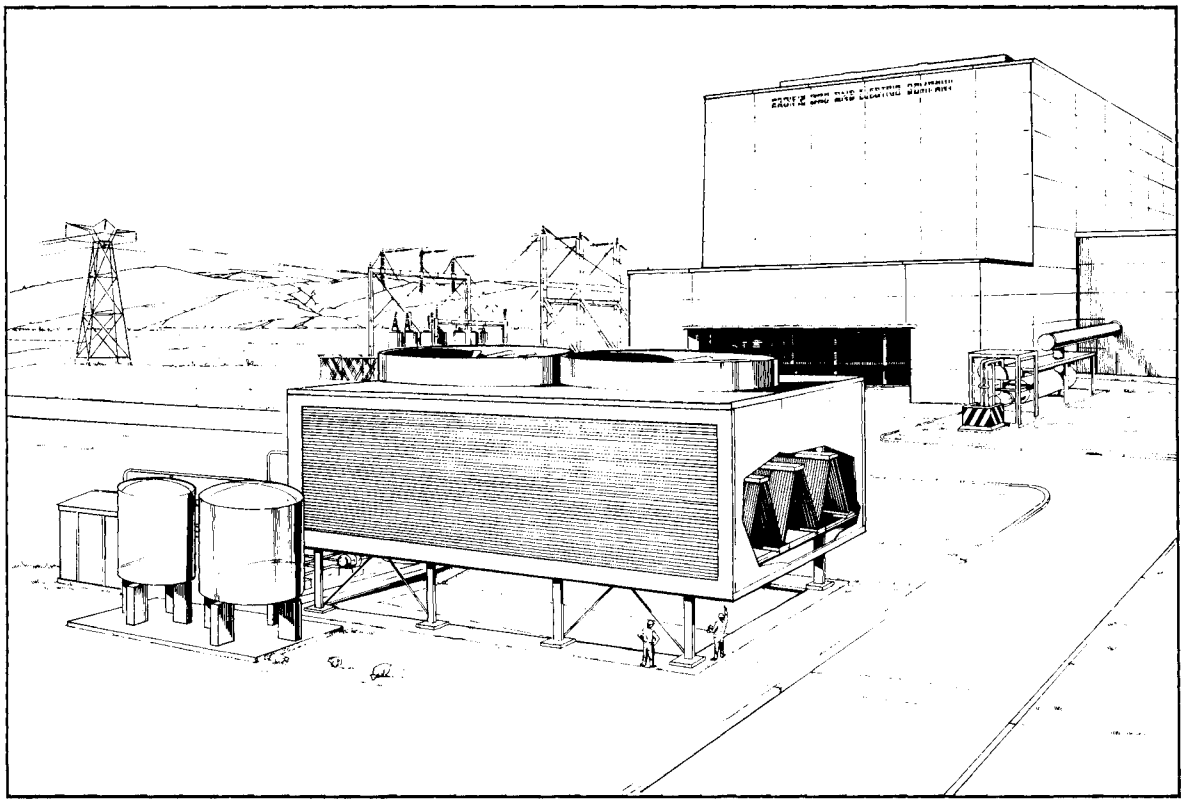


FIGURE 2.1. Advanced Concept Dry Cooling Tower Test Facility.

• LNG Safety and Control Program

The objectives of this project are: (1) to provide assistance to DOE Environmental Control Engineering in planning and technical surveillance of research, development and demonstration (RD&D) in liquefied natural Gas (LNG); and (2) to conduct R&D in specific areas of the program (principally, release prevention and control studies). An implementation plan has been prepared, an experimental strategy developed, and literature surveillance maintained. In addition, a preliminary assessment of the release prevention and control systems of a generic LNG peak-shaving plant has been completed.

LNG Safety Studies

R. J. Hall

The DOE Environmental Control Engineering (ECE) Division is conducting a multicontractor program with the goal of developing in a timely manner the liquefied natural gas (LNG) safety and environmental control information needed by industry, regulatory agencies, and the general public in LNG decision-making. The objectives of the LNG Safety Studies project are: (1) to provide assistance to DOE-ECE in planning and technical surveillance of LNG RD&D and (2) to conduct R&D in specific areas of the program (principally, release prevention and control studies).

A method of implementing the multiyear program was developed and submitted to DOE-ECE for consideration. The implementation plan was organized around the same six research areas identified in DOE/EV-0002, An Approach to Liquefied Natural Gas (LNG) Safety and Environmental Control Research. These areas are: Vapor Generation and Dispersion, Fire and Radiation Hazards, Flame Propagation, Release Prevention and Control, Instrumentation and Technique Development, and Scale Effects Experiments. The plan was based on a set of explicit but unvalidated assumptions, including assumptions on funding pattern. Regardless of whether conditions are eventually different from those assumed, the relationships between the research areas in the plan would remain valid and useful.

In order to assist ECE in maintaining awareness of current and recent RD&D related to LNG safety and environmental control, a literature surveillance effort was maintained. This year 44 articles and reports were found that were determined to be in this category. These were technically reviewed and abstracts prepared and submitted to ECE.

Some field experiments that likely will be necessary to validate the analytical techniques used to predict effects of LNG spills will be quite costly and time consuming. Such an experimental program must be extremely well planned. An important part of this planning involves development of an experimental strategy. Experimental strategies are of two basic types: the classical approach that involves changing one variable at a time, and the statistical approach that involves simultaneous variation of all selected experimental variables in a predescribed pattern selected on the basis of the objectives of the experiments. For the LNG spill studies, it appears that a statistical screening strategy involving a total of approximately 60 experiments over a range of spill sizes would be adequate.

The LNG industry employs a variety of release prevention and control mechanisms. In our study, release prevention and control systems are those systems or components necessary to contain LNG during transfer and storage operations as well as those systems that detect and control an LNG release if it occurs. The overall objective of our release prevention and control studies is to develop an adequate understanding of release prevention and control systems and the factors that may defeat them.

A staged approach is being used to accomplish this objective. First, a generic description of the LNG facility is developed. Then, this system description is used to perform a scoping or first-level analysis to identify information needs and potential

release prevention and control areas that may merit more detailed study. Initially this is an analysis of preliminary hazards followed by a failure mode and effect analysis. Next, the feasibility and methods of obtaining required additional information are investigated, and a decision is made whether to perform a more detailed assessment. This might include a refined failure mode and effect analysis or, if the system detail and data warrant it, a fault tree/event tree type analysis.

The first facility investigated in these studies was an LNG peak-shaving plant. A generic description has been prepared that includes the basic process flow, plant layout and process description. A preliminary assessment of the release prevention and control systems has been completed. Other facilities will be investigated as well.

• Oil Spill Mitigation by Combustion

The purpose of this project is to gather and evaluate scientific data on the feasibility of using burning as a means of preventing or reducing pollution of the sea by oil spills. A draft report and an annotated bibliography were written; a scheme for classifying oils in a continuum was attempted.

Oil Spill Mitigation by Combustion

C. H. Thompson, G. W. Dawson, J. L. Goodier

The objective of this project is to gather and evaluate sufficient scientific and engineering data to provide a technical rationale useful in determining the feasibility of using burning as a tool to prevent a broken vessel from polluting the sea, reducing the amount of oil on the sea, or reducing the disposal problem of oil-contaminated debris onshore.

A technical progress report from which future work could be planned and refined was submitted to the project officer. An annotated bibliography was produced along with a first draft, state-of-the-art assessment. International and domestic interests were solicited for data, experience, equipment availability and comments. An initial classification scheme was attempted which would allow all oils to be categorized into a continuum. Initial efforts at modeling combustion of oil spills were begun to serve as a national basis for defining key variables affecting the burning of oil. Scope revision meetings were effective in designing a program responsive to the needs of DOE to:

- create an iterim report that declares the technical state of the art;
- hold a meeting and receive comments and criticism on the interim report;
- evaluate the technical feasibility in terms of public and users; and
- complete the project by producing a technically justified, state-of-the-art document that provides guidance on the feasibility of the use of combustion in a decision context.

The project as defined by the revised scope is to be completed by summer of 1979.

• LPG Safety and Environmental R&D

This project is to assist the DOE Division of Environmental Control Engineering in determining research development and demonstration needs (if any) relative to safety and environmental issues in the Liquefied Petroleum Gas (LPG) industry in the United States. Work was initiated in July 1978. A literature search and review were partially completed and preliminary first drafts prepared on: (1) a description of the pipeline segment of the industry, (2) an identification of the properties of LPG, and (3) the status of R&D on predicting the consequences of LPG fires. This project is expected to continue in FY 1979, but progress will be restricted because of funding limitations.

Liquefied Petroleum Gas Safety and Environmental Research and Development

M. G. Patrick

The objective of this program is to assist the DOE Divsision of Environmental Control Engineering in the development of a research assessment that identifies current and further research, development and demonstration (RD&D) work needed for safety and environmental control in processing, storing, transferring and transporting Liquefied Petroleum Gas (LPG) in the United States.

Work on this project was initiated in July 1978. A memorandum purchase order was placed with Battelle Columbus Laboratory (BCL) for preliminary work on describing the segments of the industry that transport LPG by truck, rail and pipelines and the distribution of LPG to consumers via portable containers and truck deliveries. This work also includes describing the status of R&D on release prevention and control for these industry segments and the R&D status relative to vapor generation and dispersion, fires and explosions from any LPG release.

A proposal was obtained from the Institute of Gas Technology for a similar effort to describe the large storage installations involved in production, import, export and peak-shaving uses including ship and barge transport. The contract for this work is pending new decisions required by the FY-1979 funding reduction from previous plans; therefore, this work must be replanned for FY 1979.

A literature search has been conducted and BCL has obtained some published material pertaining to their investigation. This effort is considered partially complete. Additional information is expected from the National Liquefied Petroleum Gas Association.

Based on the information available, preliminary first drafts have been prepared on:

- a description of the pipeline segment of the industry,
- the properties of LPG,
- the R&D status of predicting the consequences of LPG fires.

The PNL project manager participated in DOE's LNG/LPG Contractors' Information Seminar in August 1978.

• Environmental Control Technology for Shale Oil Wastewaters

The capabilities and limitations of conventional treatment and disposal technology are being evaluated for shale oil wastewaters. Bench-scale treatability studies are being conducted to assess the effectiveness of alternative physical, chemical and biological processes for removing pollutants from shale oil wastewaters. The results of these studies indicate potential problems with retort-water toxicants that are deleterious to the operation of biological treatment processes. Addition of powdered activated carbon was shown to be effective in one instance for overcoming the toxicity problem. Removal of fluoride and boron contaminants from minewater was readily accomplished by ion exchange methods.

Analysis, Screening, and Evaluation of Control Technology for Wastewater Generated in Shale Oil Development

B. W. Mercer

Several different types of wastewaters may be generated in the mining and processing steps leading to the recovery of oil from shale. Retort water, produced during pyrolysis of oil shale, is generally the most heavily polluted waste stream; others, such as cooling water, may have a relatively low pollution potential. Most, or all, of these wastewaters can be used to moisturize spent shale from surface retorts, but disposal or reuse must be practiced for in situ operations. The primary objective of this program is to assess the capabilities of state-of-the-art technology for the treatment and disposal of wastewaters generated in shale oil development.

Retort Water Studies. Bench-scale treatability studies are being conducted on retort water to assess the effectiveness of steam stripping and biological treatment for pollutant removal.

Steam Stripping. Bench-scale studies were conducted to evaluate steam stripping as a means of removing ammonia from retort water. The steam stripper used in this work consists of a 2-in. ID glass pipe packed to a depth of 4 ft with 1/4-in. ceramic saddles. Feed to the stripper is introduced at the top of the column of saddles and is counter-currently contacted with steam generated by a reboiler at the bottom of the column. Steam, containing volatile constituents stripped from the feed, is removed from the top of the column, condensed, and collected in a condensate receiver. The condensate receiver is vented to a water trap and an acid trap in series to absorb ammonia vapor carried over with noncondensable gases. The steam stripped feed collects in the reboiler. The condensate may be recycled by injecting it into the feed stream to the stripping column. Recycle of the condensate eliminates the necessity of dealing with a separate wastewater stream but also reduces the efficiency of ammonia removal in the stripping column by increasing the ammonia concentration in the feed streams.

A sample of retort water from a simulated in situ retort at the Lawrence Livermore Laboratory was steam stripped while operating in the condensate recycle mode at a condensate temperature of $85.5^{\circ} \pm 3.5^{\circ}C$. The ammonia was reduced from 26,500 mg/ℓ to 135 mg/ℓ at a boiloff rate of 15% of the combined feed and condensate recycle. This boiloff rate is equal to 18% of the feed flow alone. Approximately one-fourth of the ammonia was recycled with the condensate stream and three-fourths was evolved with the gaseous ammonia stream.

Retort water contains foaming agents which can cause flooding in the stripping column. Precise control of liquid levels in the reboiler and/or addition of antifoam substances are required to prevent foam from entering the stripping column.

Biological Treatment. Biological treatability studies were conducted on five samples of retort water. One of the retort water samples came from the 6000-kg simulated in situ retort at the Lawrence Livermore Laboratory, one from an above-ground

retort in Colorado, and the other three samples from an in situ test site in Utah. Both aerobic and anaerobic biological treatment processes have been evaluated on a bench scale. Aerobic treatment consisted of activated sludge or of roughing filter (trickling filter) combined with activated sludge. The results of the aerobic treatment studies indicated toxicity problems in the treatment units as the concentration of retort water was increased in the feed to the units. Good biological growth and organic carbon removals were observed during the initial phases of the acclimation period, but an apparent toxicity problem develops as the percentage of actual retort water in the feed increases and the percentage of artificial retort water decreases. Analysis of the retort water for toxicants revealed the presence of arsenic and thiocyanate. Thiocyanate is not believed to be a problem since the concentration of this constituent is below the threshold value of 500 mg/ℓ for activated sludge. Arsenic could be a problem since it exceeds the threshold value of 0.1 mg/ℓ for activated sludge. The Livermore sample contained 1.3 mg/ℓ arsenic and the remaining samples contained 4 to 13 mg/ℓ arsenic. Results of anaerobic digestion studies conducted with 3.5-ℓ digesters also indicated toxicant problems. Gas production from the digesters diminished steadily as the concentration of actual retort water was increased.

Results of studies to evaluate powdered activated carbon addition to the anaerobic digesters indicate successful operation in the case of the Livermore retort water but continued toxicity problems with the other retort water samples. The powdered activated carbon is effective for removing certain soluble organics, including toxic organics, from solution, which could reduce the stress on microbial population in the digesters. The activated carbon is also effective in some instances for removing heavy metals from solution, but its effect on arsenic in retort water is unknown at the present time. Analysis for soluble arsenic in the digester that received in situ test site retort water revealed 0.96 mg/ℓ, which is near the toxicity threshold for anaerobic digestion. Soluble arsenic in the digester receiving Livermore retort water was 0.56 mg/ℓ. Preliminary results indicate that activated carbon treatment of Utah in situ retort water will permit aerobic biological degradation to take place, although the amount of activated carbon needed may be relatively high.

Minewater Treatment. Water pumped from underground oil shale mines or in situ operational zones in an oil shale formation may contain pollutants, such as fluoride, boron, and high dissolved salt concentrations, which will prevent unrestricted release of this water to surface receiving streams. Treatment and disposal technology for these minewaters is also being assessed.

Ion Exchange. Treatability studies were conducted to evaluate ion exchange methods for fluoride and boron removal from a groundwater sample taken from an oil shale formation in Colorado. Activated aluminum was investigated for fluoride removal, and a boron selective ion exchange resin was investigated for boron removal. Breakthrough curves for fluoride and boron are given in Figure 2.2. Anticipated discharge limits for fluoride and boron are 2 mg/ℓ and 0.3 mg/ℓ, respectively; therefore, the volume capacity for fluoride removal is about 350 bed volumes, whereas the capacity for boron removal is about 10,000 bed volumes. Estimated chemical regenerant costs for fluoride and boron removal are $0.30 and $0.01/1000 gal of water treated, respectively.

Chemical Treatment. Results of precipitation experiments with simulated oil shale ground water indicate 90% fluoride removal with phosphoric acid and lime addition. Approximately 9 moles of phosphorus and 10 moles of calcium per mole of fluoride are required to achieve this level of fluoride removal, which would be needed to meet discharge limits. The precipitation formed is basically a mixture of fluorapatite, $CA_5(OH)F(PO_4)$, and hydroxy apatite, $Ca_5(OH)(PO_4)_3$. The cost of phosphoric acid and lime to treat the ground water is estimated to be about $2/1000 gal, which is excessive relative to ion exchange methods.

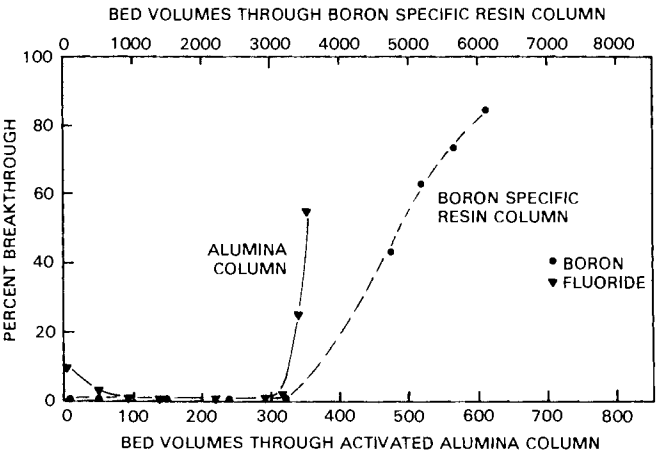


FIGURE 2.2. Fluoride and Boron Breakthrough Curves.

• Geothermal Liquid Waste Disposal State-of-the-Art Review

The disposal of spent geothermal fluids from power plants and nonelectric installations is a major expense to the resource developer. Subsurface injection, the most favored of all disposal options, accounts for 10% to 20% of the cost of power from a binary fluid cycle power plant. The disposal of liquid effluents has been successfully demonstrated at a number of geothermal sites, but numerous technological difficulties must often be overcome, including hostile fluid chemistry, large disposal volumes, adverse environmental impacts, the site-specific nature of each geothermal resource, and the lack of geothermal reservoir definition.

A summary of the applicability of various disposal options is provided. A number of areas are identified where additional work on disposal can result in more economical and reliable disposal systems.

State-of-the-Art Review

L. J. Defferding

The objective of this program is to review and evaluate the state-of-the-art disposal methods for liquid wastes from geothermal installations and to identify needed research.

The disposal of liquid effluents from geothermal installations poses some unique problems with respect to conventional waste water disposal. In addition to creating potentially adverse environmental impacts, the fluids to be disposed are large in volume, are often corrosive and have a high tendency for scale deposition. Limited experience has been gained on several disposal options, ranging from discharge to surface waters to subsurface injection. Although disposal at some operating geothermal power plants has been successful to date, additional work on improved disposal systems is needed to make more reliable and economic designs available that meet existing environmental constraints.

Disposal Experience. At the present time there are several options that are potentially available for disposing of liquid wastes from geothermal installations. These methods are being used at the major facilities or have been tried experimentally with varying degrees of success. The methods have been grouped into four general categories: (1) discharge into surface waters, (2) ponding with evaporation, (3) secondary use of effluents, and (4) injection into subsurface formations. Each of these techniques may involve some treatment of the effluent stream.

The methods that are being used at the major geothermal sites are direct discharge into surface waters at Wairakei; ponding with evaporation at Cerro Prieto; injection at the Geysers, Otake and Hatchobaru; and a combination of injection and surface disposal at Ahuachapán and Larderello.

These sites have a total installed generating capacity of almost 1300 MWe and are disposing of about 150 x 10^6t/yr of liquid wastes. Some of the sites like Wairakei and Geysers have been in operation for nearly 20 years, whereas one of the newer sites at Ahauchapán has been in operation for about 2-1/2 years. The oldest site is Larderello, which has been in operation since 1904.

Some of these plants were installed when environmental concerns were not as prominent as they are today, but most of the sites are operating under reasonable restraints. The fact is, these sites are operating and disposing of large quantities of water daily. A brief discussion will be given of the disposal experiences at each of these major electrical generating sites.

The Ahauchapán field in El Salvador is currently supporting 30 MWe of electrical production, with geothermal fluids at a temperature of 230°C and a total dissolved solid (TDS) content of 20,000 ppm. Early

injection tests at the periphery of the field were unsuccessful because of low formation permeability. The present system used four wells (two are early production wells) to inject around 30% of the liquid effluent. The remainder is discharged into a canal that terminates at the Pacific Ocean. The injection system is operational and formation plugging is prevented by maintaining injection temperatures above 150°C. Scale deposition does however occur in the canal. High boron and arsenic concentrations will prevent discharge to the river.

Cerro Prieto has a generating capacity of 75 MWe, and geothermal fluids at 250°C with a TDS of 20,000 ppm. The disposal method at Cerro Prieto is to discharge to a large evaporation pond about 12 km^2 in area. The high-temperature water from the steam separators or silencers and excess liquid from the cooling towers are directed into the pond. The evaporation pond is adequate for the present power-plant size, but increased generating capacity will require alternative disposal systems. A canal to carry the excess liquid southbound to the Gulf of California or westbound to the Laguna Salada is under study. Injection is also under consideration, along with a study of the potential for minerals extraction from the disposal pond.

The Geysers has a generating capacity of 502 MWe. The steam condensate contains 600 ppm of total dissolved solids, and has been injected since 1969. The waste fluids are piped from the cooling towers to a settling basin and from there to five or six injection wells. Each well is capable of injecting around 75ℓ/sec with no backpressure at the well head. Some formation plugging with elemental sulfur has been experienced but is easily corrected by temporary shutting-in of the well to allow the temperature to rise above the melting point of sulfur. Injection was begun in 1969 to prevent the release of arsenic and boron into Big Sulphur Creek.

Approximately 420 MWe of electricity is being produced in the Larderello-Travale area of Italy. Approximately 20% of the liquid wastes is placed in injection wells at the periphery of the field; the remainder is discharged directly into local streams. High boron concentrations may force the larger use of injection in the future. Injection has generally been successful; however, one recent field test resulted in a quenching of a nearby production well because of direct channeling of the cool liquids over several hundred meters.

The Otake and Hatchobaru fields in Japan produce mixed-phase fluids at 200°C to 230°C that are used to generate 63 MWe of electricity. Prior to 1972, liquid wastes were discharged into a local drainage system. Since then, injection has been required by law. From 1972 to June 1977, gradual plugging of the injection wells caused a 5% to 6% reduction in the gravity flow rate, but reservoir pressures were maintained by the water recharge. Between June and September of 1977, the rate of plugging at Otake increased rapidly, and power production has been curtailed while new injection wells are being drilled.

Wairakei in New Zealand has a generating capacity of 193 MWe. Production wells provide two-phase fluids containing approximately 4400 ppm in TDS at a reservoir temperature of 250°C. Liquid wastes are discharged directly into the Waikato River. To date, over 1 x 10^9t of liquid have been removed from the reservoir, and subsidence has been observed over an area of at least 25 km^2, with a maximum displacement of over 3 m. Reservoir pressures have also declined, and production flow rates have reduced by 25%. Careful reservoir management is now being practiced to prevent further production losses. Disposal into the river has resulted in a reduction of fish populations, an increase in aquatic plant growth, and the contamination of some plant growth with arsenic.

Economics. The cost of liquid effluent disposal from geothermal power plants represents a significant portion of the cost of power. One 50 MWe (net output) geothermal power plant using the binary fluid cycle energy conversion process requires large geothermal fluid flow rates. For a resource temperature of 182°C, flow rates are approximately 6,900,000 lb/hr, or 890ℓ/sec, all of which must be disposed of. The total cost of power for this size power plant at Heber, California, has been calculated at 35.2 mills/kW-hr. Based upon the capital and operating expenses of the injection well disposal system and the computed energy cost of 16.7 mills/kW-hr, the cost of disposal at Heber is expected to be about 6.8 mills/kW-hr, or 19% of the cost of power. Other estimates of disposal by injection are available. The Office of Saline Water (OSW) has examined the costs of deep-well injection for desalination plant wastes. In 1969, waste disposal costs were estimated to range from $0.026 to $0.264/1000ℓ. The lower cost involved no waste pretreatment and low injection pressures. Escalating the lower disposal cost to mid-1976 when the Heber plant costs were estimated, the cost becomes $0.055/1000ℓ. At this rate, the cost of disposal would be 4.2 mills/kW-hr, or 13% of the resulting total power cost. Deep injection of salt water in oil-field

operations provides another estimate of cost. At the East Texas oil field, the largest established oil field in the United States, 7.95×10^7 ℓ of salt water were being injected daily in 1971 at a cost of $0.145/1000 ℓ. The salt water is passed through settling ponds, filtered and pumped into a sandstone formation at a depth of 3600 ft, which is beneath the oil-bearing zone. In mid-1976 dollars, at $0.264/1000 ℓ, the cost of disposal would be 20 mills/kW-hr, or 41% of the resulting power cost for the Heber plant.

The design and operation of a geothermal liquid disposal system deserves careful consideration because of its obvious high cost, regardless of which estimate is used from the examples above. Injection without treatment of the effluents is currently the most popular disposal technique, but treatment may be necessary, just as in oil-field operations. The plugging of disposal wells and surrounding subsurface formations may need to be controlled through fluid treatment. Common causes are silica precipitation, calcite precipitation, collection of suspended solids, and alteration of formation minerals owing to chemical incompatibility. If surface disposal techniques are used instead of injection, treatment to remove harmful constituents from the waste fluids to prevent surface and ground-water pollution will be necessary.

The treatment of waste fluids may be expensive. The removal of silica and arsenic from waste fluids at Wairakei using a slaked lime process is now being tested. An estimate of the cost of this process has been made for the Aluachapan, El Salvador plant. For a 200 ℓ/sec waste flow stream containing 15 mg/ℓ of arsenic, treatment costs are estimated to be 3.2 mills/kW-hr, based on a rate of 103 lb/kW-hr for the total production flow.

These cost examples for injection and for waste fluid treatment emphasize the need for additional work to reduce the cost of the disposal of geothermal waste fluids.

Legal. The disposal of liquid effluents from geothermal installations will be regulated through a number of Federal and state laws. Surface disposal will be required to adhere to a nondegradation policy based upon the Federal Water Pollution Control Act of 1972 and the water quality requirements of the geothermal states. The disposal of liquid wastes into surface ponds and of wastes from cooling tower blowdown will be closely controlled by the Resource Conservation and Recovery Act. Currently, subsurface injection on Federal lands is regulated by the U.S. Geological Survey through the Geothermal Resources Operational Orders. The Safe Drinking Water Act, more specifically the State Underground Injection Control Program, may affect the injection of geothermal fluids in the future, but current draft versions do not specifically address the geothermal industry.

Disposal Options. Currently, injection of geothermal fluids is the preferred disposal option. Although higher in cost than direct surface discharge, injection is environmentally more acceptable and can increase reservoir productivity by returning fluids and residual heat to the formation and maintaining reservoir pressures. However, plugging of injection systems with silica or calcite represents a major problem, and existing treatment or control technology is costly for these large volume flows. Disposal of waste fluids at the surface should be considered in the planning of a geothermal field operation, especially for those fluids that are low in concentration of polluting constituents. All of the disposal options listed in the qualitative comparison in Table 2.2 should be considered prior to field development, since each site is unique. Important factors will include the chemical nature of the geothermal fluid, the type of geothermal reservoir, the surrounding land uses, and treatment technology required by environmental constraints.

Summary. The disposal of liquid effluents from geothermal installations has been successful at many locations. Most sites have experienced difficulties in three main areas: pollution of surface or ground waters, reliability of the disposal system owing to scale deposition or plugging, and adverse impact on geothermal reservoir productivity. Additional work to improve disposal systems is needed especially to reduce costs and increase reliability. Major areas include improved environmental monitoring and assessment, effective and inexpensive fluid treatment or control technology, and increased understanding of the geothermal reservoir as it is affected by liquid waste disposal, especially in controlling the underground movement of injected wastes.

TABLE 2.2. Comparison of Disposal Options.

	Cost	Status of Technology	Environmental Aspects	Legal
Direct Surface Discharge	Low	Existing technology	Unacceptable for most geothermal sites; exceptions may be low temperature fluids	Most effluents cannot meet water quality standards
Treatment and Surface Disposal	Treatment costs high for large flow volumes	Development of less-expensive treatment technology necessary	Reliability of treatment systems to prevent inadvertent release of pollutants important; subsidence potential high at liquid-dominated sites	Acceptable if systems are reliable and subsidence is controlled
Ponding	Highly variable, mainly dependent upon liner and land costs	Reliable liners that are low in cost require development	Past experience of poor performance; break-through of wastes can pollute ground waters	Close control by Resource Conservation and Recovery Act
Secondary Use of Effluents	With relatively clean effluents, revenues may be realized	Development of less-expensive treatment technology necessary	Determination of toxic effects of low-level contamination on environment needed	Acceptable if environmental constraints met
Injection	Costs may be 10% to 20% of power rate; highly dependent upon injection well capacity	Additional reservoir characterization needed; plugging is a major problem of many sites	Considered to be environmentally most acceptable for all disposal options	Acceptable; some legal restrictions possible from Safe Drinking Water Act
Injection with Pretreatment	Expensive; treatment costs are high	Development of less-expensive treatment technology needed	Acceptable	Acceptable

SOURCE: Taken from PNL-2593, *An Assessment of U.S. Domestic Capacity for Producing Reactor Grade Thorium Dioxide and Controlling Associated Wastes and Effluents*, W. I. Enderling, February 1978.

• Compressed Air Energy Storage (CAES) Environmental Control Concerns

The objective of this task is to identify environmental factors associated with the implementation of CAES technology, to quantify the environmental impacts of these factors, and to identify or develop technologies, as needed, to prevent or control adverse impacts. The first phase of the program was a survey of the full range of potential environmental concerns and the development of a management plan for future work. The complete management plan is expected to be issued by January 1979. Research in 1979 will focus on two waste disposal problems: (1) disposal of brine produced when a salt cavern is mined out for the storage of compressed air; and (2) disposal of crushed rock tailings produced when the storage cavern is mined out of hard rock. Proper control of these wastes is necessary to prevent pollution of groundwater supplies or nearby streams and lakes.

Environmental Concerns with Compressed Air Energy Storage

J. Stottlemyre and R. A. Craig

The objective of this task is to identify environmental factors that may be associated with the operation of Compressed Air Energy Storage (CAES) facilities, to quantify the impacts of these factors, and to identify or develop control technologies, as needed, to ameliorate adverse impacts.

The approach taken in this project has been to review the literature relating to CAES, including previous work relating to possible environmental concerns, and to engage in direct communication with researchers exploring the technical factors associated with CAES. This information was then assembled to develop a management plan for future work.

A management plan for that part of the program relating to CAES in a porous medium has been prepared. Expansion of this plan to include storage in conventionally mined hard-rock caverns and solution-mined salt domes as well as compensated and adiabatic systems is under way. Also, a paper was prepared for the Environmental Aspects of Nonconventional Energy Resources meeting held in September. This paper delineates the environmental concerns identified to date and describes this research program.

During the next year, those environmental factors that have been identified will be studied, and the magnitudes of the impacts derived from these environmental factors will be assessed. These impacts will be determined both in an absolute sense and relative to the corresponding impacts for conventional gas or oil-fired turbine generator sets. Where information to perform the evaluations is lacking, research to determine this needed data will be initiated.

• Assessment of Energy-Conserving Industrial Waste Treatment Technology

The Water Pollution Control Acts Amendments (PL 92-500) require substantial treatment of industrial wastes. Most waste treatment processes to date have been developed with little regard to energy use. The objectives of this program are to provide an overview of current industrial pollution control practices, to assess DOE activities in this area and to prepare a plan on recommended alternative possibilities of energy conserving industrial waste treatment processes.

A comprehensive literature review was undertaken to establish an industry priority list, develop industrial process diagrams, determine industrial pollutant discharges, and identify current study areas. Published data and information or data collected from industrial trade groups were used to develop the necessary data base. Possible industrial waste treatment areas were identified where additional research into energy conserving processes is needed.

Assessment of Energy-Conserving Industrial Waste Treatment Processes

B. W. Mercer

The energy required by industry to meet government regulations for pollution control during 1977 represents approximately 3% of the total energy consumed by industry. Although this currently amounts to only 1.3% of the total U.S. energy requirement, efforts are under way to implement energy conserving technology into the industrial pollution control field. Energy consumption has not characteristically been a key parameter considered by industry for deciding the type of pollution control strategy to implement. Instead, the decision has been based on factors such as total cost, maintenance requirements, ease of operation and dependability in controlling the pollutant. However, as the cost of energy increases in the future, it will play a major role in making decisions about pollution control and in determining operating costs. By developing and implementing energy-conserving pollution control alternatives now, the cost to industry and the related energy requirement can be maintained at a minimum as discharge standards become more stringent.

Many industries are currently involved in reviewing total in-plant energy use. This review has shown that plant process modification and waste recovery can conserve significant quantities of energy. The potential energy savings through development and implementation of more energy-efficient pollution control systems is less significant. However, a general lack of hard data relative to pollution control energy requirements for the various industrial processes makes this analysis difficult to quantify.

Prior to identifying specific areas of suggested DOE involvement, it is necessary to place into proper perspective the energy savings that will result by making industrial pollution control processes more energy-conserving. The total energy required by industry to meet government regulations for pollution control during 1977 represented approximately 2% of the total U.S. energy requirement. This amounts to a nominal value of 1.7×10^{15} Btu. Conservation efforts resulting in a 20% reduction in energy consumed for pollution control would save approximately the amount of energy required to produce about 5.5% of the steel produced in the United States during 1977.

Energy conserving pollution control practices will not make available a large quantity of energy. Industrial process modifications and general housekeeping techniques would be much more productive. However, efforts to implement energy conserving technology into the pollution control field will maintain energy consumption for pollution control at a minimum while discharge standards become increasingly more strict. Therefore, further study is recommended. In order to achieve more energy conservation in

the industrial pollution control field, the following steps should be taken:

1. Develop the capability to view the many pollution control alternatives on a comparative basis.

2. Modify or develop new energy-conserving pollution control technologies that offer an economic advantage to the user. Areas immediately amenable to such research efforts include sulfur oxide control, advanced wastewater treatment processes, high-temperature particulate collection, and collection of fine particulate matter.

• Nuclear Fuel Cycle Analysis

The operation of nuclear fuel cycle facilities will introduce noxious materials, both radiological and chemical, into the environment through routine discharges of both liquid and airborne effluents. The environmental control implications of continuing to develop existing nuclear fuel cycles and implementing new fuel cycles must be systematically determined so that technologies that control or eliminate the discharge of noxious materials to the environment can be developed and demonstrated in a timely manner.

The objective of this program is to identify areas in developing nuclear fuel cycles (1) where inadequate consideration is being given to environmental controls, (2) where inconsistencies and conflicts exist in environmental policy, and (3) where environmental control improvements can be justified on a cost/risk/benefit basis to ensure that funds are not expended for control in instances where neither the potential effects nor public concerns warrant such expenditures.

Light Water Reactor Analysis

R. M. Fleischman and C. M. Heeb

The objective of this project is to analyze the technical and economic bases for planning and analyzing research and development programs related to the treatment of radiological and chemical effluents from the Light Water Reactor (LWR) fuel cycle. The analytical methodologies developed during FY 1977 were employed during FY 1978 in a detailed analysis of the effluents from a typical light water reactor (LWR) fuel cycle. Three fuel cycle configurations were examined: the once-through uranium cycle, the once-through uranium cycle with reprocessing and no recycle, and a mixed oxide cycle with reprocessing and full uranium/plutonium recycle. The fuel cycle configuration was found to have important implications for environmental control technology requirements.

The detailed evaluation of the effluents from the LWR fuel cycles began with a generic facility and process description for each part of the fuel cycle. The generic plants included both underground and surface mines, uranium mills using the acid leach solvent extraction process, UF_6 conversion using an aqueous process, gaseous diffusion enrichment plants, both PWR and BWR light water reactors, and fuel reprocessing. The reactor fuel cycle model included first core materials at subequilibrium enrichment and exposure, first reload material, equilibrium material and finally material discharged below goal exposure at the end of reactor life. The appropriate mix of these materials was determined by an assumed nuclear generation scenario and the plant capacity factor versus age of the generic reactor type (PWR or BWR). Thus, the reactor radionuclide emissions reflect changes owing to the growth and maturing of the LWR industry. An internal mass balance analysis was performed to determine projected levels of both radioactive and nonradioactive environmental releases.

The results of this analysis were used to rank the environmental releases for the total fuel cycle according to the volume of air or water required to dilute them to safe levels, as defined by EPA and OSHA standards, in the case of nonradiological species.

None of the projected environmental releases violates current Federal regulations. However, standards do not exist for some nonradiological effluents, and others were projected to be close to current limits. Depending on fuel cycle configuration, some radioactive releases will eventually approach the EPA limits for total fuel-cycle emissions.

In the course of performing these comparisons, the natural trade-off between the impacts of increased uranium mining and milling activities and the impacts of reprocessing and recycle was quantified. These results indicate that such a trade-off is

approximately even for radioactive releases but that nonradioactive releases increase substantially in the no recycle configuration because of a higher uranium demand. The radioactive releases from reprocessing plants are concentrated in the gaseous effluent stream. In contrast, both radioactive and nonradioactive effluents from mining and milling activities are diluted with very large quantities of waste rock and process water, which makes them difficult and expensive to control. Improvements in effluent control technologies for the head end of LWR fuel cycles appear to be priorities for research and development.

Future work will include the final preparation and publication of a series of topical reports on the LWR analysis. These will include the following:

- Analysis of Nuclear Fuel Cycle Facilities
- Data Book on Effluents in LWR Fuel Cycles
- Analysis of Environmental Control Technology for LWR Fuel Cycles

Alternative Fuel Cycles

P. J. Mellinger

This project has two objectives: (1) to conduct an analytical evaluation of the gaseous and particulate aerosol effluent streams (both chemical and radiological) for the Battelle Columbus (BCL) concept for coprocessing of spent LWR oxide fuel;* and (2) to develop conceptual process flow sheets, effluent control system descriptions, and equipment and facility requirements for this concept.

Material waste streams from individual facilities were characterized for their chemical and radiological content. Mass balances were calculated consistent with conventional effluent control technology hardware. The effluents to be released to the environment were then analyzed and compared to existing regulatory limits. Special attention has been given to looking for the appearance of new effluent species or different isotopic ratios from those typically found in the LWR fuel cycles.

A draft report on the evaluation of effluent streams has been issued. The report deals with the BCL coprocessing scheme in which uranium, plutonium and a majority of neptunium are coextracted in a single-cycle, organic stream while higher actinides and fission products remain in aqueous waste stream. Higher actinides are recovered and blended with the reextracted U/Pu stream prior to oxide conversion to an actinide-oxide (ANOX) fuel. The fuel reactivity is reconstituted by the addition of enriched, nonstrategic uranium. The coprocessing scheme enhances proliferation resistance (compared to conventional design) by leaving an impure plutonium process stream and achieving only low decontamination factors. The report concludes that no unusual radiological or chemical effluents are created because of coprocessing.

During FY 1979, several pertinent alternative fuel cycles will be analyzed and compared for potential environmental effects. The "once through" low enriched uranium (LEU) cycle will be used as the basis for comparing alternative LWR cycles and synergistic fast breeder reactor (FBR) cycles. Several fuel types, representative of credible fuel cycles, will be identified and characterized. This characterization will represent a source term for comparison of potential environmental effects at the various fuel cycle operations.

A primary result of this project will be the comparison of operational control implications (environmental) at the refabrication, reprocessing, and waste disposal operations. Also, the long-term ramifications of disposing of high-level and TRU wastes will be compared for the various alternative fuel cycles. Waste streams will be identified at each fuel cycle operation, and the fuel characterizations will allow quantitative comparisons of waste source terms. The long-term implications of high-level and TRU wastes will be analyzed by comparing alternative fuel cycle waste characteristics and quantities with previous LEU waste analysis.

Thorium and Uranium Resource Recovery

C. H. Bloomster

The objectives of this project are to: (1) identify potential rates of effluent generation from thorium and uranium productions, (2) determine the potential impact of more stringent environmental control technologies on the costs of production. An analysis of existing domestic thorium production capacity and the generation of associated wastes and effluents was completed in FY 1978. Wastes and effluents generated during placer mining are shown in Table 2.3.

*All liquid streams are internally treated and recycled.

TABLE 2.3. Effluents and Wastes Generated by a Typical Heavy-Mineral Placer Mining Operation.[a]

Effluent/Waste	Source	Rate of Discharge	Type of Contaminant	Concentration of Contaminant	Current Control Method	Discharge Point
Mine Water	Dredge Pond and Concentrate Dewatering	700-3000 gpm	Suspended Mineral and Organic Fines	18×10^3 - 20×10^3 mg/ℓ	Add Alum to Flaculate and Settle Fines in Holding Ponds	Flow to River and Evaporation to Atmosphere
			Organic Acids	pH ≦ 5	Add Caustic to Adjust pH	
			Na^+	U[b]	None	
Mill Tailings	Wet Mill	511 ton/hr	Fines	U	Reclaim Land	Dredge Pond
			Organic Debris	U		
	Dry Mill	6 ton/hr	Monazite	0.3% - 2.1%	Recycle Tailings to Remove Monazite (in the future)	Dry Mill Tailings Pile
Radionuclides	Ore		Th-232 Ra-226	0.96 ± 0.02 pc/g 1.7 ± 0.1 pc/g	None	Atmosphere
	Wet Mill Tailings		Th-232 Ra-226	0.17 ± 0.01 pc/g 0.32 ± 0.05 pc/g		
	Ore Concentrate		Th-232 Ra-226	30 ± 1 pc/g 51 ± 3 pc/g		
	95% Monazite Product		Th-232 Ra-226	6800 ± 100 pc/g 4800 ± 500 pc/g		
	Dry Mill Tailings		Th-232 Ra-226	93 ± 1 pc/g 90 ± 6 pc/g		
Fugitive Dust	Dry Mill	25 lb/day	Free Silica Organic Matter Other Minerals	U	General Ventilation with Dilution Used at One Mill and Induced Draft with Cyclone Used at the Other Mill	Atmosphere
Gasses and Smoke	Ore	U	H_2S	Noticeable Odor at Dredge Pond	None	Atmosphere
	Dry Mill	U	#6 Fuel Oil Products of Combustion	U	None	Atmosphere
	Burning Brush	15 acre/mo	Smoke	U	None	Atmosphere

[a] Based on data furnished by mine operators and by the State of Florida Department of Health and Rehabilitative Services.
[b] U = unknown

SOURCE: Taken from PNL-2593, *An Assessment of U.S. Domestic Capacity for Producing Reactor Grade Thorium Dioxide and Controlling Associated Wastes and Effluents*, W. I. Enderling, February 1978.

Figure 2.3 illustrates the thorium extraction process; associated wastes and effluents are shown in Table 2.4.

Future demands for energy may necessitate development of additional thorium reserves and new lower-grade uranium reserves. Analysis of the mining, milling and refining technologies associated with large-scale thorium production has been completed for the principal domestic thorium deposits (Table 2.5). Quantitative estimates of the generation of wastes and effluents from producing these deposits will be completed next year.

Future work will investigate the potential environmental control problems related to producing uranium from low-grade resources. Potential production processes will be evaluated and the potential generation of wastes and effluents associated with the development of lower grade uranium deposits will be determined. Appropriate environmental control technologies can then be evaluated and potential problems identified.

The relationship between cost and level of control will be determined for both thorium and new uranium deposits. These cost relationships will be derived for each of the major effluents for each deposit. Technological and economic barriers to more stringent control will be identified.

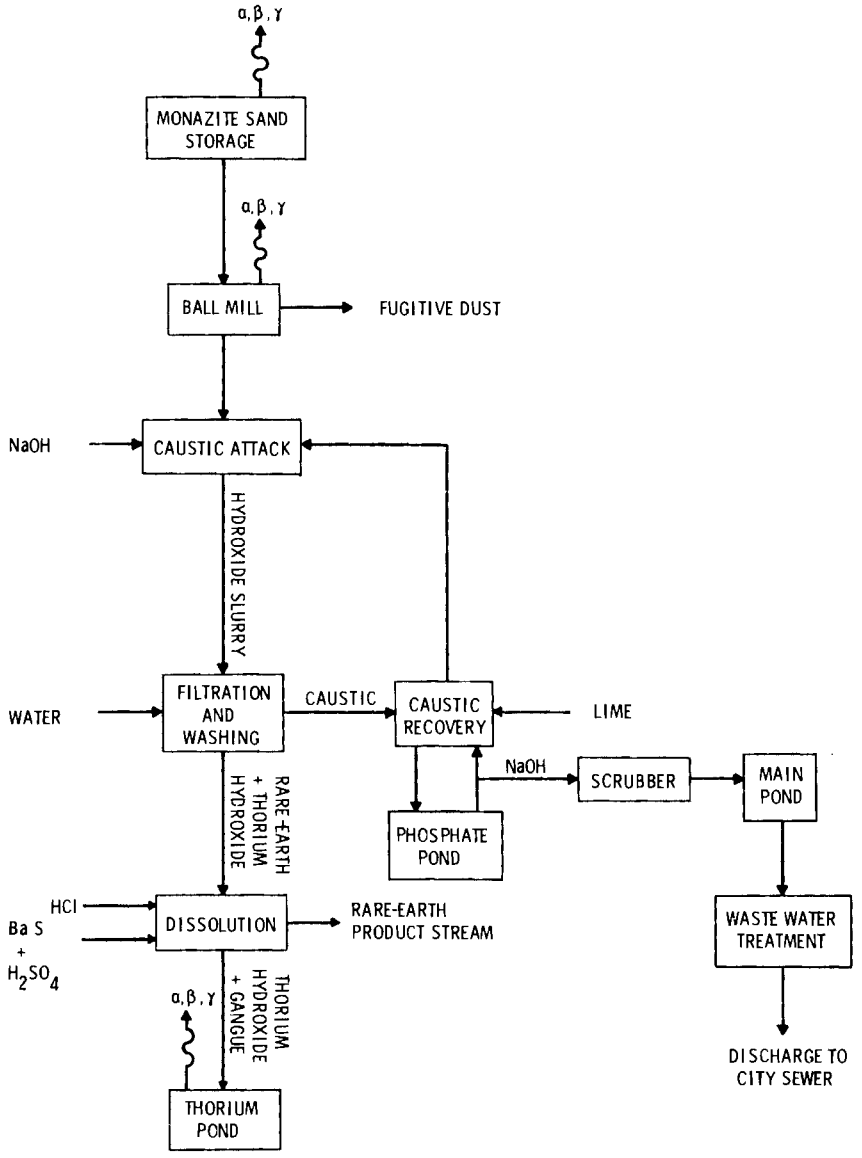


FIGURE 2.3. Simplified Schematic of Thorium Extraction Process.

SOURCE: Taken from PNL-2593, *An Assessment of U.S. Domestic Capacity for Producing Reactor Grade Thorium Dioxide and Controlling Associated Wastes and Effluents*, W. I. Enderling, February 1978.

Fusion Materials Resource Cycle

H. J. Willenberg

The objective of this research program is to identify environmental control engineering (ECE) requirements associated with all aspects of the deuterium-tritium fusion materials resource cycle. The complete materials resource cycle is being investigated, from raw materials extraction to ultimate waste disposal. The information developed will be used to identify research needs and internal DOE interfaces for the Division of Environmental Control Engineering role in the fusion energy program. Early identification of ECE needs will ensure that environmental control considerations will

TABLE 2.4. Effluents and Wastes Generated by a Typical Rare-Earth Processing Plant.[a]

Effluent/ Waste	Source	Rate of Discharge	Type of Contaminant	Concentration of Contaminant	Current Control Method	Discharge Point
Mill Water Discharge	Main Settling Pond	70 gpm Average	Suspended Solids	0.15 g/ℓ Average	Dilution	City Sewer
			Soluble α and β Activity	0.011 μCi x 10^{-4}/ml Average		
			Insoluble α and β Activity	0.002 μCi x 10^{-4}/ml Average		
Phosphate Pond Water	Caustic Recovery Process	U[b]	Suspended β	19 pc/ℓ	None	Evaporation to Atmosphere and Seepage to Ground Water
			Dissolved β Phosphate	3 pc/ℓ		
Thorium Pond Water	Monazite Dissolution Process	U	Suspended α	2000 pc/ℓ	None	Evaporation to Atmosphere and Seepage to Ground Water
			Dissolved α	74 pc/ℓ		
			Suspended β	900 pc/ℓ		
			Dissolved β	39 pc/ℓ		
Fugitive Dust	Entire Plant	U	Radionuclides	0.06 x 10^{-11} μCi/ml at NE Corner of Property and 0.095 x 10^{-11} μCi/ml at NW Corner of Property with NE Wind at 5 mph Sample at 23 cfm on Watman #40 Filter	None	Atmosphere
		U	Suspended Particles	U		
	Ball Mill	U	Radionuclides	1.9 x 10^{-11} μCi/ml		
		U	Suspended Particles	U		
Radioactivity	Sand Storage Building		γ	15 mR/hr	Restricted Area	Atmosphere
	Abandoned Thorium Pond		γ	8-10 mR/hr at 3 ft Above Surface	Restricted Area	Atmosphere
	Active Thorium Pond		γ	0.5 mR/hr	Restricted Area	Atmosphere
	Soil-Settling Pond Dam		Radionuclides	0.4 x 10^{-4} μCi/gm	Restricted Area	
	Soil-Field Between Phosphate Pond and Lab		Radionuclides	16 x 10^{-4} μCi/gm	None	

[a]Data furnished by Tennessee Department of Public Health.
[b]U = unknown

TABLE 2.5. Principal Domestic Thorium Deposits and Associated Production Processes.

Deposit	Type	Production Processes
Lemhi Pass, Idaho	Vein	Mining, Milling
Hall Mountain, Idaho	Vein	Mining, Milling
Wet Mountain, Colorado	Vein	Mining, Milling
Palmer, Michigan	Conglomerate	Mining, Milling, Refining
Iron Hill, Colorado	Carbonatite	Mining, Milling, Refining
Conway, New Hampshire	Granite	Mining, Milling, Refining
Bear Lodge, Wyoming	Disseminated	Mining, Milling, Refining

not limit the development of fusion energy. Availability of information regarding potential environmental impacts should also strengthen the influence of environmental considerations in decisions affecting the direction of the fusion technology program.

The technical approach being pursued is to first characterize the elements, processes, and flow rates of a complete materials cycle. This information should provide the basis for a materials balance that quantifies resource requirements, environmental effluents, and waste disposal. Environmental effluents will be identified for each facility and process associated with the generation of power from fusion. Potential pathways for release of toxic and radioactive effluents will be identified, and the quantitative effect of various existing environmental control and fusion power-plant design options will be determined. An assessment will be made of those areas in which current techniques are adequate to ensure acceptable environmental impact, and those areas in which environmental control research and development should be focused.

A materials balance has been developed around an envelope of conceptual fusion reactor designs. These designs consist of deuterium-tritium fueled tokamak reactors using helium as the primary coolant, liquid metal or solid lithium compounds as fertile materials for in-reactor tritium breeding, and stainless steel or nickel alloy as the structural material. The quantity of materials required for plant construction has been determined. Annual makeup quantities and out-flow of materials have been evaluated based on estimates of component lifetimes in the fusion radiation and thermal environment. A schematic of the deuterium-tritium materials resource cycle is shown in Figure 2.4.

Radioactive materials inventories in a fusion power plant have been calculated. These inventories include tritium in the fuel stream, tritium-contaminated equipment, and neutron activation products. Tritium is present as stored fuel in metal hybrid form, in the fuel input stream, plasma, fuel effluent, effluent separations system, and breeding modules. Tritium-contaminated equipment includes the complete fuel and heat transfer systems and blanket absorption beds, fuel storage equipment, pump fluids, and steam system resins. All equipment near the reacting plasma will become activated by neutron reactions. Activation products will be generated in the blanket and first wall, neutral beam injectors, magnets, and reactor building air. Systems contaminated with activation products might include the primary coolant system, vacuum system, and reactor building air.

The materials resource requirements for deployment of fusion power plants on a large scale depend to some extent on the degree to which materials can be recycled. For this reason, the effort in FY 1978 was focused on the back end of the materials resource cycle, enclosed in the the box to the right of Figure 2.4. The disposition of reactor components after they are removed has been investigated. All component removal operations must be performed remotely because of high radiation levels from activation product decay. The degree to which used blanket materials can be recycled is dependent on three factors: the physical state of the lithium fertile material, the ease of disassembly, and the size of blanket modules. Liquid lithium can be drained and recycled. Solid lithium compounds, neutron-multiplying material such as beryllium and lead, and graphite reflectors can be removed and recycled if the blanket module design lends itself to straightforward disassembly. Steel or nickel alloy structural materials are highly radioactive and must be stored at least for several decades before recycle is viable. Small blanket modules from which lithium, graphite, and neutron-multiplying materials have been removed may be crushed or melted to minimize transportation and storage volume. Large modules, or those which cannot be disassembled, must be shipped and stored intact.

Future work will include the characterization of the complete materials resource cycle for fusion power plants. Conceptual fusion power plant designs will be reviewed as the basis for describing materials flow and supporting facilities for the complete materials resource cycle, including mining and milling, deuterium extraction, isotopic

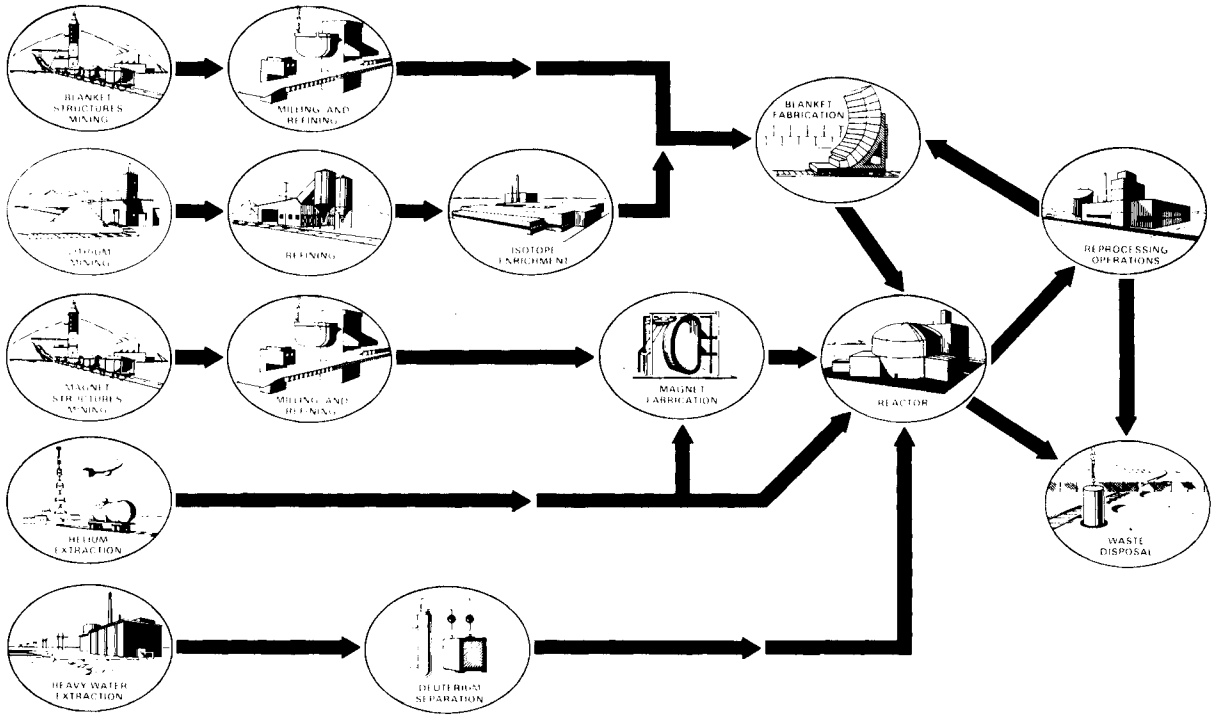


FIGURE 2.4. D-T Fusion Materials Resource Cycle.

enrichment, fabrication, transportation, waste removal, storage, and recycle operations. Environmental effluents will be identified for each facility and process associated with the generation of power from fusion. Potential pathways for release of toxic and radioactive effluents will be identified.

• Transportation Safety Studies

In order to ensure adequate protection of man and the environment in the transport of energy materials, it is necessary to understand the safety and potential environmental effects of the shipments of energy materials, both in normal transport and under accident conditions. The objective of the Transportation Safety Studies Project, conducted for the Transportation Branch of the DOE Division of Environmental Control Technology, is to assess these potential effects in terms of risk. The initial objective of this program was to develop and use a model to assess the risk associated with the shipment of radioactive materials, although the scope of the program has since been expanded to include transport of nonnuclear energy-related materials.

The risk analysis technique was chosen for assessing the safety of transporting energy materials. Risk is defined as the probability that an undesirable event will occur, multiplied by the type and degree of consequence.

Final reports were published this fiscal year on the risk of shipping uranium hexafluoride by truck and train; the safety and economics of shipping spent fuel in special trains; the consequences of the loss at sea of spent fuel and plutonium shipping packages; and the results of two surveys taken of receivers of plutonium shipping packages. Draft reports were produced on the risk of transporting spent fuel by truck and a conceptual design of a rail cask for shipping high-level waste. Studies were undertaken to assess the risk of shipping spent fuel by train, propane by truck and train, and chlorine by train. These studies are nearly complete. A study to assess the risk of transporting transuranic waste between DOE facilities was begun during the last quarter of the fiscal year.

SAFETY ASPECTS OF TRANSPORTING POTENTIALLY HAZARDOUS ENERGY MATERIALS

R. E. Rhoads, W. B. Andrews,
H. K. Elder, C. A. Geffen

Work was conducted on six transportation safety studies during FY 1978: (1) the risk of transporting uranium hexafluoride by truck and train; (2) a safety and economic study of special trains for the shipment of spent fuel; (3) the consequences of the loss of spent fuel and plutonium shipping packages at sea; (4) a survey of receivers of plutonium shipping packages; (5) the risk of transporting spent nuclear fuel by truck; and (6) a conceptual design of a shipping container for transporting high-level waste by rail.

For the studies of shipping uranium hexafluoride by truck and train and spent fuel by truck, risks were estimated on the basis of quantities of those materials projected for transportation in the 1980s. Reference shipping systems were described, fault trees were developed to identify release sequences, release consequences models were initiated, accident environments were described and package failure thresholds were estimated. A brief summary of each analysis follows.

An Assessment of the Risk of Transporting Uranium Hexafluoride by Truck and Train

C. A. Geffen and J. F. Johnson

A final report on the risk assessment of the shipment of uranium hexafluoride (UF_6)

by truck and rail was completed. The primary risk associated with transporting UF_6 was found to be chemical in nature, with essentially no contribution to fatalities from its radiological properties. Shipment risks for UF_6 were found to be comparable to the risks estimated in previous studies for shipment of plutonium by these transport modes, and much less than other risks in society.

A Safety and Economic Study of Special Trains for Shipment of Spent Fuel

W. V. Loscutoff et al.

The final report on the safety and economics of shipping spent fuel in special trains was published. The study showed that special trains had a limited potential to reduce the frequency of involvement of spent fuel casks in rail accidents when compared to regular train service. However, the frequency of involvement in regular train service is already quite low. The use of special trains was also shown to substantially increase transportation costs for spent fuel in most circumstances, although economic and logistical advantages could result for some shippers.

Consequences of the Loss of Spent Fuel and Plutonium Shipping Packages at Sea

S. W. Heaberlin

The final report on the assessment of the consequences of the loss of spent fuel and plutonium shipping packages at sea was completed. The assessment showed that the radiation doses to the public from consumption of seafood contaminated by postulated accidents was relatively low when compared to the exposure from natural background.

Plutonium Transport Package Closure Survey

S. W. Heaberlin

The final report on the plutonium shipping packages survey was published. The surveys of receivers of plutonium shipping packages, conducted in 1974 and 1976, showed that the incidence of nonstandard package closure conditions was small and that the rate appeared to be declining because of new quality control measures that had been introduced.

An Assessment of the Risk of Transporting Spent Nuclear Fuel by Truck

H. K. Elder et al.

A draft report on the risk assessment of the shipment of spent nuclear fuel by truck was completed. The results of the analysis are presented in Figure 2.5. The risk of shipping spent fuel by truck is seen to be comparable to the risks of transporting plutonium and much less than other risks in society. Sensitivity studies showed that the spent fuel shipment risk could be reduced by 80% if the fuel were shipped only after it had cooled more than two years after discharge from the reactor.

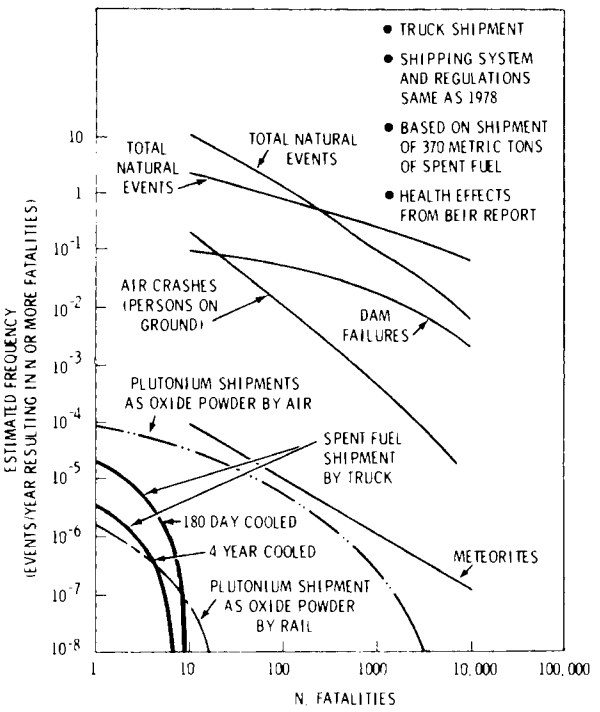


FIGURE 2.5. Risk Spectrum for Truck Shipments of Spent Fuel in the Mid-1980s.

Conceptual Design of a Shipping Container for Transporting High-Level Waste by Railroad

P. L. Peterson and R. E. Rhoads

The draft report on the conceptual design for a rail cask for shipping high-level waste was completed; the design is shown in Figure 2.6. The figure is a photograph of an HO gauge (1/87 scale) model of the conceptual design that was also produced as part of this study. The conceptual cask has the capacity to transport the high-level waste produced from reprocessing about 30 MT of spent fuel. The cask is shipped with dry air in the cavity and cooled by natural convection from the cooling fins on the cask surface.

PLANS FOR NEXT PERIOD

Draft reports on the risks of transporting spent fuel by train, chlorine by train and propane by truck and train will be completed and circulated for review. Final

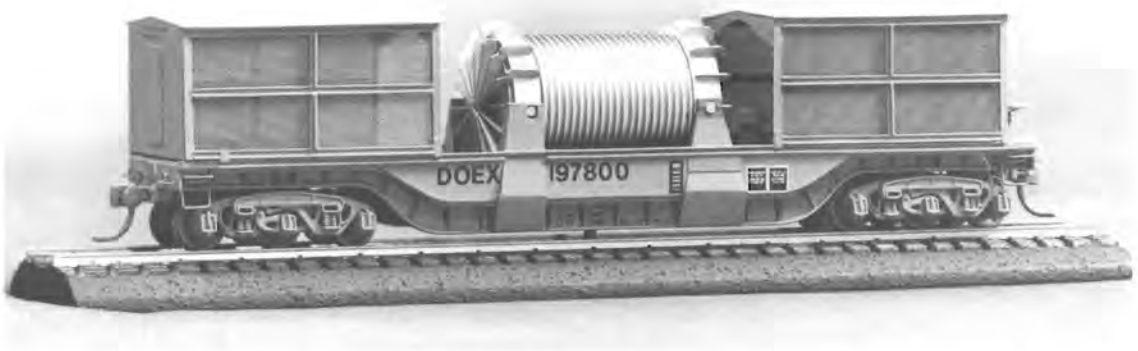


FIGURE 2.6. Model of Conceptual Cask and Railcar for Transporting Solidified High-Level Waste.

reports for these three assessments will also be published when reviews have been completed and appropriate comments incorporated. Final reports on the risk of transporting spent fuel by truck, gasoline by truck and the conceptual high-level waste cask design will also be published. The study of the risk of transporting DOE transuranic wastes will be completed and a draft report prepared. System description information for the remaining assessments of transportation risks in the current nuclear fuel cycle and alternative fuel cycles will be developed. Risk assessments will be initiated for materials that are common to more than one of the fuel cycles.

• Decommissioning of Retired Facilities at Hanford: Planning

The objectives of the Hanford Decommissioning Planning Project are to establish a plan for decommissioning retired contaminated DOE facilities at Hanford; to undertake needed site characterization of the Hanford areas; and to initiate detailed planning for future decommissioning projects at Hanford. The FY-1978 accomplishments included transfer of the Hanford Decommissioning Information System to an onsite computer and enhancement of the capabilities of the computer-based interactive planning system. Work on this project was interrupted by the higher priority assigned by the sponsor to the National Decommissioning Planning Project and by preemption of project management staff for work on the Commercial Waste Management Statement.

Decommissioning Planning

J. C. King

The objectives of the Hanford Decommissioning Planning Project are to establish a plan (methods, costs, priorities, schedule) for decommissioning retired contaminated DOE facilities at Hanford; to undertake needed site characterization of the Hanford areas; and to initiate detailed planning for future decommissioning projects at Hanford. Tasks planned for this project in FY 1978 included continuation of Hanford decommissioning data management efforts and revision of preliminary plans for Hanford.

Site Characterization and Data Management Resource Book. Additional sections prepared for the Hanford Decommissioning Resource Book (BNWL-MA-88) included Waste Management Systems and 300 Area Laboratories. These sections are currently in draft form.

Data Management. The System 2000 data management package on the Boeing Computer Services (Richland) UNIVAC machines was selected for the Hanford decommissioning data base (DDINFO). Following successful transfer of DDINFO to System 2000, the offsite account was terminated.

Hanford Decommissioning Plans. Additional Hanford Interactive Planning System (IPS) capabilities to support future revision of Hanford decommissioning plans were developed and tested. New capabilities include the ability to incorporate up to five "planning units" having differing land-use objectives into an overall planning schedule and budget. Also provided is the ability to incorporate projects of two or more facilities into decommissioning schedules and budgets.

• Characterization of Hanford 300-Area Burial Grounds

Substantial quantities of high-level, transuranic, and other nuclear materials have been disposed of in solid-waste burial facilities on the Hanford Reservation in Washington State. Some of these sites are located in the proximity of the 300-Area laboratory and engineering development complex. The objectives of the characterization study of the 300-Area burial grounds are: (1) to develop the technologies required to conduct comprehensive geologic, geophysical, biological, and computer model analyses of specific waste sites; and (2) to conduct specific analyses on select waste disposal sites. These studies will provide information that will augment analyses of risks associated with the alternatives of either designating sites for permanent storage or removing and translocating wastes and contaminated sediments.

300-Area Burial Ground Studies

S. J. Phillips

The investigatory procedures that precede actual decontamination and decommissioning (D&D) activities are based on evaluation of past and present operational procedures and site-specific information. These evaluations provide background for task activities and permit a framework for disposition recommendations. In addition to comprehensive evaluation of historical records, inventory, and engineering operations, this program is also documenting the status of retired radioactive waste burial sites. Characterization of the geohydrologic system that contains disposal materials is being conducted by geophysics, drilling, radiochemistry/geochemistry, fluid migration, simulation modeling, monitoring, and biologic analysis.

The location of waste burial structures and the gross composition and material distribution within 300-Area waste burial structures have not been accurately recorded. Preliminary geophysical test surveys have been made to dimensionally locate and map burial trenches, caissons, and related structures. Metal detector and ground penetrating radar surveys are being conducted at a test facility to assess the accuracy and reliability of these instruments. Figures 2.7a and 2.7b show equipment used in these surveys. The information derived from these surveys is used in defining drilling locations for retrieval of samples and subsequent assessment of potential radionuclide migration since such migration is a primary concern in developing D&D recommendations. An estimate of the distribution and type of waste materials assists in evaluating the location and fate of contaminants within the ground-water pathway.

FIGURE 2.7a. Transducer Vehicle with Ground Penetrating Radar Unit and Telemetry System Used to Collect Data Concerning the Morphology and Contents of Waste Burial Structures.

In addition, an evaluation of the chemical interactions of the burial media is required to determine potential leachate migration. By core drilling the burial grounds, we have developed a methodology to determine the distribution of radwaste contaminants that may migrate through the

FIGURE 2.7b. Data Processing Vehicle with Computer and I/O Devices Used to Process and Analyze Data Telemetered from the Geophysical Transducer Vehicle.

unsaturated to the saturated ground-water zone. Drilling and sediment core collection have proceeded in areas directly adjacent to burial structures, i.e. the areas in which the probability for migration of radio-contaminants is greatest. The apparatus for this work is shown in Figure 2.8. Where applicable, slant core drilling has been conducted and samples were collected from directly below each structure. These geo-logic samples have been screened for con-tamination by hand survey instruments.

Initial core sample screening results from 28 drilled sampling wells within burial grounds were analyzed. Samples from each well were submitted for gross alpha and gross beta multispectral analysis of gamma-emitting isotopes. To date, no significant radionuclide concentrations (above or ap-proaching maximum permissible concentration levels) have been determined. Where known significant concentrations of materials are found below a liquid waste disposal crib, radiochemical analyses of such isotopes as plutonium, strontium, and uranium have been conducted by acid leaching and subsequent counting and spectrophotometric analysis. Leaching tests have been performed on con-taminated samples. From this information, an estimate of the breakthrough of radio-nuclides into water pathways can be made.

Water originating from meteoric sources, i.e., precipitation and/or snow melt, is a principal agent for transporting radio-nuclides. Therefore, characterization and

FIGURE 2.8. Core Drilling Apparatus Used for Taking Partially Disturbed Sediment Cores at Radioactively Contaminated Burial Trenches.

assessment of fluid migration is being studied. In order to estimate the rate and magnitude of meteoric fluid entering or leaving the ground-water system, an assess-ment of the mass and energy balance which controls potential and actual fluid migra-tion is required. The energy and mass

FIGURE 2.9a. Installation of In-Situ Monitoring Test Site. Background shows large buried caissons used for evaluating fluid and radionuclide flux. Foreground shows partial installation of a weighing lysimeter used to evaluate energy and mass balance parameters which control the rate of migration of radionuclides through the geologic media.

FIGURE 2.9b. Post Installation After Burial and Backfill of Items Shown in Figure 2.9a. Neutron monitoring access wells and micrometeorological instruments are shown.

balance has been determined by laboratory characterization and field monitoring (Figures 2.9a and 2.9b) of micrometeorologic and geohydrologic parameters. Data are continually being collected from in situ field monitoring stations. In addition, data collected at a weather station over a period exceeding 10 years have been used for evaluating potential water transport in and through burial-grounds.

Simulation of fluid flux through burial ground geologic materials provides an assessment of the potential for water migration. Assessment includes computer evaluation of fluid migration through the partially saturated ground-water system. These simulations are being conducted using a one-dimensional computer code that uses micrometeorologic and geohydrologic data obtained from field monitoring and laboratory activities. The model's sensitivity has been evaluated by varying the input to reflect measurement error as well as spatial and temporal variability. This study will produce a method that will, in part, permit assessment of critical factors influencing water transport through waste burial geologic media. This information can be used to assess and develop long-term recommendations regarding burial-ground disposition related to the ground-water pathway.

Investigations of possible biological transport of contaminants from radioactive waste disposal structures by means of deep-rooted plants and burrowing animals have also been conducted. These studies will recommend methods and barrier designs for reducing waste exhumation. Further review will cover means of retarding growth of deep-rooted plants and simultaneously preventing further infiltration of meteoric water through the burial media.

This project will be completed and a final report issued during the second quarter of FY 1979.

• Decontamination and Decommissioning of Hanford Facilities: Technology

An extensive, long-term and costly effort will be required to decommission the contaminated DOE facilities that are no longer in service or that will be retired in future years. Improved technology is required to minimize the risk and cost of the decommissioning effort. The objective of the Hanford decommissioning and decontamination (D&D) technology program is to conceive, develop and test advanced methods applicable to this decommissioning effort. During FY 1978, concrete surface removal techniques were evaluated. Water cannon and rock splitter techniques were shown to be effective and potentially useful concrete decontamination methods. Core samples taken from selected Hanford facilities were examined. Compressive strength test results indicate that after 35 years' exposure to the Hanford environment, the concrete still exceeds specifications. Electropolishing decontamination technology was shown to be effective in the D&D of a reference Hanford facility. A "biobarrier" (rock, gravel, sand, topsoil) technique was shown to be a potentially useful method of preventing plant and animal penetration of contaminated burial grounds. A prototype field instrument was developed for measuring low levels of residual transuranic activity in structural materials and soils.

Concrete Decontamination

J. M. Halter, R. G. Sullivan, R. R. King

Two methods to spall contaminated concrete surfaces have been developed. The primary method uses a tool to exert radial pressure with expanding split wedges on the sides of a shallow cylindrical hole drilled in the concrete. The second method, a "water cannon," is a device that fires a high-velocity jet of fluid at the concrete surface, causing spallation.

The water cannon and concrete spaller were tested in the 100-F Area on concrete typical of that found in contaminated Hanford facilities. These tests demonstrated that both techniques rapidly and economically remove concrete surfaces. The concrete spaller was tested on 3 ft x 3 ft panels. Holes 1 in. in diameter and 2 in. deep were drilled in an 8-in. triangular pattern. Figure 2.10 illustrates the spalling that resulted. Approximately 8 min were required to drill and spall the 3 ft x 3 ft surface area. The rubble produced was of convenient size for handling, and much of the surface layer remained intact, which is believed to be a contamination control advantage. The water cannon was tested on a 1-ft^2 panel. Approximately 6 min were required to remove the test surface area. Figure 2.11 shows

FIGURE 2.10. 3 ft x 3 ft Test Panel After Spalling with Hand-Held Hydraulically Actuated Split-Wedge Spalling Tool.

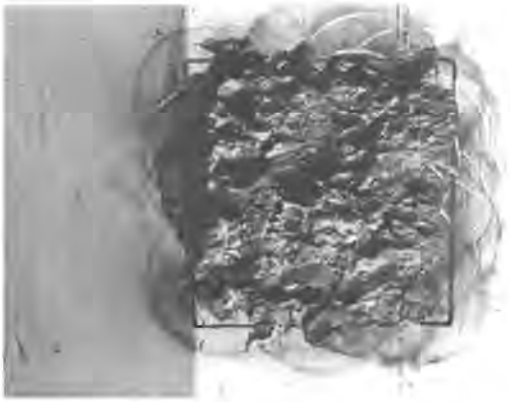


FIGURE 2.11. 1 ft² Test Panel After Spalling by Water Cannon.

the spalling that resulted. The water cannon was also found to work well for removing small areas that the mechanical spaller might leave because of aggregate variations. A new, high-speed water cannon is under development. The unit will have a firing rate of 5 shots/sec and has the potential to remove concrete surfaces at the rate of 3 to 6 ft/min. A nonautomated prototype concrete surface removal system has also been designed and fabricated. It consists of a man platform upon which hand-operated drilling and spalling and dust collecting equipment will be mounted. The platform is positioned to the desired surface area by forklift.

Concrete Properties

G. H. Beeman

The major factors that affect the durability of Portland Cement concrete have been identified. Although concrete is susceptible to deterioration from many types of exposure, properly made concrete possesses excellent resistance to weathering action and other processes of deterioration. This resistance is enhanced significantly in concrete made with good aggregates, low water-cement ratio, the proper cement, air entrainment, good workmanship and good curing practices. At Hanford, these practices generally have been followed very well, particularly in the construction of the reactor and separations buildings and their auxiliary buildings. The Portland Cement used has been Type II, low alkali, and the aggregates, made from the Columbia River sands and gravels, are among the best in the world.

This program began evaluation of some Hanford facilities for integrity of concrete. Cores have been taken from the head end of the 221-T and Purex buildings. The mechanical properties of these cores give an indication of the integrity of the concrete. Table 2.6 shows the results of tests performed on eleven cores from 221-T.

In general, the specification for bulk concrete calls for a minimum compressive strength of 3000 psi. The modulus of elasticity should be at best 33,000 x $\sqrt{f'_c}$ (f'_c = compressive strength). After 35 years of exposure to the Hanford environment, this concrete still exceeds specifications.

A test machine to determine the integrity of reinforcing steel in concrete in various hostile environments was designed, fabricated and initially tested. The tests are designed to determine whether the interaction of rebar stress and environmental conditions under slow stress cycling is detrimental to the performance of the composite rebar concrete system.

To date, three sets of rebar integrity tests have been completed. The first test was stopped at 5000 cycles. These specimens

TABLE 2.6. Mechanical Properties of Concrete Core from 221-T.

Specimen No.	Compressive Strength, psi	Elastic Modulus, 10^6 psi	Poisson's Ratio
1	3875	2.51	0.17
2	4440	2.53	0.41[a]
3	3480	2.98	0.14
4	3760	2.66	0.20
5	4860	2.91	0.16
6	5495	3.99	0.22
7	3305	3.43	0.30[a]
8	4700	2.96	0.16
9	3205[b]	3.30	0.22
10	3840	3.23	0.16
11	4490	3.72	0.19

Mean Compressive Strength
4132 psi ± 721

Mean Modulus of Elasticity
3.11 x 10^6 psi ± 0.48 x 10^6

Mean Poisson's Ratio
0.21 ± 0.079

[a] These values may be high because of internal cracking.
[b] Strength value on this specimen is low owing to handling damage.

were tested at 70°C in air and low humidity. This test was intended as a proof of principle. No visible damage was done to the rebar.

The second test was stopped after 15,000 cycles. It was tested in a CO_2 atmosphere with 100% humidity at 70°C, a combination of CO_2 and H_2O producing a carbonation reaction. This carbonation changes the Ph at the tip of the crack near the rebar interface. If this Ph change is great enough, the rebar can begin to corrode. No visible damage was done to the rebar.

The third set of beams was tested at 70°C and 100% humidity. These were also intermittently sprayed with water saturated with NO_3 salts. This test was stopped after 15,000 cycles. There was some evidence of corrosion of the rebar at the crack tip.

Applications of Electropolishing Technology

R. P. Allen and H. W. Arrowsmith

Research conducted at Pacific Northwest Laboratory for the DOE Division of Waste Products has shown that electropolishing is a rapid and effective technique for removing plutonium and other radionuclide contamination from a variety of metal surfaces. Figure 2.12, for example, illustrates some of the wide range of objects that have been decontaminated by electropolishing. These include:

- stainless steel vacuum system components heavily contaminated with plutonium oxide. Electropolishing reduced the radiation level from 1 million dis/min/100 cm^2 to background level in less than 10 min.
- stainless steel animal cages contaminated with radium and lead-210. Electropolishing for 20 min with the lid closed removed contamination that had resisted all previous decontamination efforts using standard techniques.
- mild steel reactor end caps and inserts contaminated with beta-gamma fission products. Electropolishing rapidly reduced the radiation level of these corroded components to near background, effecting a significant reduction in exposure to maintenance personnel.
- Hastelloy C fission product storage capsules contaminated with strontium fluoride. Electropolishing for 20 min reduced smearable contamination levels from 5 R/hr to less than 5 mR/hr.

These and other items that have been decontaminated by electropolishing are listed in Table 2.7 to further illustrate the ability of electropolishing to decontaminate materials and components representing a variety of alloy compositions, a wide range of sizes and geometries, and different types of radioactive contamination.

FIGURE 2.12. Typical Metal Objects Decontaminated by Electropolishing.

The objective of the present work is to evaluate this new decontamination technology for D&D operations and to identify and develop the optimum approaches and techniques for representative D&D applications. Studies are in progress to:

1. characterize the expected metallic waste from reference surplus facilities with respect to type, quantity and suitability for electropolishing decontamination.

2. compare processing facility costs, materials balance factors, and safety considerations for various electropolishing decontamination approaches. These approaches are:

- Central Transuranic (TRU) Electropolishing Decontamination Facility -- Metallic waste is transported from the decommissioning site to a central automated processing facility where the containers can be decontaminated by electropolishing.
- Modular TRU Electropolishing Decontamination Facility -- A modular electropolishing system that uses the building's utilities is installed in the facility to be decommissioned.
- Portable TRU Electropolishing Decontamination Facility -- A portable, self-contained electropolishing system mounted on railroad cars or trucks is used at the site and then decontaminated and moved to a new site.

3. investigate the applicability of in situ electropolishing techniques for the decontamination of equipment and facility components prior to disassembly to reduce costs and minimize exposure to D&D personnel.

A reference facility has been selected for the initial evaluation studies of electropolishing techniques. A preliminary inventory of the contaminated metallic

TABLE 2.7. Representative Surface-Contaminated Metal Items Decontaminated by Electropolishing.

Item	Material	Contamination
Core Drill Bit	Mild Steel	Beta/Gamma
Animal Cages and Trays	Stainless Steel	Radium; Lead-210
Product Receiving Canister	Stainless Steel	Plutonium
Standards Capsules	Stainless Steel	Plutonium
Traveling Wire Flux Monitor	Stainless Steel	Beta/Gamma
Waste Sampling Tubes	Mild Steel	Alpha/Beta/Gamma
Large Reactor Valves	Mild Steel	Beta/Gamma
Electropolishing Tank	Stainless Steel	Plutonium
Compressor Blades	Aluminum	Uranium; Beta/Gamma
Ducting	Stainless Steel	Plutonium
Pipe	Mild Steel	Plutonium
Glove-Box Waste	Stainless and Mild Steel	Plutonium
Vacuum System Parts	Stainless Steel	Plutonium
Manipulator Tong Assemblies	Stainless Steel and Mild Steel and Aluminum	Beta/Gamma
Analytical Instrument Components	Stainless Steel	Alpha/Beta/Gamma
Laboratory Ware	Stainless Steel	Beta/Gamma
Storage Capsules	Hastelloy C	Strontium Fluoride
	Stainless Steel	Cesium Chloride
Pneumatic Cylinder	Mild Steel	Beta/Gamma
Demister	Stainless Steel	Plutonium
Connector Rings	Mild Steel	Beta
Pipe Clamps	Mild Steel	Beta/Gamma
Mass Spectrometer Components	Stainless Steel	Alpha/Beta/Gamma
Chemical Vessel	Mild Steel	Plutonium
End Caps and Inserts	Mild Steel	Beta/Gamma
Foot Clamp	Mild Steel	Cesium
Glove-Box Panels	Stainless Steel	Plutonium
Power Reactor Valve Components	Stainless Steel	Cobalt-60

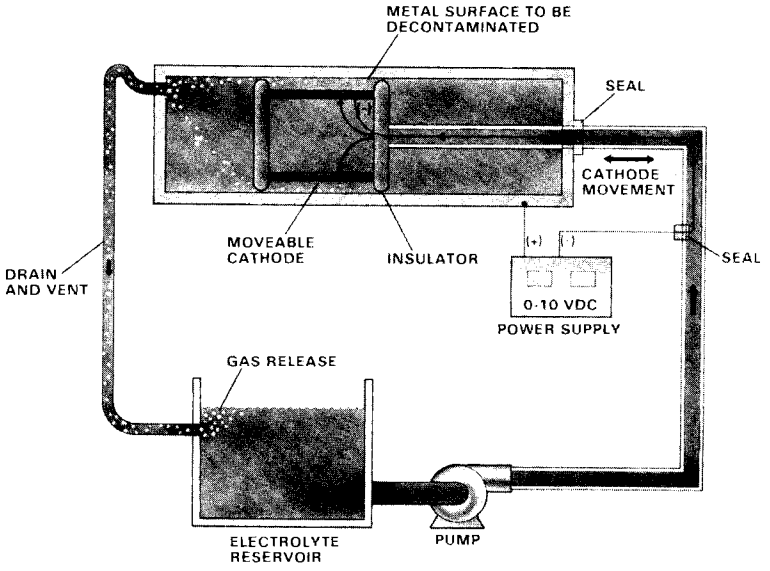
equipment contained in the reference facility has been completed. Metals to be decontaminated include galvanized steel, stainless steel, copper, aluminum, titanium, and tantalum. All of these metals, except galvanized steel, have been successfully decontaminated by electropolishing. Laboratory studies are under way to determine if electropolishing is an effective decontamination technique for galvanized material. The inventory also revealed that most of the exposed metallic surfaces in the reference facility have been coated with epoxy paint for contamination control. The epoxy coating must be removed prior to decontaminating the metallic part since electropolishing techniques are not effective on nonconducting material. Laboratory studies are in progress to evaluate the effectiveness of several paint stripping compounds that are also compatible with an electropolishing decontamination system.

In situ electropolishing techniques for decontaminating equipment prior to disassembly are being investigated. The decontamination of a 6-m long corrosion test loop at the Hanford N-Reactor using a movable 0.6-m long cathode demonstrated that in situ electropolishing techniques can reduce exposure. Each 0.6-m section of pipe was electropolished for 20 min at a current density of approximately 11 A/square decimeter using a portable electropolishing system as illustrated in Figure 2.13 This treatment reduced the average radiation levels in the less-contaminated portion of the pipe from about 4 R/hr to near background; radiation levels near pipe fittings where pockets of contamination had collected were reduced from 40 R/hr to near background. Work is continuing to determine which components in the reference facility could be effectively decontaminated using this technique.

Instrumentation Development

R. L. Brodzinski and K. K. Nielson

The objective of this research is to develop sensitive instrumentation specifically for detection of low-level transuranic contamination on surfaces. Our earlier studies (Nielson et al., 1976) suggested the use of



FEATURES:

- DECONTAMINATE INTERNAL SURFACES OF PIPE
- DECONTAMINATE LONG LENGTHS
- DECONTAMINATE CURVED SECTIONS

FIGURE 2.13. Portable Electropolishing System (Internal Cathode Technique).

a large germanium detector for obtaining the best sensitivity and detection limits. Such an instrument has now been field tested and evaluated. Sensitivity, detection limits, and time and cost estimates for surveying facilities undergoing D&D efforts are reported here.

A portable, omnidirectional, planar 19 cm^2 intrinsic germanium detector was coupled by a 30-m cable to a multichannel analyzer and a cassette data recorder. Nominal detector resolution was 680 eV Full Width Half Maximum (FWHM) at 59.5 keV. An optional annular lead collimator (1.27 cm thick x 10.2 cm long) was used to reduce background and restrict the detector's field of view. Figure 2.14 illustrates typical spectra obtained in surveying a contaminated surface, both with and without the lead collimator.

Although prominent peaks, such as the L x-rays and the 26- and 60-keV gamma rays, were observed in the field, detailed peak analyses, attenuation corrections, calculations of the various nuclide activities, and estimations of the mean depth of the activities were done in the laboratory by a PDP-15 computer. Calculations were based on prior laboratory calibrations determined for various materials such as concrete, wood, steel, lead, lucite, sand, glass, and floor tiles. Figure 2.15 illustrates detection limit curves for the various photopeaks for a concrete surface as a function of source and depth. Americium-241 is detectable at much lower activities than the other nuclides. Since ^{241}Am is characteristically found in transuranic contamination, this nuclide can be used for rapid, cost-effective monitoring of large surface areas.

Figure 2.16 illustrates the time required to survey 1000 m^2 of surface area as a function of detection limit and surface-to-detector separation. For example, this surface could be surveyed at a distance of 1 m in 25 hr at a sensitivity level of 0.01 nCi/cm^2 for ^{241}Am (1 nCi/cm^2 for plutonium). This survey would consist of 476 individual 2.2 min counts covering 2.1 m^2 each. Since the 59.5 keV ^{241}Am gamma rays penetrate about 1 cm on the average in concrete, and x rays from plutonium penetrate about 1 mm, the detection limits in this example are approximately 0.003 nCi/g for ^{241}Am and 0.3 nCi/g for plutonium assuming a concrete density of 3 g/cm^3. Longer counting times would lower these detection limits, if desired, or alternatively, shorter counts could be used to speed up the

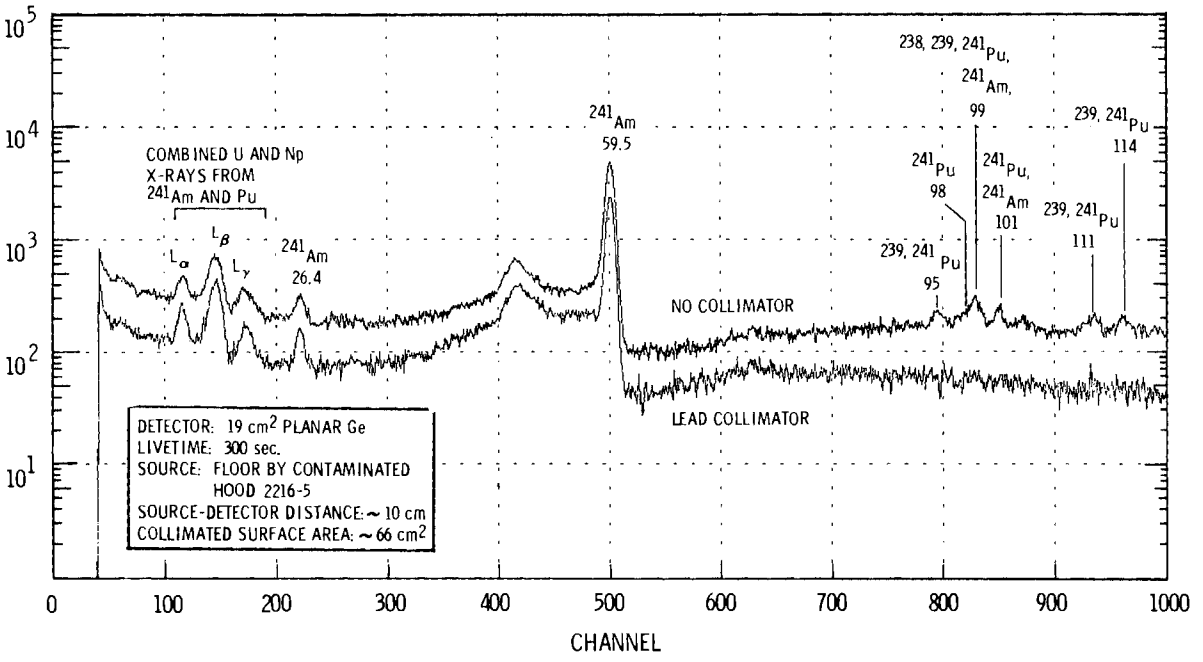


FIGURE 2.14. Low-Energy Photon Spectra from a Contaminated Floor Area Showing the Results of Collimation.

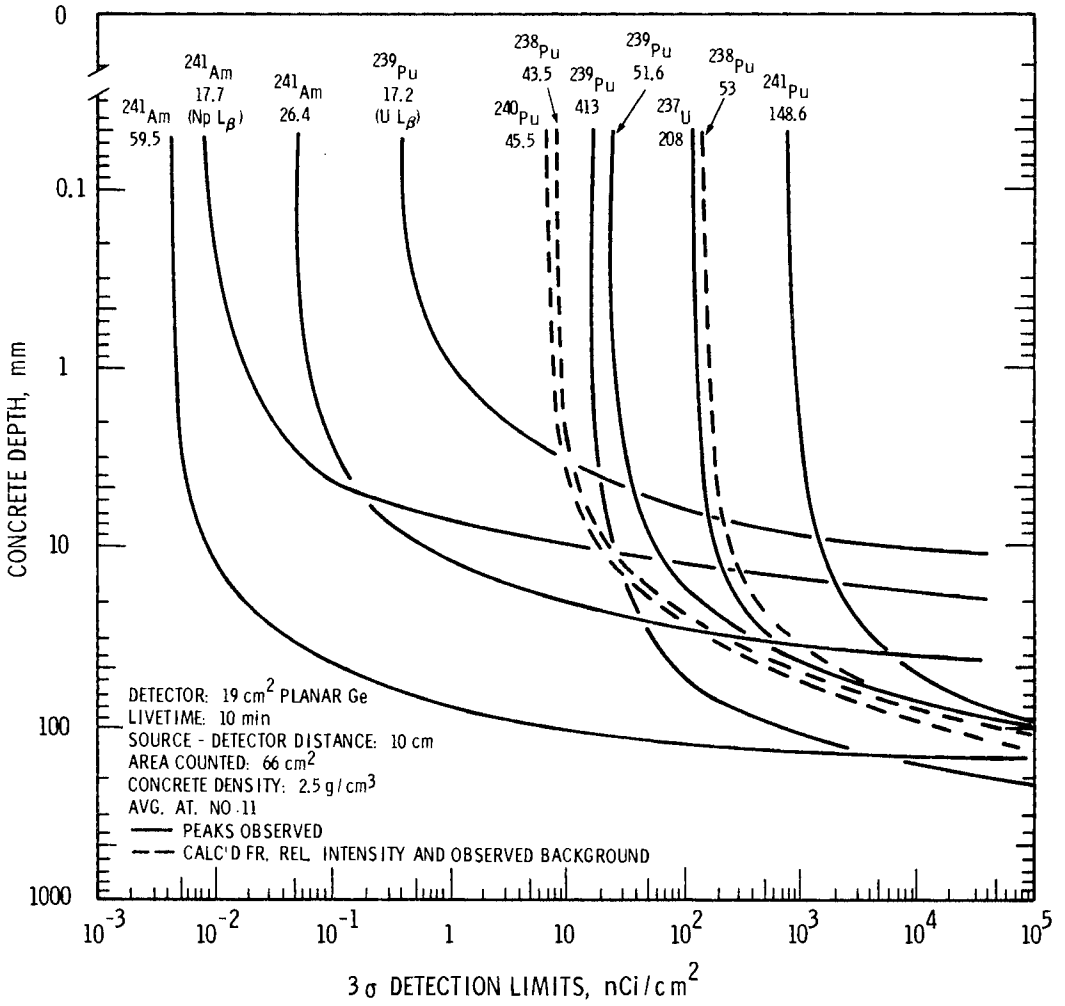


FIGURE 2.15. Plutonium and Americium Detection Limits Versus Depth in Concrete.

survey process at the expense of sensitivity. The darkened lines in Figure 2.16 represent practical limits since the actual counting times become negligible compared to the time needed to move the detector to the next location.

Burial Ground Stabilization

J. F. Cline

This research is designed to test the ability of a "biobarrier" (a rock-gravel-sand-topsoil cover) to prevent plant and animal penetration of contaminated burial grounds. Field tests and greenhouse experiments are under way. Lithium chloride mixed with soil simulates radioactive wastes. Plant and animal samples are collected at regular intervals and analyzed for lithium. In the three years the field tests have been conducted, three tumbleweed plants have penetrated the cobblestone barrier, one in 1976 and two in 1978. There is no evidence of other plant or animal penetration of the field test site.

Sixteen lysimeters have been constructed for the greenhouse experiments. Four of the lysimeters have been constructed with layering detail similar to the field test trench. Other groups of four lysimeters were constructed with (1) pea gravel over the cobble, (2) pea gravel plus an asphalt emulsion over the cobble, and (3) pea gravel plus an asphalt emulsion plus a root toxin over the cobble. The lysimeters were planted with cheatgrass. Cheatgrass penetration of the

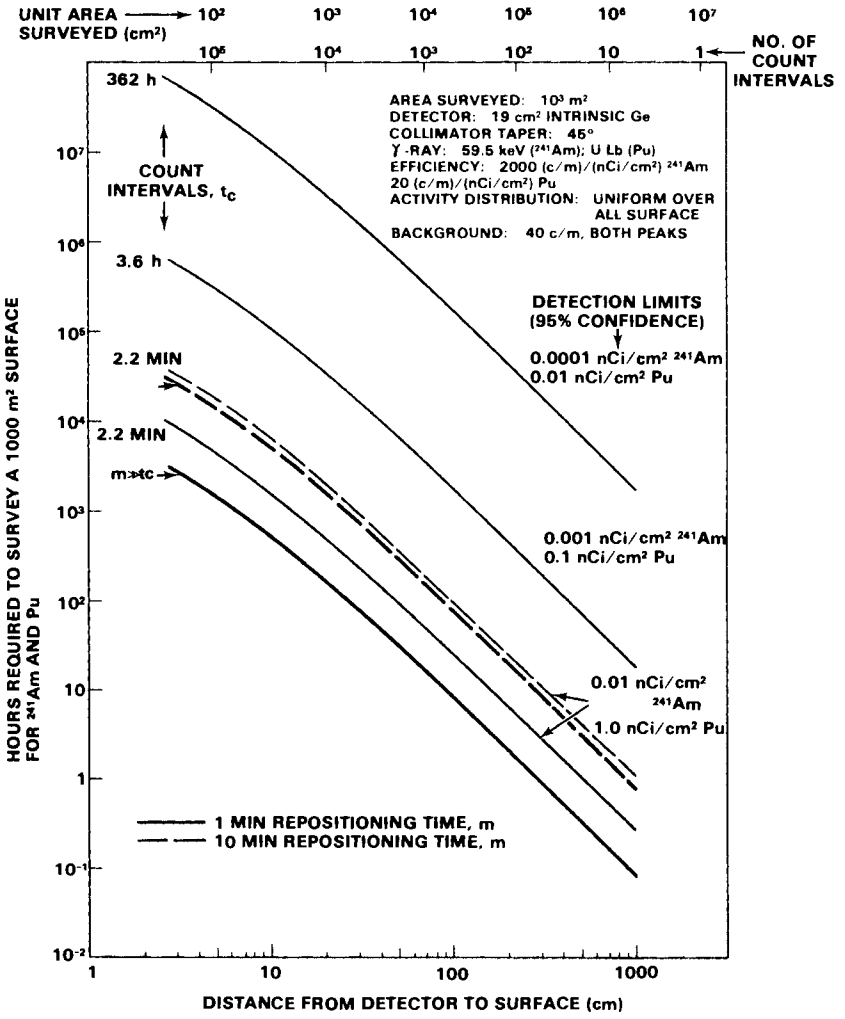


FIGURE 2.16. Time Required to Survey 1000 m² of Surface Area as a Function of Detection Limit and Surface-to-Detector Separation.

barriers is summarized below:

Barrier Construction	Root Penetration, %
Cobble only	100
Cobble + pea gravel	50
Cobble + pea gravel + asphalt emulsion	0
Cobble + pea gravel + asphalt emulsion + root toxin	0

The greenhouse experiments differ from the field study in that the surface soil and cobble layers are 3 and 2 times shallower, respectively. Also the cheatgrass plants in the lysimeters were watered regularly, whereas the only water received by the field plants was rain. These factors are believed to explain why the cheatgrass penetrated the greenhouse lysimeters but not the field test trench. The addition of pea gravel, asphalt emulsion and root toxin all increase the effectiveness of the biobarrier.

REFERENCE

K. K. Nielson, C. W. Thomas, N. A. Wogman and R. L. Brodzinski (1976). "Development of a Plutonium-Americum Monitor for In-Situ Soil Surface and Pond Bottom Assay," Nucl. Instrum. Methods 138:226.

• Assistance for Nationwide Decommissioning Planning for DOE Nuclear Facilities

The objectives of the national decommissioning planning project are to develop a nationwide inventory of surplus DOE radioactively contaminated facilities and to establish priorities for their decommissioning. The inventory and priorities were used to develop five-year decommissioning plans and budgets. PNL contributions included development of survey forms for inventory of surplus facilities, creation of a computer-based data management system, and determination of priorities for decommissioning of surplus DOE nuclear facilities.

Planning Nationwide Decommissioning of DOE Facilities

J. C. King and J. W. Litchfield

The objectives of the national Decommissioning Planning Project are to develop a nationwide inventory of surplus DOE contaminated facilities and to establish priorities for disposition. This information will be used by other contractors to develop five-year plans and associated budgets for decommissioning retired DOE nuclear facilities.

Progress. PNL participation in this project includes three tasks: (1) developing a computerized information system for surplus radioactively contaminated DOE nuclear facilities; (2) establishing a priority of these facilities for decommissioning; and (3) providing project overview as requested.

Facility Inventory and Data Management. Questionnaires were designed in conjunction with Atomics International (AI) of Canoga Park, California to obtain information on surplus contaminated DOE facilities for use in the subsequent planning effort and setting of priorities. Questionnaires were issued and responses compiled by AI. A data management system was established on the Boeing Computer Services (Richland) UNIVAC machine using the System 2000 data management package. Administrative, geographical, structural and radiological information for 430 surplus DOE nuclear facilities is currently available on the system.

Facility Priorities. The sponsor identified potential offsite hazard as the most important concern relative to surplus DOE nuclear facilities; thus it was selected to be the basis for decommissioning priorities. Potential offsite hazard was assumed to be proportional to the estimated population dose resulting from complete release of the radioactive inventory of a facility. Site-specific dose conversion factors, relating population dose to unit releases of radioisotopes were calculated for sixteen sites containing the 430 surplus facilities. Dose conversion factors based on surrounding population distribution and site meteorological characteristics, were calculated for major isotopes within the surplus facilities. The radioisotopic inventory of each facility was multiplied by the appropriate dose conversion factors to obtain an estimate of population dose, assuming atmospheric release of the facility's entire radioactive contents.* Population dose estimates were summed across all isotopes present within each facility and the resulting dose estimates normalized on a scale of 0-1000 to obtain a priority index. The priority indices were used in the development of a five-year decommissioning plan for surplus DOE nuclear facilities.

Project Overview. PNL personnel participated in project review sessions through completion of the draft National Decommissioning Plan.

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* A release fraction of unity (total release) was assumed for the initial priority effort. A follow-up effort (not completed) was to incorporate facility-specific release fractions based on physical characteristics of the various types of facilities.

• Asphalt Emulsion Sealing of Uranium Tailings

Long-term stability of uranium tailings is of concern because of the long-term release of radioactive decay products. Milling of uranium ore produces large quantities of tailings containing two potentially hazardous radioactive decay products: radium-226 (half-life 1620 yr) and its daughter product, radon-222 (half-life 3.8 days). With increases in the mining and milling of uranium ores expected over the next few decades, more and larger tailings piles will result, thus creating even greater problems of controlling the release of radium-226 and its daughter, radon-222. Therefore, methods need to be developed for stabilizing uranium mill tails to reduce radon exhalation and radium permeation.

The overall objective of this project is to investigate the use of asphalt emulsion as a stabilizing sealant to contain radon and radium in uranium tailings. Asphalt emulsions can potentially provide an economical, relatively inert, durable, and long-lived barrier to radon diffusion and radium permeation.

Evaluation of Asphalt Emulsion Sealing of Uranium Tailings

J. N. Hartley and P. L. Koemstedt

The use of asphalt emulsion for containing radon and radium in uranium tailings is being investigated by conducting two tasks. The first task consists of laboratory studies including uranium tailings characterization, asphalt emulsion formulation, radon and radium permeation measurements, seal stability review, and application technology review. The second task consists of onsite investigations of radon and radium seals. Field demonstrations will be conducted at selected inactive uranium tailings sites using the most promising application techniques. The stability of the seals will be studied including the effects of mechanical abuse, overburden requirements, root penetration, and so forth. The effectiveness of the application technique and seal in radiation containment will be established. The progress on this project since its reinitiation in June 1978 is presented in the following paragraphs.

Laboratory Studies. Laboratory facilities for radon and radium diffusion and permeation measurements were reestablished. Modification of the experimental equipment was made in order to conduct two tests at a time using a 120 mCi radium chloride radon source.

Uranium tailings samples from selected inactive sites were obtained. These include: Falls City, Texas; Mexican Hat, Utah; Monument Valley and Tuba City, Arizona; and Shiprock, New Mexico. Previous samples of the Vitro site and Philips Ambrosia Lake site are available for additional testing.

The latest technology for measuring radon and its daughter products was reviewed and equipment selected for both laboratory and field studies. Activated carbon will be used to trap the radon; this will be followed by gamma counting. The carbon canister will be placed in an alcohol-dry ice bath to improve radon removal from the gas stream. A multidimensional NaI counting system will be used to determine radon content.

Application technology is being reviewed including standard asphalt emulsion road paving equipment such as Koehring's Bomag paver, which looks promising. The Bomag blends the top few inches of soil with the asphalt emulsion. Modification of the paving procedures, such as using an excess asphalt emulsion and/or overcoat spray in order to obtain a gas-tight seal, will be made.

Field Studies. Several sites are being reviewed for the initial demonstration test which will include: (1) preparation of a

100 ft x 100 ft area (contouring, compacting, prewatering, etc.); (2) sealing the prepared area with selected asphalt emulsion formulations using the most promising techniques; and (3) studying the effects of mechanical abuse and overburden requirements. The effectiveness of the application technique and seal to contain radon will be established.

3.0 Operational and Environmental Compliance

OPERATIONAL AND ENVIRONMENTAL COMPLIANCE

- **Assessment of Criticality Safety**
- **Guidelines for Radiation Exposure—ALAP**
- **Effluent Monitoring Handbook**
- **Environmental, Safety, and Health Standards for Geothermal Energy**

The responsibility of the DOE Office of Operational and Environmental Compliance is to assure that DOE-controlled activities are conducted in a manner that will minimize risks to the public and employees and will provide protection for property and the environment. The program supports the various energy technologies by identifying and resolving safety problems; developing and issuing safety policies, standards, and criteria; assuring compliance with DOE, Federal, and state safety regulations; and establishing procedures for reporting and investigating accidents in DOE operations.

The PNL Operational and Environmental Compliance Program contributes to these objectives through projects in the nuclear and nonnuclear areas. Nonnuclear R&D is assuming growing significance and in the future will constitute a major portion of the program. During 1978 the major emphasis was on developing criteria, instruments, and methods to assure that radiation exposure to occupational personnel and to people in the environs of nuclear-related facilities is maintained at the lowest level technically and economically practicable.

• Assessment of the Status of Criticality Safety

A study has been completed on 100 violations of criticality safety specifications (CSS) that were reported over a ten-year period in the operations of a fuels reprocessing plant. Based on the limited data available, and the underlying assumptions made which affect accident probability, accidents might be expected to occur at a maximum rate of one during each 244 years of plant operation ranging down to a minimum rate of one in every 3000 years. Some general suggestions for improvement were formulated based on the cases studied. Although details may differ, the general method of analysis and the fault-tree logic should prove applicable to other plants as well. The study is being expanded to include other DOE contractors. With a broader, more complete data base, a more definitive result of the status of overall criticality safety will be possible.

Analysis of Criticality Safety

R. C. Lloyd, S. W. Heaberlin,
E. D. Clayton, W. E. Converse

The objective of this program is to develop and apply a systematic method to analyze the criticality safety programs in DOE facilities. An analysis of past data on criticality safety violations, in terms of criticality safety philosophy and the human and mechanical factors involved, permits judgments that may help reduce the number of future violations. Further, these data may be used in a fault-tree analysis by which causes are assigned frequency values. Thus, when the most frequent causes of violations are identified, corrective action can be taken to eliminate them.

Fault-tree analysis is a form of risk assessment in which the pathways to the failure of a system are identified. (Failure is the occurrence of a criticality accident.) The fault-tree is developed from the various conditions, events and components leading to an accident, even though there may be little or no experience with complete failure of the system. This risk-assessment technique is well suited for analyzing criticality safety. A study of 100 criticality safety specification (CSS) violations that were reported between 1967 and 1976 has been completed. Two reports on this study have been written (Lloyd et al., 1977; Lloyd et al., 1978). Analyzing the event-tree data, calculational mathematical models were generated with the computer code ACORN. A second code, MFAULT, was used to predict probabilities based on the tree. Calculations were made for several time frames. Table 3.1 gives estimated probabilities for operating plant years per accident.

TABLE 3.1. Estimated Probability for Criticality (assuming no single-cause events).

Duration of Fault[a]	Probability/ Area-Year	Plant Probability/ Year	Year/ Accident
No Repair	2.05×10^{-5}	4.1×10^{-3}	244
6 Months	2.00×10^{-5}	4.0×10^{-3}	250
3 Months	9.71×10^{-6}	1.9×10^{-3}	526
1-1/2 Months	4.77×10^{-6}	9.5×10^{-4}	1053
1/2 Month	1.57×10^{-6}	3.1×10^{-4}	3226

[a] Period violation exists before detection or corrective action is taken. "No Repair" assumes violation remains undetected, and hence, no corrective action is taken at all.

The data for this calculational model were not as complete as they might have been. For example, no data exist for single-error criticality events.* In addition, the data available were spread over a 10-year period. The improvements that have been made in criticality safety

* No criticality incident has occurred in a U.S. chemical processing plant for nuclear materials in fourteen years.

make the likelihood of an accident today smaller than the model suggests. For more definitive results, broadly based data are clearly required, including data from other DOE contractors. The model can also be used to show how a criticality safety program can be affected by changes (e.g., in inspection periods).

To develop a wider data base, data from the past five years are being collected from various DOE sites handling nuclear materials.

REFERENCES

R. C. Lloyd et al. (1977) "Criticality Safety Assessment," Trans. Nuc. Soc. 427: 404-405.

R. C. Lloyd et al. (1978) "Assessment of Criticality Safety," BNWL-SA-6361, Pacific Northwest Laboratory, Richland, WA 99352. Accepted for publication in Nuclear Technology.

• Guidelines for Radiation Exposure—ALAP

A three-phase project was planned to assist the nuclear industry in ensuring that radiation doses to personnel shall be maintained "as low as practicable" (ALAP), technically and economically. Phase one (identification and characterization of radiation exposure activities) was completed in FY 1977. FY 1978 focused on the second phase of the project, a published summary of ALAP efforts at DOE facilities. Based on the results of this report, a first draft of an ALAP manual has been completed. During phase three, PNL will further develop these and publish the manual.

Technical Guidelines For Maintaining Occupational Exposures As Low As Practicable (ALAP)

R. L. Gilchrist and J. M. Selby

The objective of this project is the preparation of a technical document that will provide the basis to assure that radiation dose to DOE personnel, DOE contractors, and nuclear industry radiation workers be maintained at levels as low as practicable. ("Radiation dose" means the dose from sources either within or outside the body--also referred to simply as "exposure.") The need for such a document is the result of an industry commitment that not only shall worker and public exposures not exceed specified limits, but also that "operations shall be conducted in a manner to assure that radiation dose to individuals and population groups is limited to the lowest levels technically and economically practicable."

Although interim guidance for meeting this commitment has been provided, an in-depth analysis must be made to look at recent radiation exposure trends, present radiation protection practices, production needs, and alternatives for reducing exposure at contractor sites throughout the United States. Based on this analysis and other available information, including computer modeling, a document will be prepared with guidelines for assuring that ALAP exposures for radiation workers are maintained. This document will be used in current programs, and in designing future programs.

The project has three phases: (1) identification and characterization of activities at DOE-owned facilities that ensure "reasonably avoidable" radiation exposure, (2) in-depth analyses of methods for exposure reduction, and (3) development of minimum ALAP exposure performance criteria. The initial phase has involved reviews of facilities' exposure records, instrumentation, training, facility layout and design, and any relevant studies and discussions with health physics and operating personnel at the facilities.

The information gathered in the site visits has been summarized and was published in August 1978. This report is entitled, Technical Guidelines for Maintaining Occupational Exposures as Low as Practicable (Summary of Current Practices). During the third phase of this project, PNL will develop a manual based on the results in the above report.

• Handbook on Effluent Monitoring

A revised working paper of A Guide for Effluent Monitoring at DOE Installations was assembled for sponsor review. The new draft incorporates revisions necessitated by recent legislation, as well as basic discrimination levels for measurement of pollutants in airborne and liquid effluents. A letter report was submitted concerning the analysis and comparison of 26 ERDA site annual environmental reports with requirements of ERDA Manual 0513 and recommendations of ERDA-77-24.

Handbooks of Recommended Practices for Environmental and Effluent Monitoring and Reporting

J. P. Corley, B. V. Andersen,
G. W. Dawson, L. C. Schwendiman

The objectives of this program are to provide:

1. suggested methods and procedures to bring greater uniformity and comparability to DOE contractor systems for environmental and effluent radiological monitoring and reporting, and

2. guidelines for suggested environmental and effluent radiological monitoring practices for the Office of Operational and Environmental Safety.

Effluent Guide. A completely revised draft, which still requires further editing, was assembled for initial sponsor review. Major changes from an earlier draft incorporate requirements and advice stemming from the extensive legislation passed in 1977, including the Clean Air Act and Federal Water Quality Act amendments and the Toxic Substances Control Act. Recent advances in analytical and screening procedures being developed for fossil fuel technologies are also reviewed, but suggested requirements are based on standard procedures and commercial instrumentation. The original draft outline was only slightly changed.

The report includes suggested basic discrimination levels for measurement of radioactive and nonradioactive pollutants in airborne and liquid effluents. These levels are 10% (for airborne effluents) and 1% (for liquid effluents) of the radioactivity concentration guides or the equivalent for nonradioactive material. These suggested levels would, of course, be subject to National Pollutant Discharge Elimination System or other requirements, as well as improved detection levels to demonstrate ALAP (as low as practicable) compliance.

Environmental Guide. Analysis of the 1976 annual environmental reports and the supporting surveillance programs was completed for all 26 ERDA sites reporting. A letter report was submitted to the sponsor. Evaluations and comparisons were made against both the requirements of ERDA Manual Chapter 0513 and the recommendations of the previously prepared Environmental Guide, ERDA-77-24. By agreement with the sponsor, a second complete analysis and comparison was postponed to FY 1979, permitting the sites more time to react to both the Guide and our comments on the CY-1976 reports.

• Environmental, Safety and Health Standards for Geothermal Energy

Environmental, Safety and Health (ES&H) Standards are being identified and evaluated for their potential application to geothermal energy development. For this evaluation, the ES&H problem areas were subdivided into 14 topics: airborne emissions, liquid waste disposal and water pollution, blowouts/hot water and steam releases, subsidence and induced seismicity, noise, heat stress, sampling and analyses, falling hazards, electrical hazards, heavy equipment operations, soil effects and land-use planning, fire hazards, construction, and hazardous substances. Drafts of seven of these reports are currently being reviewed. The remaining seven reports and the final report are being written.

Environmental, Safety and Health Standards Identification for Geothermal Energy

J. B. Martin, A. Brandstetter,
F. L. Thompson, R. A. Walter,
W. R. McSpadden, D. G. Quilici,
T. N. Bishop, D. C. Christensen,
N. E. Maguire, R. G. Anderson,
A. E. Desrosiers.

The objective of this project is to identify and assess existing environmental, safety and health standards that may be applicable to geothermal energy development. The standards were identified by reviewing applicable Environmental Protection Agency documents and the National Bureau of Standards publication Index of U.S. Voluntary Engineering Standards.

These standards were assessed after a comprehensive evaluation of ES&H problems that have been encountered by the geothermal industry. In most cases, recommendations were made that either existing standards or modified standards should be applied to solve these problems. For specialized areas in which standards were found to be nonexistent or inappropriate, research was recommended to provide a suitable data base for the development of ES&H standards.

The problem areas have been subdivided into 14 topics as shown in Table 3.2. Each report includes a detailed discussion of problems, an evaluation of the need for standards, an evaluation of existing standards and recommendations for application of the standards. The final report will condense all conclusions and recommendations. At present, seven draft reports have been written; a brief summary of each follows.

TABLE 3.2. Reports on ES&H Standards for Geothermal Energy.

Report No.	Title	Code
1	Airborne Emissions	E & O
2	Liquid Waste Disposal and Water Pollution	E
3	Blowouts/Hot Water and Steam Releases	E & O
4	Subsidence and Induced Seismicity	E
5	Noise	E & O
6	Heat Stress	O
7	Sampling and Analyses	E
8	Falling Hazards	O
9	Electrical Hazards	O
10	Heavy Equipment Operation	O
11	Soil Effects and Land-Use Planning	E
12	Fire Hazards	O
13	Construction	O
14	Hazardous Substances	O
	Final Report	

E = Environmental Topics
O = Occupational Safety and Health Topics

Report 1 - Airborne Emissions The environmental effects and occupational safety hazards of airborne emissions from geothermal fluids vary widely. Airborne emissions discussed in Report 1 include: hydrogen sulfide, carbon dioxide, methane in combination with oxygen, ammonia, arsenic, boric acid, mercury, radon, asbestos, steam, and heat.

Existing environmental standards regulating these emissions adequately address most needs identified in this study; however, a research project is recommended to assess the need for special standards.

The existing occupational health and safety standards seem adequate, given available data. However, only rough estimates of the probabilities of worker exposures were made because of a lack of data. Therefore, a full determination of the need for standards will not be possible until comprehensive data on occupational exposures are available. In spite of this lack of data, a number of existing standards (e.g., Threshold Limit Values) are directly applicable to the geothermal industry. Several other standards have indirect geothermal applications, and these are recommended for adoption as interim standards to be tested while data on actual worker exposures are collected and published.

Report 2 - Liquid Waste Disposal and Water Pollution. The chemical and physical characterization of geothermal liquid wastes varies widely depending on the reservoir characteristics and the type of geothermal conversion technology used. Of primary concern in geothermal liquid waste disposal are the environmental effects of the potentially large content of total dissolved solids, the temperature of the spent geothermal brine, and potentially toxic substances.

Research is needed to determine at what concentrations these chemicals, alone or in combination with other chemicals, would present a hazard to users of the water. Many of the chemicals for which research and/or stricter control is warranted are discussed in this report. Federal and/or state environmental protection regulations have been developed for most options for geothermal waste disposal, and these regulatory mechanisms are discussed in this report. In addition, this report includes recommendations for research that is necessary for the development of any other needed regulations and standards.

Report 3 - Blowouts/Hot Water and Steam Releases. Geothermal well blowouts occur when a drill penetrates a geothermal reservoir containing high-pressure fluids or steam, thereby permitting this pressure to be exerted against the well head equipment and upper geologic formations. This report is concerned with the causes and effects of unplanned releases coming primarily from blowouts or failures owing to corrosion and erosion in the steam distribution system.

Recommended practices and standards from the American Petroleum Institute, the U.S. Geological Survey, the American Society for Testing Materials, the American National Standards Institute and Underwriters Laboratories were evaluated to determine their applicability to well blowouts and releases of gases and vapors. These recommended practices and standards are summarized in this report.

Report 4 - Subsidence and Induced Seismicity. Subsidence and induced seismicity are associated with geothermal systems, but understanding of these geologic activities is not well developed. Impacts of subsidence include alterations in surface and ground-water flow and storage, alteration of topography, and damage to surface facilities. Primary impacts of seismicity result from damage to surface facilities; secondary effects include landslides and fires.

Current regulations on subsidence and induced seismicity are few in number and general in nature. No new standards are recommended in this report; rather, research on subsidence and induced seismicity (fine-grind monitoring, use of accelerometers, reservoir analysis, and analytical monitoring) is recommended.

Report 5 - Noise. Noise emissions from geothermal facilities may cause environmental problems for workers employed at geothermal sites. This report identifies intense noise sources associated with geothermal development and operations and makes recommendations about current noise exposure standards.

This study concludes that present environmental standards are adequate for normal muffled operations of geothermal facilities. However, Occupational Safety and Health Administration (OSHA) noise exposure standards are not adequate because they permit worker hearing loss at some sound frequencies. Also, a vibration standard is necessary, and this report urges the use of the International Standards Organization (ISO) Guide 2631 (1974) as an interim standard.

Report 6 - Heat Stress. Heat stress may occur whenever an imbalance between body heat and heat loss to the environment causes the body to become burdened with excessive heat that it cannot lose to its surroundings. In the geothermal industry, heat-stress problems may arise from the extensive use of hot surfaces, steam and/or hot water. In addition, radiant heat stress may occur because of elevated temperature exposures.

Currently, no recognized consensus exists for a heat-stress standard, although several permissible exposure limits have been recommended. Of the many indices developed, those discussed in the following three documents represent guidelines from which a standard may eventually develop:

- Occupational Exposure to Hot Environments (NIOSH, 1972)
- "Recommendations for a Standard for Work in Hot Environments" (OSHA, 1974)
- Threshold Limit Values for Physical Agents (TLV) (ACGIH, 1977).

Each document refers to Wet Bulb-Globe Temperature (WBGT) as the index used for measuring the environmental factors that influence the dissipation of body heat. However, the documents vary in their use of other factors such as workload, work-rest regimen, air velocity, employee training and monitoring.

Report 11 - Soil Effects and Land-Use Planning. Soil contamination may occur during geothermal development and operation from both inadvertent and intentional release of geothermal fluids. Leaching and runoff from improperly stored wastes may also contribute to soil contamination. Inadvertent releases of geothermal fluids occur when wells blow out, pipes fail, or reinjection wells unexpectedly communicate with surface strata.

This report is divided into four main sections. The first discusses the potential for soil erosion and contamination during various phases of geothermal development. The second discusses land-use planning, with emphasis on the incorporation of environmental constraints and standards into the formulation of land-use policy. The third section presents an exhaustive compilation of the standards and regulations presently applicable to geothermal development. In the fourth section, criteria and standards that should be developed are discussed.

REFERENCES

ACGIH, 1977. The American Conference of Governmental Industrial Hygienists, Threshold Limit Values for Chemical Substances and Physical Agents in the Workroom Environment with Intended Changes for 1977, pp 58-65. Cincinnati, Ohio.

NIOSH, 1972. National Institute of Occupational Safety and Health, "Criteria for a Recommended Standard." Occupational Exposure to Hot Environments, U. S. Department of Health and Welfare, Health Services and Mental Health Administration, Washington DC.

OSHA, 1974. "Recommendations for a Standard for Work in Hot Environments" proposed by the OSHA Standards Advisory Committee on Heat Stress. Draft V.

4.0 Human Health Studies

HUMAN HEALTH STUDIES

- **Statistical Health Effects**
- **Urinary Excretion of Metals and DTPA Salts**
- **Radioisotope Customer List**

A program of accumulation of data on the mortality of workers at the Hanford plant has been in progress for 14 years. Since 1975, this epidemiologic data set has been analyzed here by statistical procedures alternative to those used by other investigators. The PNL analyses indicated that the general health of Hanford employees is favorable with respect to cancer generally and to other diseases. The study disclosed possibilities that warrant additional follow-up in two cancer types. The Hanford Environmental Health Foundation is associated with PNL in this continuing study.

PNL is currently analyzing urine samples from a person accidentally exposed to americium-241 and treated with Ca and Zn DTPA. These analyses will provide useful information concerning the influence of these salts of DTPA on the excretion of trace metals during therapy. This information has important implications for the long-term use of DTPA in the decorporation of deposited radionuclides.

• Statistical Health Effects Study

A major part of our current work is a study of Hanford employee mortality, with particular attention to the effects of exposure to ionizing radiation. Our broader objective is the development of improved methodology for assessing health effects of chronic low-level exposure to harmful agents or substances. During the past year, a computer program that permits a more refined analysis of the relationship of exposure level to mortality was developed. Results of our analyses of the Hanford data were presented to a variety of groups. The year has also included research on the problems of quantifying risks.

Statistical Health Effect Studies to Assess the Influence of Low-Level Exposure to Environmental Contaminants

E. S. Gilbert

The overall purpose of this project is to develop and evaluate methods for assessing health effects of chronic low-level exposure to environmental agents, particularly ionizing radiation. A more specific objective is the analysis of mortality and exposure data for Hanford workers. This activity includes the development of appropriate methodology for the analysis of this data set and critical evaluation of other analyses of these data.

During the past year, the Hanford Environmental Health Foundation (HEHF) assumed responsibility for management of the Hanford mortality study; they will also collect the data that they have generated for this study in the past. PNL has participated in the planning of further data collection and processing by HEHF. At present, the study is closely coordinated between HEHF and PNL.

A computer program that has been completed uses exact doses at yearly intervals and also allows for more complete control of variables such as occupation, employment cohort, and length of employment. Use of this more refined analysis resulted in no substantial change in the conclusions reached earlier. However, the revised analysis is easier to understand and will allow considerably more flexibility in the analysis of future data.

In our latest analysis, an absence of positive correlation was obtained for all deaths, all malignant neoplasms and cancer types other than multiple myeloma and cancer of the pancreas. The statistically significant correlation we observed previously for the latter two cancer types was corroborated. A description of this analysis and its results were presented at the SIAM (Society for Industrial and Applied Mathematics) Institute for Mathematics and Society (SIMS) Conference on Energy and Health, June 26-30, 1978. This presentation also included a discussion of the problems of quantitating risks in occupational populations.

The alternative analysis of this data set by Mancuso, Stewart and Kneale continued to receive considerable scientific and public interest. The claim of those investigators that the number of radiation-induced cancers among the Hanford workers far exceeds that expected on the basis of current estimates of radiation effects is in conflict with the results of our analysis and the analyses of others. Sidney Marks and Ethel Gilbert presented testimony on this subject to the U.S. House of Representatives Subcommittee on Health and the Environment of the Committee on Interstate and Foreign Commerce, in February 1978. Dr. Gilbert also testified at the hearing of the Oregon Energy Facility Siting Council (September 1978) on siting of the proposed Pebble Springs nuclear power reactors.

• Urinary Excretion of Metals and DTPA

Analyses are being conducted on urine samples from a person accidentally contaminated with ^{241}Am and treated intravenously with DTPA salts to promote the americium's excretion. Assays for essential body metals and DTPA species are of particular concern. Only a small fraction of the assays have been completed as yet, but the final results should be very useful to physicians in improving the effectiveness of DTPA therapy for persons contaminated with radionuclides.

Urine Analysis for Heavy Metals and DTPA Salts

D. R. Kalkwarf, V. W. Thomas,
K. K. Nielson, V. H. Smith

The purpose of this project is to determine the urinary excretion of essential body metals and diethylenetriaminepentaacetic acid (DTPA) salts by a person who was accidentally contaminated with approximately 5 mCi of ^{241}Am and is being treated intravenously with large quantities of calcium- and zinc-DTPA to hasten its removal. The results should indicate: (1) the possibility of essential metal depletion by DTPA therapy, (2) the effectiveness of oral zinc supplements to inhibit this depletion, and (3) the relationship between the amounts and forms of DTPA salts excreted in urine to those administered intravenously. This information is needed to guide physicians in regulating the dosage of DTPA salts during treatment of patients contaminated with radionuclides and to judge the adequacy of animal models for predicting the effects of DTPA salts on man.

Approximately 600 urine samples have been collected since the patient's treatment was begun; these have now been assembled from various storage locations and inventoried. Most of the samples were stored in the frozen state, and these are being analyzed both for metals and DTPA salts. Samples stored at room temperature are being analyzed only for metals since DTPA has been found to degrade by microbial action at room temperature.

Metal analysis has consisted of melting and homogenizing the urine samples, evaporating an aliquot to dryness, weighing the residue, sealing it in a plastic bag mounted in a 35-mm slide mount, and evaluating the metal content by energy-dispersive x-ray fluorescence (XRF) analysis. Initial results indicate that the samples can be assayed adequately for the following elements (those considered essential for normal metabolism are underlined):

Na	P	S	Cl	K	Ca
Ti	Cr	Mn	Fe	Co	Ni
Cu	Zn	As	Se	Br	Rb
Sr	Pb.				

Prior to evaporation, the urine samples are also being assayed for H^+, F^-, Na^+ and Cl^- with selective-ion electrodes in order to cross-check the XRF data and to provide supplementary information. Approximately 130 samples have been prepared to date for XRF analysis; however, only seven have been completely analyzed. These indicate a high zinc excretion while Ca-DTPA was used and a high excretion of lead. Depletion of other metals has not been distinguished within the few samples analyzed as yet.

A new method was developed to assay for total DTPA species in urine. The method consists of adding ^{55}Fe to displace other metals bound to DTPA in the sample, concentrating the ^{55}Fe-DTPA complex by paper chromatography, and counting the ^{55}Fe positions in a liquid scintillation system. When applied to DTPA-spiked urine samples, the method was found to detect as little as 10^{-5} moles of DTPA per ℓ. This sensitivity has been found adequate to measure DTPA concentrations in the patient's urine samples examined thus far, provided the samples were kept frozen prior to analysis.

• Radioisotope Customer List

L. C. Counts

The purpose of this program is to prepare and distribute the annual document entitled List of ERDA Radioisotope Customers with Summary of Radioisotope Shipments. This document lists the FY-1978 commercial radioisotope production and distribution activities of ERDA (now the Department of Energy) facilities at Argonne National Laboratory, Pacific Northwest Laboratory, Brookhaven National Laboratory, Hanford Engineering Development Laboratory, Idaho Operations Office, Los Alamos Scientific Laboratory, Mound Laboratory, Oak Ridge National Laboratory, Savannah River Plant, and United Nuclear Industries, Inc. The report was distributed in July 1978.

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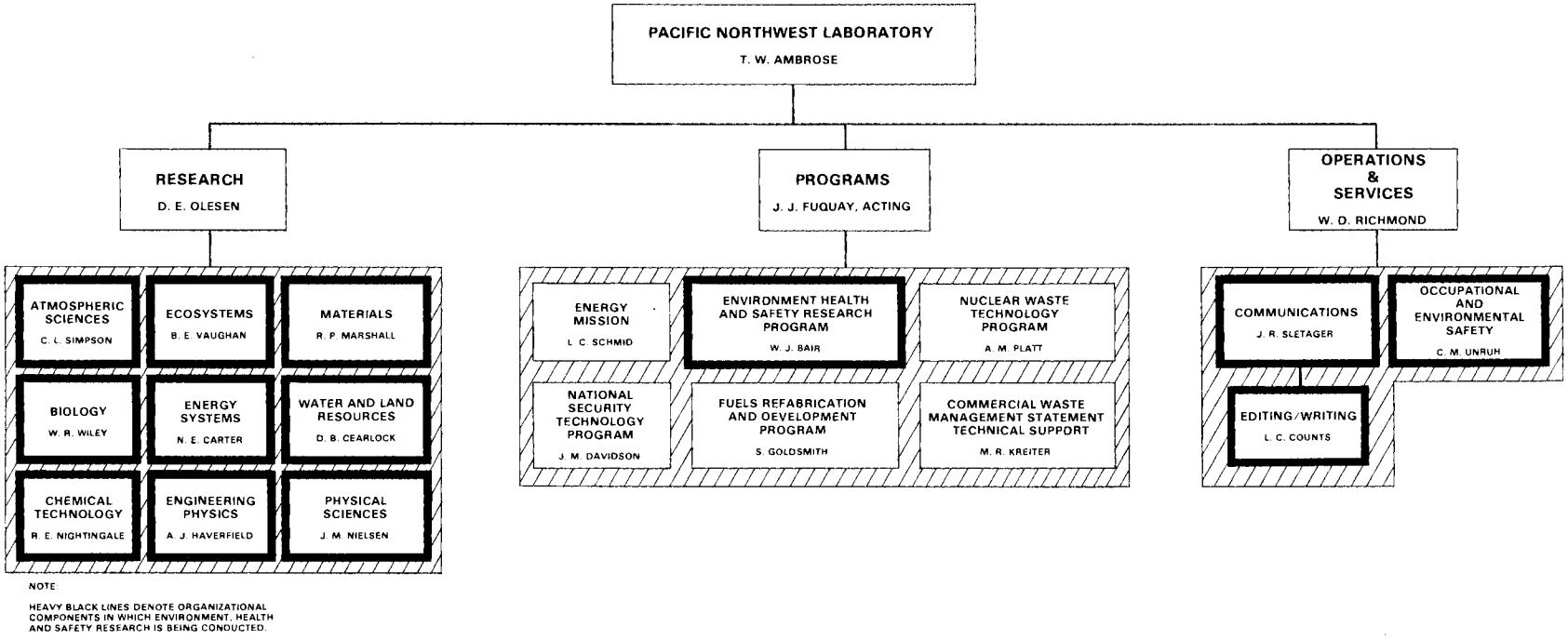

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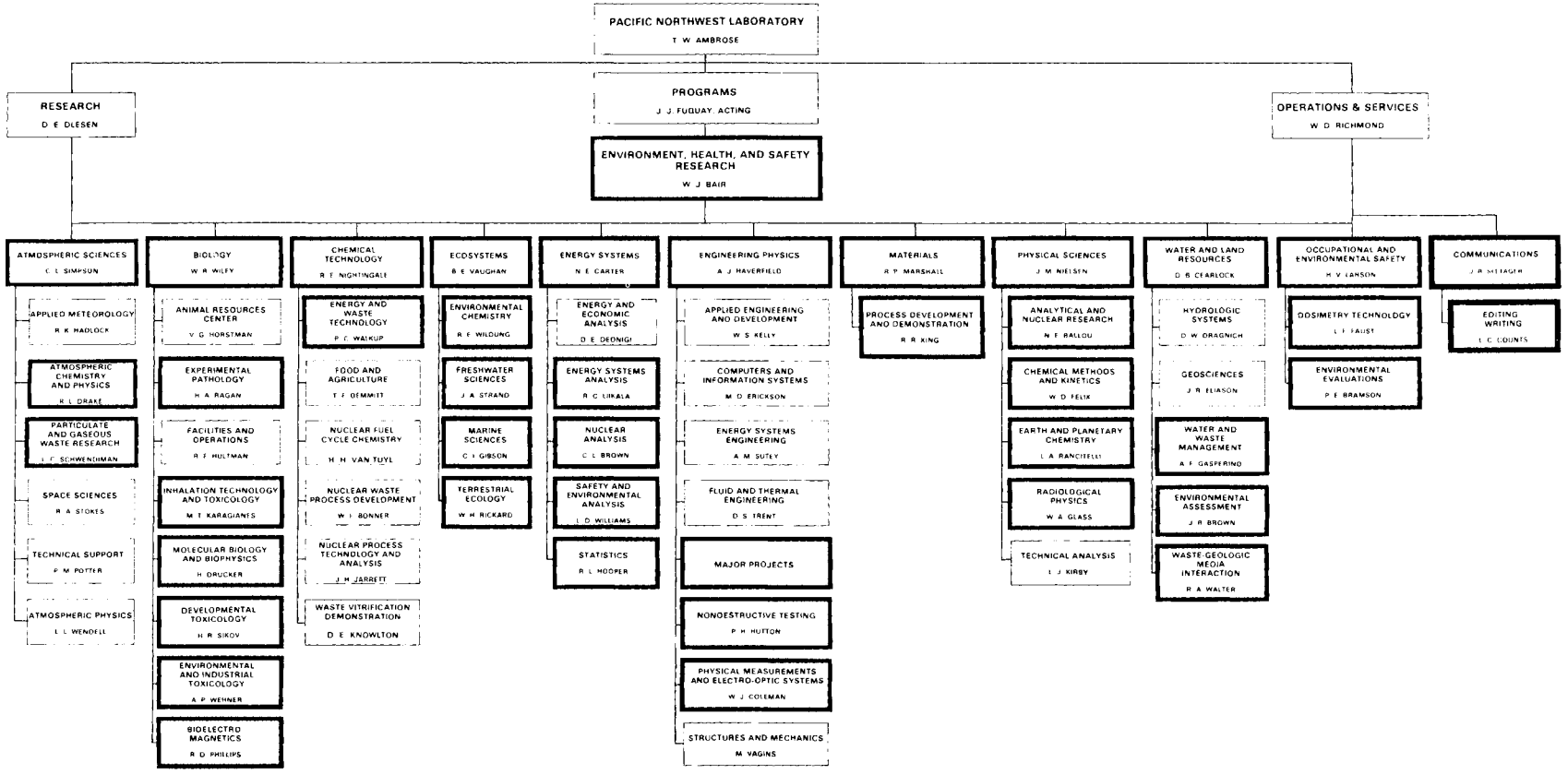

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