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Pacific Northwest Laboratory Annual Report for 1980 to the DOE Assistant Secretary for Environment

Part 5 Environmental Assessment, Control, Health and Safety February 1981

Prepared for the U.S. Department of Energy
under Contract DE-AC06-76RLO 1830

Pacific Northwest Laboratory
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Part 5 Environmental Assessment, Control, Health and Safety

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

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Pacific Northwest Laboratory
Richland, Washington 99352

PREFACE

Pacific Northwest Laboratory's (PNL) 1980 Annual Report to the Department of Energy (DOE) Assistant Secretary for Environment describes research in environment, health, and safety conducted during fiscal year 1980. The report again consists of five parts, each in a separate volume.

The five parts of the report are oriented to particular segments of our program. Parts 1 to 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 Environmental Assessment 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 to 4 are organized primarily by energy technology.

The parts of the 1980 Annual Report are:

Part 1:	Biomedical Sciences Program Manager - H. Drucker	D. L. Felton, Editor
Part 2:	Ecological Sciences Program Manager - B. E. Vaughan	B. E. Vaughan, Report Coordinator C. M. Novich, Editor
Part 3:	Atmospheric Sciences Program Manager - C. E. Elderkin	R. L. Drake, Report Coordinator M. F. Johnson, Editor
Part 4:	Physical Sciences Program Manager - J. M. Nielsen	J. M. Nielsen, Report Coordinator I. D. Hays, J. L. Baer, Editors
Part 5:	Environmental Assessment, Control, Health and Safety Program Managers - D. L. Hessel S. Marks W. A .Glass	W. J. Bair, Report Coordinator R. W. Baalman, I. D. Hays, Editors

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 Ray Baalman and Irene D. Hays, editors 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

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1954	HW-30306, HW-33128, HW-35905, HW-35917
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1964	BNWL-122
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1977	PNL-2500, Pt. 1-5
1978	PNL-2850, Pt. 1-5
1979	PNL-3300, Pt. 1-5

FOREWORD

Part 5 of the 1980 Annual Report to the Department of Energy Assistant Secretary for the Environment presents Pacific Northwest Laboratory's progress on work performed for the Office of Environmental Assessment and the Office of Environmental Compliance and Overview. Included also are 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 and Safety Engineering, Operational and Environmental Safety, and Human Health Studies.

In each section, articles describe progress made during FY 1980 on individual projects, as identified by the Work Package Proposal and Authorization System. Authors of these articles represent a broad spectrum of capabilities derived from various segments of the laboratory, reflecting the interdisciplinary nature of the work.

For additional information on any of the projects reported in Part 5, contact the authors of the articles.

CONTENTS

1 Technology Impacts

TECHNOLOGY IMPACTS

- **Regulatory Analysis**
- **Technology Assessment**
- **Regional Impacts**

The integrated technology overview program funded by the Department of Energy Office of Environmental Assessment, 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 combined information about the potential effects of alternative energy technologies (such as waste releases, land and water use, and social effects) and about constraints on the development and use of these technologies 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 Environmental Assessment is organized around three divisions: Regulatory Analysis, Technology Assessment, and Regional Impacts. The program at the Pacific Northwest Laboratory (PNL) is similarly divided.

Projects conducted for the Division of Regulatory Analysis are typically aimed at reviews of specific policy actions outside of DOE that 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 Regional 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. This component of the division 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.

• Regulatory Analysis

Pacific Northwest Laboratory supported the Regulatory Analysis Division in the review of some proposed radiation protection regulations. However, the principal effort conducted under this part of the program concerned transuranics in the environment on Bikini Atoll in the Marshall Islands.

Regulatory Analysis--Bikini Atoll

W. J. Bair, J. W. Healy[a],
B. W. Wachholz[b]

The purpose of this project was to write a booklet to support a Department of Energy (DOE) presentation to the people of Bikini Atoll in the Marshall Islands. The document, The Meaning of Radiation at Bikini Atoll, authored by W. J. Bair, J. W. Healy, and B. W. Wachholz (1980), describes the current radiological conditions resulting from the nuclear weapons tests conducted on Bikini Atoll between 1948 and 1958. The booklet summarizes Lawrence Livermore Laboratory's dose assessments for various living conditions at Bikini Atoll and discusses the possible health risks the people might face should they decide to return to live on the Atoll. It also explains why the people were allowed to return to Bikini in 1968 and were subsequently asked to leave.

This dual-language booklet was drafted in English and translated into Marshallese using a dynamic-equivalent translation method. The English text is a modified literal translation of the Marshallese by A. Buck, M. Jelke, and K. Sam from the Marshall Islands. H. E. Krueger, with assistance from P. A. Anderson, created special graphics and R. W. Baalman edited the booklet.

(a) Los Alamos Scientific Laboratory
(b) Department of Energy

Reference

Bair, W. J., J. W. Healy, and B. W. Wachholz. 1980. Melelen Radiation Ilo Ailin in Bikini: The Meaning of Radiation at Bikini Atoll. U.S. Department of Energy, Washington, D.C.

• Technology Assessment

Work in Technology Assessment considered a variety of energy technologies. Some of this work was directed toward the preparation or revision of brief Environmental Development Plans and Environmental Readiness Documents. Other work focused on major technology assessments. The products of both types of effort are used by the Assistant Secretary for Environment for adopting a position on further development and application of respective energy technologies, and on other energy policy matters.

Environmental Development Plans and Environmental Readiness Documents

D. L. Hessel, D. A. Dingee, D. W. Felix, F. P. Hungate, P. J. Mellinger

Environmental Development Plans (EDPs) are prepared by the Technology Assessment Division in the Office of the Assistant Secretary for Environment jointly with appropriate energy technology divisions. The objective of this part of the Technology Assessment program is to prepare and, as necessary, revise EDPs for technologies of interest. The EDP provides a mechanism to identify areas of potential environmental concern, to evaluate the current status of the environmental studies relevant to the respective technologies, and to identify research programs needed in areas not receiving adequate attention in current studies. The EDPs include compilations of known pertinent research programs with summaries of the results of these efforts, as appropriate. They also identify areas where further research and development programs are required.

Environmental Readiness Documents (ERDs) are prepared by the Technology Assessment Division as statements of the Assistant Secretary for Environment's evaluation of the prospects for the respective technologies. EDPs and ERDs are updated every year or two to keep them abreast of changes in the status of the technologies and of knowledge about the potential effects of these technologies.

During FY 1980, PNL contributed to the formulation of two EDPs. One concerned coal liquefaction; the other dealt with coal gasification. The initial versions of these EDPs were published by the Department of Energy (DOE) in 1978 (DOE 1978). During FY 1980, information contained in those EDPs was updated, concerns and requirements were reevaluated and modified, and schedules for technology development were adjusted (DOE 1980). Information on the environmental consequences of liquefaction and gasification is becoming available at an accelerated rate from studies sponsored by the DOE, the Environmental Protection Agency (EPA), and National Institute of Occupational Safety and Health (NIOSH) in this country and from similar studies in other countries. Consequently, it is important that information from such studies be compiled and analyzed continually.

In cooperation with the Teknekron Corporation, PNL completed a draft of the magnetic fusion Environmental Readiness Document (ERD). The ERD identified the key physical environmental impact areas, and evaluated the technical capabilities of the research and development to meet the needs of the fusion program in these areas. The ERD also looked broadly at the fusion development program to find "show-stoppers," areas where the impact could be very great or the level of knowledge about it is too low to permit the program to continue.

It is apparent from the work conducted on the ERD that there are no environmental/health concerns that are predicted to constitute serious obstacles to the continued development of fusion energy. Clearly there is a need for continuing development of control technologies to enable adequate control of radiation/toxic materials and assure that workers and the public will not be excessively exposed. Likewise there will need to be a refinement of the knowledge about the biological and environmental behavior of specific materials so that accidents, decontamination/decommissioning, and waste disposal problems can be properly handled.

Newly identified alternatives for fuel breeding show promise in reducing the potential for serious accidents and in minimizing the consequences if they occur. Possible adverse public perceptions were identified as a potential serious problem. It is notable that a current PNL study identifies high technology and material commitment as the most likely areas for adverse public reaction. The ERD also recommends early development of policy for anticipating the large demand for helium in the 21st century.

Finally, PNL also completed a draft of an ERD on Advanced Isotope Separation (AIS) technology for enriching uranium. This ERD evaluates the readiness of the AIS technology to proceed from the technology development phase to the engineering development phase and ultimately to commericialization/production. The transition is keyed to the selection of a single separation process and initiation of design effort on the Demonstration Module (DM) for the selected process.

In FY 1980, PNL contributed to the assessment of the state of knowledge about identified environmental health and safety (E/H/S) concerns and estimated the technical readiness, timing, and costs to achieve acceptable knowledge in the areas of concern. The environmental concerns covered deal with proliferation, safeguards, radiological exposure, hazardous chemical usage and handling, magnetic and electromagnetic field effects, laser radiation exposure, accident analysis, waste management, transportation, socioeconomic impacts, and dismantling and decontamination. The focus of the ERD is on near-term decisions, but it recognizes the longer-term deployment of the technology.

In addition to E/H/S concerns, the ERD examines the capabilities of the industry to control the expected environmetal effluents from the AIS technologies. Areas of additional research are identified and cost ranges predicted.

References

U.S. Department of Energy (DOE). 1978. "Environmental Development Plan: Coal Liquefaction, FY 1977." DOE/EDP-0012, Washington, D.C.

U.S. Department of Energy (DOE). 1980. "Environmental Development Plan: Coal Liquefaction." DOE/EDP-0044, Washington, D.C.

Technology Assessment of Enhanced Oil Recovery

E. F. Riedel

Enhanced oil recovery (EOR), sometimes referred to as tertiary oil recovery, is one of the energy technologies that offers promise in the near term of helping the United States decrease its dependency on foreign oil. It has been estimated that as much as two million bbl/day of tertiary oil could be produced by the year 2000. This quantity represents about 25% of all current domestic production.

Enhanced oil recovery includes most processes that inject fluids, other than natural gas and brine, into a reservoir. Large quantities of petroleum (as much as 95% for heavy crudes to 30% for a light crude reservoir) frequently remain in a reservoir following primary and secondary production. These large amounts of remaining oil are the target of EOR.

EOR processes include miscible fluid injection, chemical flooding, and thermal methods. Thermal processes include in-situ combustion, cyclic steam injection, and steam drive. Miscible fluid injection is usually carbon dioxide flooding, although liquified petroleum gas (LPG) and other fluids that are miscible with crude oils have been used. Chemical flooding is the injection of certain complex fluids to recover oil. Among the most popular methods are polymer flooding, caustic flooding, and miscellar-polymer flooding.

The objective of this program is to evaluate the environmental risks and consequences of projected EOR activities in the near and long term. Equal emphasis is being given to all primary EOR activities. Results will be used by the Department of Energy to evaluate the overall risk/consequences from the commercialization of EOR.

This is a multilaboratory project involving Pacific Northwest Laboratory (PNL), Lawrence Berkeley Laboratory (LBL), and Brookhaven National Laboratory (BNL). PNL's primary responsibility is to provide technical information on oil-field practices and operations that are associated with EOR. In FY 1980, the primary focus of this project has been to identify and evaluate potential environmental concerns associated with EOR technologies. A three-day workshop titled, "ENHANCED OIL RECOVERY WORKSHOP: Problems, Scenarios and Risks," was held to receive a wide range of input in these areas. In addition to participating in the workshop, PNL staff prepared a projection of the use of enhanced oil recovery techniques to the year 2000.

Technology Assessment of the Environmental, Health, and Safety Issues Associated With the Commercialization of Unconventional Gas Recovery

E. F. Riedel

Efforts to find more natural gas have intensified over the past decade. As the more conventional geologic resources are being depleted, other more unconventional geologic sources are receiving more attention. However, before these newer more unconventional resources can add significantly to our nation's supply of natural gas, the public health and safety, environmental, economic, and legal/political consequences and constraints that might be associated with these resources and technologies must be examined. This assessment focuses on potential public health and safety problems, potential environmental impacts, legal/institutional constraints, and other potential barriers to commercialization.

The objective of this project is to identify all barriers to the commercialization of unconventional gas recovery (UGR). This study is evaluating the commercialization of four resources:

- western tight-gas sands
- methane associated with coal seams
- eastern Devonian-age shales
- methane contained in geopressured aquifers.

Results will be used by the Department of Energy for ranking the commercialization effort for the development of these resources.

In FY 1980, Pacific Northwest Laboratory (PNL) studied primarily the resources of western tight-gas sands, methane associated with coal seams, and eastern Devonian-age shales. Lawrence Berkeley Laboratory is preparing the analysis for methane contained in geopressured aquifers. Final reports were published for both of the first two resources during FY 1980 (Riedel, Cowan, McLaughlin 1980; Riedel, Ethridge, Cowan 1980).

Technology Assessment of Oil Shale

D. L. Hessel

Oil shale is a resource of great potential significance to the United States. The major oil-shale deposit in the country, the Green River Formation of Colorado, Wyoming, and Utah, contains the equivalent of two trillion bbl of oil. That portion of the resource with greatest economic potential, averaging 25 or more gal/ton of rock, contains the equivalent of some 600 billion bbl. By comparison, the U.S. domestic petroleum reserves were estimated at about 30 billion bbl in January 1978. However, the shale oil potential is tempered by physical limitations on the rate of production, long technical development lead time, and high costs.

No shale oil production method has been demonstrated beyond the scale of 1000 bbl/day. Numerous uncertainties exist about the physical and economic suitability for development of the current processes to commercial-sized plants of 10,000 to 50,000 bbl/day. As with other energy technologies based on fossil fuels, shale oil production and use pose controversial questions about possible undesirable effects on the natural environment, agriculture, and human health and safety.

The oil-shale assessment described here was undertaken:

1. to provide a comprehensive, objective review of shale oil technologies as a means of supplying domestically produced fuels within acceptable limits for environmental, social, economic, and legal/institutional impacts;
2. to examine the major points of uncertainty regarding potential impacts in light of all reasonably available data, analyses, and experienced judgment;
3. to resolve issues when data and analyses are compelling or where conclusions can be reached on judgmental grounds; and

4. to specify issues that cannot be resolved using only the data, analyses, and experienced judgment currently available.

Since most of the rich oil shale lies in northwestern Colorado, northeastern Utah, and southwestern Wyoming, this assessment is focused on development of the resource in that area. A variety of aboveground and modified in-situ retorting processes are incorporated into a hypothetical, but realistic, technological mix as a basis for analysis. This mix is designed to produce 300,000 bbl/day when fully implemented, assumed to be about 1990 or 1995. Rigorous consideration of these technologies at this scale will result in recognition of most of the potential significant impacts of a mature shale oil production industry. The assessment considers these impacts in the categories of effects on media (air, surface water, ground water, and land); ecosystems and agriculture; human health and safety (primarily occupational); social and economic systems; and legal/institutional systems.

The assessment is being conducted by an interdisciplinary team of scientists and recognized oil-shale authorities. These individuals are drawn from Pacific Northwest Laboratory, universities, consulting firms, and several other national Department of Energy laboratories.

Technology Assessment of In-Situ Uranium Mining

C. E. Cowan

In recent years, in-situ mining has emerged as a viable method for recovery of uranium from sandstone ore bodies. Since the licensing of the first commercial facility in Texas in 1975, the industry has grown to 17 commercial facilities and numerous pilot facilities in four states. Because of the technology's low capital and operational costs, persons familiar with the technology expect to see more growth in numbers of commercial facilities and in geographic locations in the next few years. There are predictions that in-situ mining will account for over 10% of the domestic yellowcake production in the near future. In those areas where the in-situ uranium mining technology is applicable, it is receiving considerable attention by industry, regulators, and interest groups.

The objectives of PNL's portion of the Technology Assessment were to:

- describe the current in-situ uranium mining technology
- describe the physical, ecological, institutional, and socioeconomic environment within which the technology exists
- evaluate, based on available data, the potential environmental impacts and, in a limited fashion, health effects
- explore the impediments to development and deployment of the in-situ uranium mining technology.

The results will be used as a source document for the Technology Assessment.

This study, which is reported in PNL-3439, indicates that, based on available information, demonstrated negative environmental impacts appear to be minor. The impacts compare favorably with those expected from conventional uranium mining technologies. Exposure to radioactive elements, atmospheric emissions of radiological and nonradiological materials, and negative socioeconomic impacts are less for in-situ than for conventional mining. In fact, because of the small and unskilled labor force associated with in-situ uranium mining, development has provided much needed economic stimulus to economically depressed areas of Texas. There are still, however, several areas with unknown or inadequate data that will need to be addressed before a complete quantitative evaluation of the impacts can be done. In addition, there are several issues mostly relating to the interaction of the in-situ mining industry with state and Federal regulators, that need to be addressed. Research and monitoring programs are under way to evaluate the unknowns, and increased emphasis is being placed on ways to encourage effective communications between regulators and industry representatives, thus facilitating the evolution of strategies for dealing with institutional impediments.

This technology assessment was started in April 1979; in FY 1980 PNL completed the source material collection and reporting. In FY 1981, the Department of Energy (DOE) will complete and publish its report.

Technology Assessment of Magnetic Fusion Energy

R. M. Scheer, D. A. Dingee

Because the overall fusion program represents such a considerable effort by the Federal government, and because numerous major decisions about the technology will have to be made over the coming decades until fusion is a commercial energy technology, it is essential that the Department of Energy (DOE) be thoroughly prepared to address the various intended and unintended environmental and social impacts that could result from the utilization of fusion energy.

The objectives of this study are:

- to identify and analyze the consequences of the development and utilization of fusion technology
- to identify and analyze the potential for society to affect the fusion development and utilization of fusion
- to identify strategy alternatives and technology choices related to potential fusion technology impacts
- to identify decision points where environmental, health, safety, and societal impacts can be controlled.

The Magnetic Fusion Technology Assessment has been a joint effort between Pacific Northwest Laboratory (PNL) and The Futures Group, Inc. PNL's major effort has been to develop a Technology Delivery System (TDS) which describes the fusion technology and parties at interest in the introduction of fusion. The Futures Group is developing State of Society (SOS) parameters which establish the range of attitudes, institutions, beliefs, and conditions of society at the time when fusion is a significant portion of the energy generation system of the United States.

A mutually consistent set of TDS and SOS assumptions has been used to formulate a base-case description of fusion and society. This base-case description was completed in FY 1980. It will be applied to evaluate possible physical and societal impacts of fusion. Following this an analysis of the sensitivity of the impacts to variation in base-case assumptions will be completed. The sensitivity analysis will be used to identify key areas for policy discussions; these key areas will be related to fusion development plans to define the timing for these policy discussions.

Expert review and guidance are essential for a study of this kind which implicitly considers a long-time horizon and a wide spectrum of impacts. A workshop was conducted in September 1980 to review and critique the TDS and SOS framework, to review and critique the internal consistency of the base case, and to identify key impacts for the project team to analyze during the second year of the study. Workshop participants were selected according to three broad categories: 1) fusion power plant design engineers, 2) social and environmental scientists, and 3) potential users of fusion power from electric utilities and private vendors.

Technology Assessment of Uranium Enrichment

P.J. Mellinger

Additional nuclear fuel is retrievable by recovering uranium (U-235) from uranium fluoride (UF_6) tails. This potential, along with the development of a more cost-effective method for enriching yellowcake (U_3O_8) directly to fuel grade material, has led to the establishment of the Advanced Isotope Separation (AIS) program in the Department of Energy. The goals of the AIS program are to develop environmentally acceptable technologies that will 1) provide the means to recover U-235 from the depleted tails of the current gaseous diffusion and planned gas centrifuge uranium enrichment plants and 2) achieve primary enrichment directly from uranium oxide (U_3O_8) to reactor-grade material. Three candidate AIS processes have been identified that may meet these objectives. Two use lasers and one uses supermagnetic plasmas. These candidate processes are currently in the applied research stage.

The uranium enrichment technology assessment (TA) was started late in FY 1979. It is examining the potential environmental, health, and safety considerations of the conversion (head end), reconversion (back end), and tails utilization alternatives surrounding candidate AIS processes. This TA will be used in the FY-1982 selection of one of the AIS technologies for further evaluation in an Engineering Demonstration Facility. The production plant is scheduled for construction beginning in 1989 and operation in 1995.

Progress during FY 1980 includes technology descriptions of each alternative AIS technology and the gaseous diffusion process used as the base case technology. These descriptions include the identification of essential materials for use in the processes, in-plant mass balances, and the identification of environmental releases. Preliminary institutional analysis data have been collected.

Technology Assessment of Solar Energy

E. Edelson, K. J. Allwine, Jr., W. J. Hopp, A. D. Chockie

Pacific Northwest Laboratory (PNL) is one of six national laboratories involved in the multiyear assessment of the national, regional, and subregional environmental and socioeconomic impacts resulting from maximum practical use of solar technologies in the year 2000. The project has examined two solar scenarios for the year 2000 to compare the benefits of a high level of application of solar technologies versus a low level.

A presidential domestic policy review has determined that under "business as usual" conditions deployment of 6.0 quadrillion Btu of solar energy would occur by the year 2000. The review concluded that the maximum practical level of solar energy by the year 2000 is 14.2 quadrillion Btu. To quantify the benefits and negative effects of a high level of solar deployment, scenarios based on these national projections were disaggregated into state and county levels using the Strategic Environmental Assessment System (SEAS). The SEAS was programmed to quantify the differences in environmental impacts between the high and low solar scenarios.

PNL was responsible for analyzing air quality impacts from changes in particulate emissions using an existing long-range transport model. Figure 1.1 illustrates the difference in particulate concentrations between the high and low solar scenarios in the year 2000 as estimated through PNL's analysis. The degradation in air quality shown is largely due to the increased use of biomass technologies. Biomass-burning installations, such as woodstoves and agricultural residue combustion systems, were judged too small and dispersed to utilize pollution control technologies. They produce more particulate emissions than the coal and nuclear plants they displace.

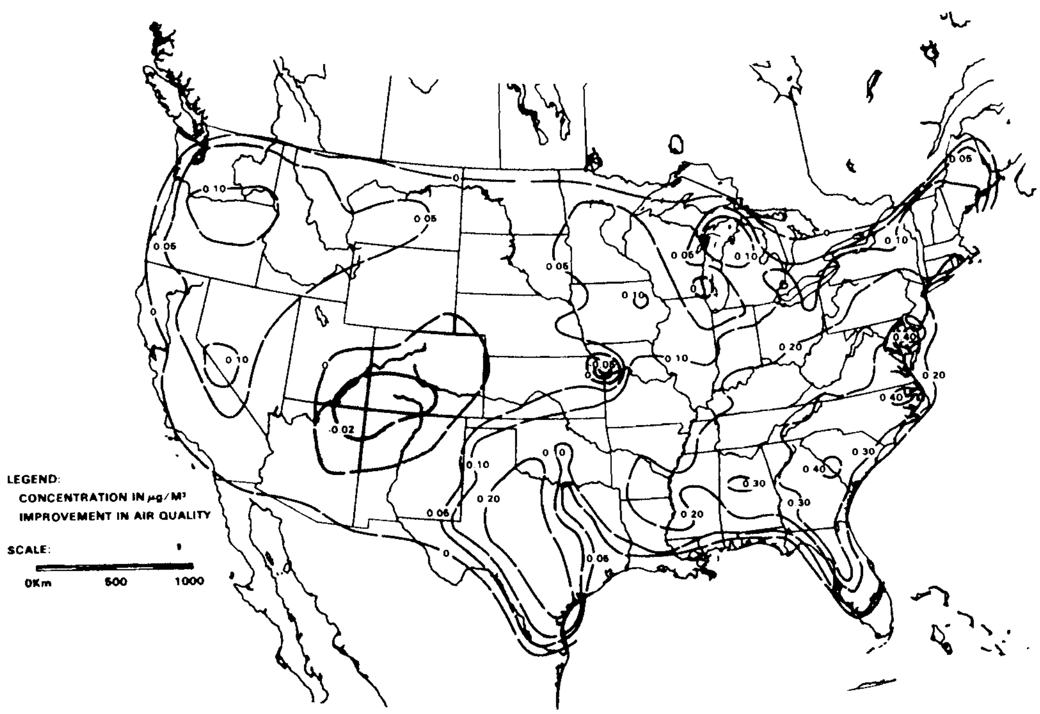

Figure 1.1. Primary Fine Particulate Concentration ($\mu g/m^3$) in the Year 2000, High Solar Minus Low Solar Using January 1974 Meteorology

Because the impacts associated with the biomass technologies were judged to be considerably more severe than those of the other, relatively benign solar technologies, the solar assessment will concentrate on an assessment of biomass energy in FY 1981. Also, the assessment will examine a third solar scenario based on the most recent domestic policy review estimate of 20% solar energy out of a total energy supply of 95 quadrillion Btu in the year 2000.

Industrial Energy Utilization: Aluminum

A. L. Kretz

Electrical power represents one of the most important costs for aluminum smelting. The large projected increases in Northwest power costs and power interruptions will, therefore, have a major impact on the Northwest aluminum industry. Without some form of regional planning, it is evident that the aluminum industry will have to purchase large amounts of expensive surplus power from outside the region. The result could be substantial adverse effects for the region and the industry.

The Pacific Northwest Regional Power Act, enacted in late November 1980, represents one form of regional planning that will affect the regional power situation. This Act provides the aluminum industry with guaranteed amounts of firm power at costs the industry believes it will be able to pay. The industry still will be subject to power interruptions, but it will receive a credit for these interruptions. The industry's ability to accept interruptible power supplies helps to smooth the demand in the region, increasing the efficiency of power production and lowering power costs.

The primary objective of this assessment has been to study the effects passage of the Pacific Northwest Regional Power Act would have on the aluminum industry. Our analysis consisted of three parts:

- Task 1 identified the major issues in the Regional Power Bill as they relate to the aluminum industry in the Northwest.

- Task 2 analyzed the specific potential impacts of the bill on the industry. Specifically considered were the effects on the incentive to retrofit existing plants to conserve energy, the possibility of plant shutdown, and the overall effect of the bill on costs of aluminun production.

- Task 3 looked at other regional implications of the power situation including the supply curve of aluminum and environmental loadings.

Our overall approach consisted of modeling the aluminum smelting process and analyzing the factors giving rise to cross-plant variations in electrical energy use. The information came from secondary sources, consultations with process engineers, and plant visits. Data on environmental emissions were collected from state sources. Alternatives to industrial location in the Northwest for the smelting and aluminum producing processes were analyzed. Future electrical power costs were projected from Bonneville Power Administration (BPA) sources. Consideration was also given to the costs imposed on the industry by its practice of taking interruptible power, and the extra costs imposed under the Northwest Power Bill. The benefits and costs to the region were analyzed from the perspective of using the industry as a power reserve. This part of the analysis was especially important as the interruptible power rate-design was encouraged by the Public Utility Regulatory Policy Act of 1979. The subject of interruptible power is also important for understanding industry location behavior.

• Regional Impacts

The principal work conducted by Pacific Northwest Laboratory for the Regional Assessment Division in FY 1980 was analysis of the consequences from and constraints applicable to the possible use of a specified mix of energy technologies in Federal Region X (Alaska, Washington, Oregon, and Idaho). The mix of technologies considered was reflective of the National Energy Plan II as that plan was proposed by the President of the United States. This analysis was conducted in cooperation with other national laboratories, each of which focused on one or more of the other Federal Regions. The aggregate national analysis comprised the Regional Issues Identification and Assessment Program. PNL also worked on improvements in the use of models of long-range transport of air pollutants from the application of energy technologies.

Interregional Transfer Matrices for Atmospheric Pollutants

W. J. Eadie, W. E. Davis, R. L. Drake

In assessing environmental impacts to be expected from implementation of various energy policies, it is necessary to evaluate the effects of changes in pollutant emissions on air quality in many places. Pacific Northwest Laboratory (PNL) has approached this problem by preparing interregional transfer matrices. The matrices allow the concentrations of pollutants coming from several sources at different distances from a point of interest to be added together to produce an estimate of air quality at that point. In this project, matrices were developed to describe air quality impacts of sulfur pollutants over the 238 Air Quality Control Regions (AQCRs) of the continental United States. The matrices can be used to evaluate a variety of emission scenarios according to the National Energy Plan.

This study concentrated on the airborne transport, diffusion, transformation, and removal of SO_2 and SO_4 from point emission sources. All SO_2 emission sources in a given AQCR were assumed to be located at the centroid of the AQCR. Using the PNL long-range transport model, SO_2 and SO_4 monthly average air concentrations were computed for each cell of a 32-km resolution grid spanning the United States and adjacent areas. These monthly average air concentrations were then averaged over the AQCRs with a population weighting. In this manner, AQCR-to-AQCR transfer matrices were developed for SO_2 and SO_4.

Several improvements and simplifications were tested during the year. Many of these were incorporated into our procedures to give a more efficient and cost-effective model. For example, we concluded that detailed, nonlinear sulfur chemistry is not warranted in regional assessment models; linear SO_2 and SO_4 chemistry is totally adequate. We improved our in-cloud conversion rates of SO_2 to SO_4, and we also found that under certain conditions model sensitivity to primary emissions of SO_4 is negligible if they are 2% or less of the total sulfur emissions. However, if primary SO_4 emissions are 10% or greater of the total sulfur emissions, the resultant air concentrations of sulfate will be significantly changed over those obtained by ignoring primary sulfate. Finally, we developed significantly more efficient methods for processing and calculating the wet removal of pollutants.

Matrices for the sulfur compounds were generated for four months of meteorological data: January, April, July, and October 1974. Comparative studies were made against AQCR-to-AQCR transfer matrices generated by the Brookhaven National Laboratory (BNL). When single sources were used, there were significant differences between the PNL and BNL results. However, for an actual emissions inventory, the comparisons between the PNL and BNL models were good. There was a high spatial correlation between SO_2 and SO_4 air concentrations; however, the PNL SO_4 concentrations were about 2/3 of the BNL values. These sulfate differences resulted from differences in the methods used by the two models for handling mixing heights, removal, and transformation processes.

Regional Issues Identification and Assessment

D. L. Hessel

Significant changes in the national pattern of energy production and consumption are necessary during the remainder of this century. At the national level, energy policy and priorities are being considered that will affect historic production and consumption patterns. The purpose of this research is to help improve the effectiveness of Federal energy policy by identifying areas where policy changes may be necessary.

This program was developed by the Department of Energy's (DOE) Assistant Secretary for Environment to provide a regional understanding of the environmental and socioeconomic issues as they relate to alternative energy futures (scenarios) implied in the Second National Energy Plan (NEP-2). Two national energy scenarios developed as part of the NEP-2 were the subject of the Regional Issues Identification and Assessment (RIIA) analysis. These scenarios were based upon two world oil price trajectories, a low price scenario ($21.00/bbl) and a high price one ($38.00/bbl).

The study will be reported on early in FY 1981 in a publication to be produced by DOE based upon contributions from the six national DOE laboratories. This report will present a comprehensive, consistent description of the regional environmental impacts and implications of future national energy development.

Detailed analyses of air, water, ecology, land-use, solid-waste, health and safety, and socioeconomic and institutional factors show that impediments to implementing the national scenarios in Region X are primarily institutional. Although socioeconomic impacts may be significant because of the location of energy facilities in rural areas, the region is somewhat accustomed to rapid growth. This circumstance reduces the potential significance of identified socioeconomic impacts in the analysis.

The national scenarios place heavy emphases in Region X on capturing remaining hydropower capacity and developing extensive nuclear capacity in southeastern Washington on the Hanford Reservation.

Long-Range Transport of Primary Fine Particulates

K. J. Allwine

Modeling the long-range transport of primary fine particulates for the high and low oil price scenarios was one of Pacific Northwest Laboratory's (PNL) responsibilities in the Regional Issues Identification and Assessment (RIIA) program. Fine particulates are that portion of total suspended particulates (TSP) having an aerodynamic equivalent diameter of 2.5 micrometers (μm) or less. These particulates are of environmental concern because of their potential adverse impacts on human health and visual air quality. Fine particulates can penetrate into the gas-exchange region of the respiratory tract. Also evidence exists that suggests that some toxic metals, such as arsenic, cadmium, nickel, lead, antimony, and selenium tend to be more highly concentrated in this particulate range (Natusch and Wallace 1974).

The Federal Regional results of the PNL analysis are displayed in Figure 1.2. The following observations can be made:

- In all Federal regions, the higher price of oil improves the population-weighted fine particulate air concentrations. The improvement ranges from 0.1 to 1.2 $\mu g/m^3$ in the year 2000. This can be attributed, primarily, to reductions in industrial oil use and, secondarily, to reductions in residential/commercial oil use.
- The regional variation in air concentrations is large, ranging in January from 9.7 $\mu g/m^3$ in Federal Region 2 to 0.8 $\mu g/m^3$ in Federal Region 8 in the year 2000. For July, the range is from 5.8 $\mu g/m^3$ in Region 2 to 1.0 $\mu g/m^3$ in Region 8.
- In 2000, the January concentrations are greater than July in all Federal regions except numbers 4, 8, 9, and 10. These differences are due to seasonal variations in residential/commercial particulate emissions and differences in winds and precipitation.
- The fine particulate air concentrations are greater in 2000 than 1975 for all regions except 1, 2, 3, and 5 for January, and 3 and 5 for July.
- The large decrease in air concentrations from 1975 to 1985 for some regions is

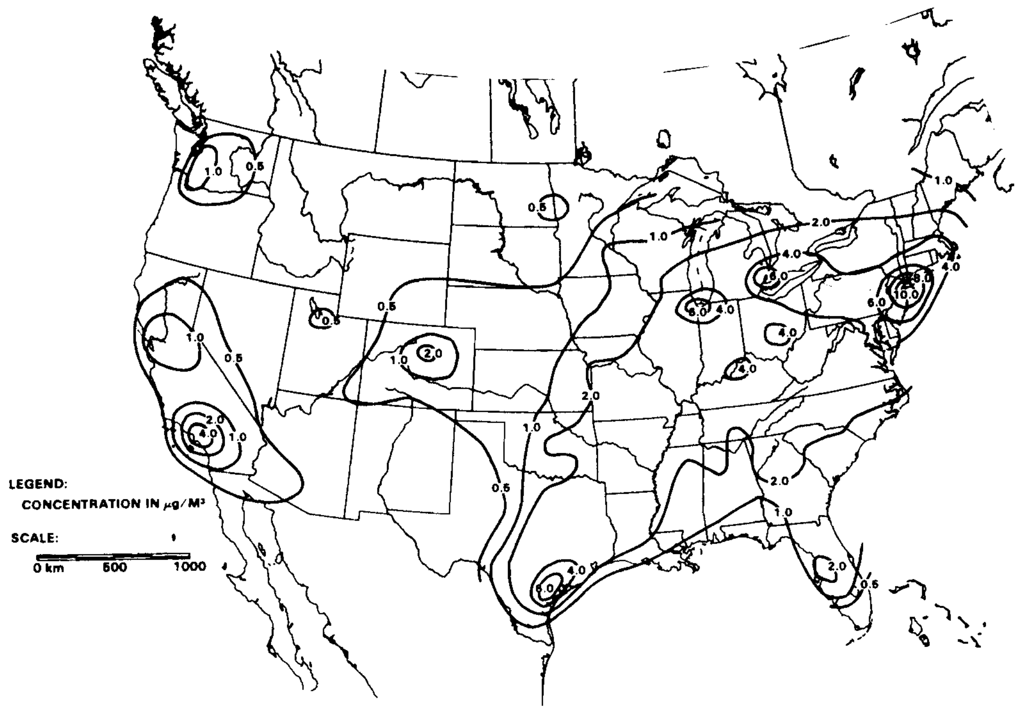

Figure 1.2. Monthly Average Population-Weighted Primary Fine Particulate Air Concentration for the Year 2000, High Oil Price Scenario, Using January 1974 Meteorology

primarily due to improved controls on process emissions, e.g., iron and steel manufacturing, stone and clay processing.

Concentrations of fine particulates projected for the year 2000 are shown for January and July meterology in Figures 1.2 and 1.3, respectively. The concentrations are greater in the West during July and greater in the East and South during January. In the West, this seasonal pattern is especially evident around Los Angeles, and in the East and South around New York and southern Texas. Maps comparing 1975 to 2000 and low scenario to high scenario showed only slight changes in the regional pattern of population-weighted fine particulate air concentrations.

Fine particulates can be emitted directly into the air (primary fines) or can form as a result of atmospheric gas to particle conversions (secondary fines). Ambient air concentrations of fines vary from 15% to 25% of TSP levels at Denver to 40% to 60% of TSP levels at Los Angeles and New York (Miller et al. 1979). Of the total fines in these urban areas, 60% to 80% can be secondary. This implies a range for primary fine air concentrations of from 3% to 24% of TSP levels. These particulates may remain in the atmosphere from a few days to several months and may be transported up to several thousand kilometers (Price et al. 1980). Because of these long residence times and distant transport characteristics, interregional transport matrices developed at PNL (Eadie and Davis 1979) were used to assess the impact of the two future world oil price scenarios on primary fine particulate air concentrations throughout the United States. These matrices were used to convert AQCR primary fine particulate emissions into monthly average population-weighted air concentrations for each of the 238 AQCRs in the contiguous United States.

The primary fine particulate emissions were calculated from the total particulate emissions estimated by DOE's Strategic Environmental Assessment System (SEAS) model. First the total particulate emissions were predicted by SEAS for all major source categories excluding fugitive emissions and natural sources for the years 1975 (base year), 1985, 1990, and 2000. Then the fine particulate emissions were determined from the total particulate emissions by multiplying the total emissions for each source category by a fine particulate fraction.

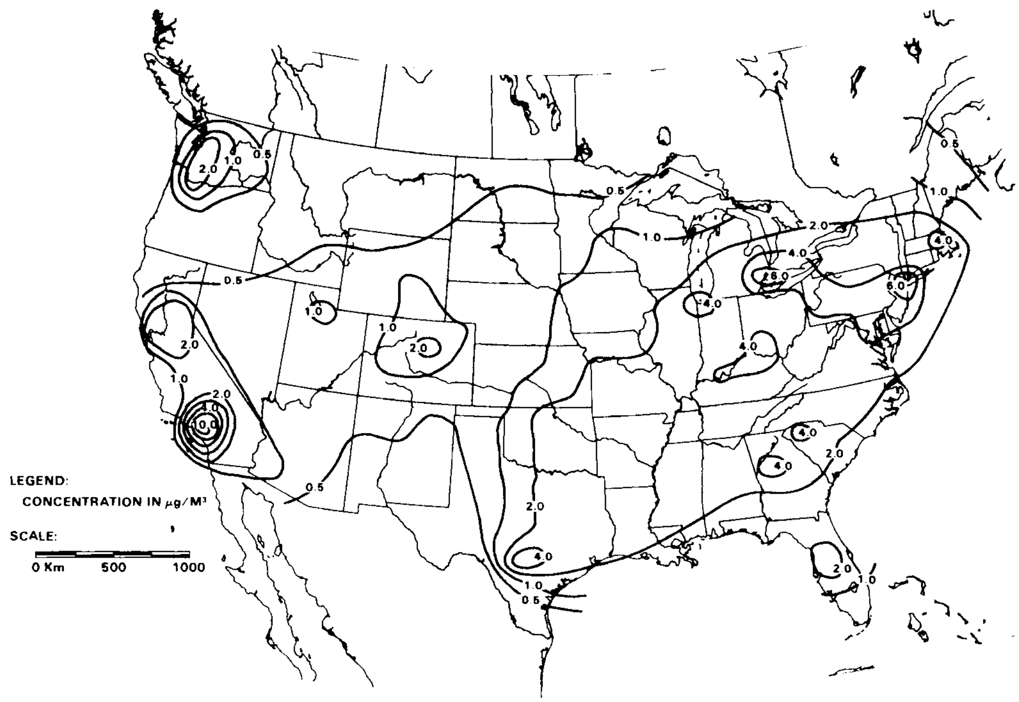

Figure 1.3. Monthly Average Population-Weighted Primary Fine Particulate Air Concentration for the Year 2000, High Oil Price Scenario, Using July 1974 Meteorology

This fraction was estimated from particle size distribution data.

Fine particulate air concentrations were calculated using AQCR to AQCR interregional transport matrices generated from January 1974 and July 1974 meteorology. Two months of meteorology were used to account for the effect of variations in transport characteristics. Also the particulate emissions from the residential/commercial sectors were adjusted according to seasonal variations in loading. A comparison of the January and July meteorology by Federal Region is shown in Figure 1.4.

The calculated average air concentrations are population-weighted. This simply means the concentration exposing the majority of the population is weighted the most in the averaging process. Federal regional population-weighted concentrations were calculated from the AQCR values for the two months of meteorology for both scenarios.

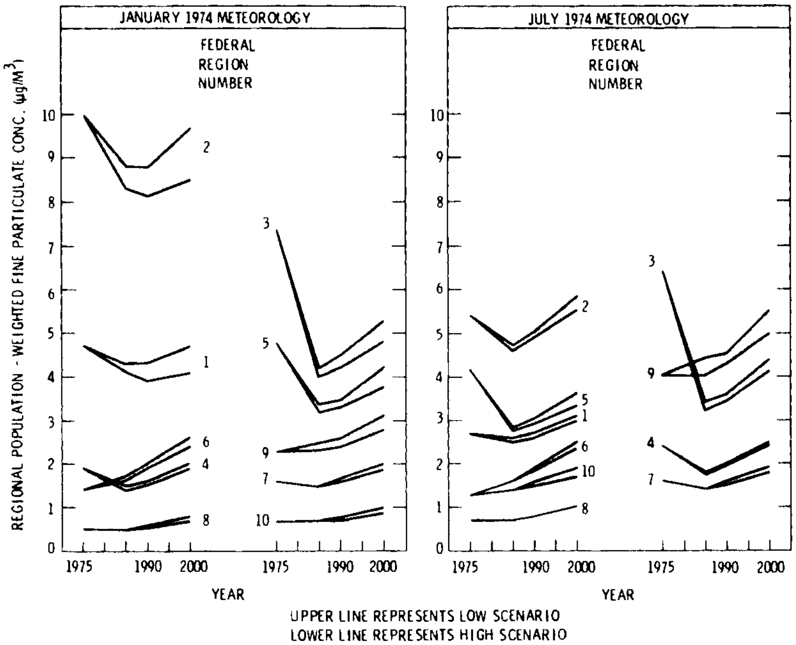

Figure 1.4. Regional January and July Population-Weighted Primary Fine Particulate Air Concentration for Two Future Energy Scenarios

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Eadie, W. J. and W. E. Davis. 1979. The Development of a National Interregional Transport Matrix for Respirable Particulates. PNL-RAP-37, Pacific Northwest Laboratory, Richland, Washington.

Miller, F. J., D. E. Gardner, J. A. Graham, R. E. Lee, W. E. Wilson and J. D. Bachman. 1979. "Size Considerations for Establishing a Standard for Inhalable Particles." J. APCA. 29(6):610-615.

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Institutional Analysis Lead Laboratory

F. A. Morris

Regional Issues Identification and Assessment (RIIA) identifies environmental, health and safety, socioeconomic and institutional issues that could accompany national energy policies and plans. The final report of this project (Morris, Cole 1980) was prepared to help analysts at PNL and other DOE laboratories identify institutional issues as part of the RIIA program. In particular, the report identifies three key techniques for performing institutional analyses: institutional mapping, institutional assessment, and institutional planning. Of these, institutional mapping and institutional assessment should be of particular help to DOE analysts. Institutional mapping is useful in understanding the processes for bringing on-line energy technologies and facilities contemplated in RIIA scenarios; institutional assessment assists in identifying the institutional constraints, opportunities, and impacts that affect decisions to develop and apply these technologies and facilities.

Reference

Morris, F. A., R. J. Cole. 1980. Institutional Analysis for Energy Policy. PNL-3529, Pacific Northwest Laboratory, Richland, Washington.

Urban and Community Impact Analyses

F. A. Morris

This project was in support of the Office of Environmental Assessment's effort to develop pilot urban and community impact statements, as required by Executive Order 12074, for the Department of Energy. In particular, the final report of this project (Morris et al. 1980) provided some qualitative guidance for describing impacts of Federal energy policies with respect to neighborhood stability, housing availability, and quality and availability of public services. The report specifies a definition and measure for each category of impact; reviews the social science literature to identify principal determinants of each type of impact; and illustrates how a simple causal model can be used to describe impacts, by applying it to three illustrative policies: domestic oil price decontrol, building energy performance standards, and increased Federal aid for mass transit.

Reference

Morris, F. A., A. A. Marcus; D. Keller. 1980. A Conceptual Framework for Describing Selected Urban and Community Impacts of Federal Energy Policies. PNL-3492, Pacific Northwest Laboratory, Richland, Washington.

2 Environmental and Safety Engineering

ENVIRONMENTAL AND SAFETY ENGINEERING

- **Liquefied Natural Gas (LNG) Safety Studies**
- **Oil Spills**
- **Liquefied Petroleum Gas (LPG) Research Assessment**
- **Environmental Control Technology for Shale Oil Wastewaters**
- **Geothermal Liquid Waste Disposal**
- **Compressed Air Energy Storage (CAES) Environmental Concerns**
- **Analysis of Nuclear Fuel Cycles**
- **Analysis of Fusion Fuel Cycles**

The objective of the overall Environmental and Safety 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.

Pacific Northwest Laboratory's effort in this program is growing rapidly. During 1980, we conducted studies in support of both nonnuclear and nuclear technologies, with programs in oil shale, oil, coal, gas, geothermal waste, compressed air energy, and nuclear fuel cycle analysis.

• Liquefied Natural Gas (LNG) Safety Studies

The objectives of this project are 1) to conduct research and development in specific areas of the DOE Liquefied Gaseous Fuels (LGF) Safety and Environmental Control Assessment Program and 2) to provide assistance to the DOE/EV Environmental and Safety Engineering Division in the planning and technical surveillance of the Program. Several tasks and milestone reports were completed in FY 1980, including reports on the LNG facility scoping assessment, a detailed assessment of release prevention systems in LNG import terminals, human factors engineering, and LNG storing tanks. In the Ammonia Assessment Task, studies were conducted on potential future applications of ammonia as an energy material and the trace ecological effects resulting from increased ammonia usage. Literature surveillance and the development of an LNG library continued. Assistance was provided in the preparation of the Second Status Report (DOE/EV-0085) on progress in the LGF Assessment Program. Five PNL project reports were published by the DOE in this status report. In addition, a survey of foreign experience in the use of LNG as an automotive fuel was performed and a video tape was completed showing selected LNG wind tunnel simulation runs conducted at Colorado State University.

Liquefied Natural Gas (LNG) Safety Studies

J. G. DeSteese, P. J. Pelto,
D. L. Brenchley, W. E. Davis,
A. L. Franklin, D. J. McNaughton,
M. M. Orgill, R. Shikiar

The Environmental and Safety Engineering Division (ESED) of the Department of Energy, Office of the Assistant Secretary for Environment (DOE/EV), is conducting the DOE Liquefied Gaseous Fuels (LGF) Safety and Environmental Control Assessment Program. The object of this effort is to gather, analyze, and disseminate technical information that will aid future decisions made by industry, regulatory agencies, and the general public relating to facility siting, systems operations, and accident prevention. This LGF Program is coordinated with the efforts of other agencies, and is supported by research at national laboratories and technical institutions, and by industrial contractors. The Liquefied Natural Gas (LNG) Safety Studies Project conducted by the Pacific Northwest Laboratory (PNL) provides research on LNG release prevention and control, planning assistance, and technical surveillance in support of the DOE/EV Program. Many of the safety and environmental issues identified for LNG apply to the handling of other liquefied gaseous fuels and energy materials. A further task in the PNL Safety Studies Project is to provide assistance in planning the Ammonia Safety and Environmental Control Assessment portion of the LGF Program. The PNL project is structured around four major tasks:

- LNG Release Prevention and Control Studies
- LNG Technical Surveillance
- Ammonia Safety and Environmental Control Assessment
- Special Studies.

Progress in these tasks is summarized below.

LNG Release Prevention and Control Studies

P. J. Pelto, A. L. Franklin, R. Shikiar

The objective of the LNG Release Prevention and Control Task is to develop an adequate understanding of LNG release prevention and control systems, and the factors that may defeat them. This study combines separate assessments of major LNG facilities including import/export terminals, marine vessels, peakshaving plants, and satellite facilities. It identifies information and research needs that can aid the future development of LNG release prevention and control systems. A more detailed assessment was made of release prevention systems in LNG import terminals. This assessment considered the frequency and quantities of release events identified in the scoping assessment. Important release prevention equipment components were identified and the effects of alternative designs examined. A similar detailed assessment of peakshaving facilities was continued. A review and preliminary safety assessment of LNG storage tank designs were completed in support of the detailed facility assessments. The various structural components that make up an LNG storage tank were examined qualitatively to determine their basic response to several potential hazards.

An assessment of LNG fire and vapor control devices was also started. A description of the state-of-the-art of fire and vapor control equipment was completed, and initial work was begun on a survey of equipment performance verification methods. An analytical model of an insulated dike was developed for use as a tool to assess the effectiveness of this method of vapor control in the event of an accidental LNG spill.

Human interaction is essential in the operation, testing, and maintenance of LNG facilities; therefore, human factors engineering and important human interactions with LNG release prevention and control systems were examined.

Two reports, an evaluation of LNG fire and explosion phenomena (Corlett 1980), and a summary assessment of LNG release prevention control were completed for publication in the Second Status Report of the LGF Assessment Program (Pelto et al. 1980).

LNG Technical Surveillance

W. E. Davis, D. J. McNaughton

The objective of the LNG Technical Surveillance Task is to assist the ESED in establishing and maintaining technical surveillance of research and development activities related to LNG safety and environmental control. Literature surveillance and the development of an LNG library continued. Four quarterly supplements to the "LNG Annotated Bibliography" and additions to the "LNG Safety and Control Literature and Research Updates" were completed and distributed to the sponsor and other contractors. A survey of information contained in European LNG literature was started under a subcontract performed by Battelle-Institut e.V. in Frankfurt, West Germany. The LNG Annotated Bibliography (1980) in Volume I of the DOE/EV Second Status Report was provided by this effort.

Ammonia Safety and Environmental Control Assessment

D. L. Brenchley, D. J. McNaughton

The objective of this task is to contribute planning information by identifying potential problem areas relating to ammonia safety and environmental control. This information will be a basis for planning research on ammonia as part of future effort in the LGF Assessment program.

Four subtasks in the ammonia assessment were completed. An introductory assessment of safety and environmental control information was written to provide 1) background information, 2) a literature survey, and 3) a basis for organizing the balance of the ammonia study in the PNL project (McNaughton and Brenchley 1980). Literature pertaining to the production, storage, transportation, and use of ammonia was reviewed. The report describes ammonia properties, potential hazards, production methods, accident reports, regulations, and control techniques. Potential research and development needs were identified that are subjects for more detailed evaluation in other subtasks.

A review of potential uses of ammonia as a fuel was completed. Ammonia may be burned directly as a fuel or used as a storage medium for hydrogen. The production of ammonia may be a future method for converting energy from large-scale alternative energy sources, such as fusion energy, into a convenient fuel for uses such as transportation. Reports on the introductory assessment and fuel uses of ammonia were published in Volume III of the DOE/EV Second LGF Status Report (Bomelberg and McNaughton 1980). Work also continued on the trace ecological effects resulting from increased ammonia usage and potential future increases in the use of ammonia as an energy material.

Special Studies

J. G. DeSteese, D. J. McNaughton, M. M. Orgill

The Special Studies Task provides the ESED with assistance in specific activities that contribute to the implementation and management of the Liquefied Gaseous Fuels (LGF) Safety and Environmental Control Assessment Program. A major effort in this task was the preparation of the Second Status Report on progress in the LGF Assessment Program. Four reports and an annotated bibliography (as described above) were contributed by PNL and its subcontractors summarizing the results of studies conducted in Fiscal Years 1979 and 1980. Other PNL efforts included the preparation of the Executive Summary Section in Volume I of the DOE/EV-0085 Document (LNG 1980), and the compiling and editing of reports supplied by other DOE contractors. This involved all document preparation activities needed to produce a camera-ready, three-volume master for subsequent publication by the DOE.

Effort in the Model Comparison and Evaluation Subtask was completed. The object of this subtask was to compare and evaluate LNG vapor generation and dispersion models, to identify dense gas models and differences between them, and to examine the sensitivity of these models to various input parameters. The results of this effort provided recommendations for test cases that will be used to evaluate the capabilities of models supplied by other contractors. A literature review and survey of scaling techniques were completed in the Scaling Techniques Analysis Task. Uncertainties in scaling methodologies are under investigation.

Other information requested by the sponsor was provided, as needed, to assist the planning and technical surveillance of the LGF Assessment Program. A survey of information on foreign experience in the use of LNG as an automotive fuel and the preparation of a video tape summarizing simulated LNG spill runs in the Colorado State University wind tunnel, were activities that contributed to this effort.

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"LNG Annotated Bibliography." 1980. Section II in Liquefied Gaseous Fuels Safety and Environmental Control Assessment Program: Second Status Report, Vol. 1, DOE/EV-0085.

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Pelto, P. J., E. G. Baker, T. B. Powers, S. L. Weber, G. H. Holter and A. M. Schreiber. 1980. "LNG Release Prevention and Control." Report I in Liquefied Gaseous Fuels Safety and Environmental Control Assessment Program: Second Status Report. Vol. II, DOE/EV-0085.

• Oil Spills

The objective of a field test on the combustibility of various crude oils was to determine their burning rates, the requirements for igniting them, and the conditions under which combustion will occur. Several representative crude oils were tested. The test shows that, under optimal conditions, the major portion of an oil spill can be burned, leaving a residue that is more easily removed and smaller in volume than the crude oil itself. Most crude oils will burn successfully if significant weathering has not occurred.

The study of fuel conservation by the application of spill prevention and failsafe engineering resulted in the development of a guideline manual for use by plant engineers and managers, Federal employees, and insurance and fire prevention inspectors. Nationwide surveys of plants clearly indicated the need for the publication which, when used to advantage, should reduce the annual loss of hydrocarbon products from accidental discharges. Special emphasis is placed on plant security in an effort to reduce the number of spills experienced annually from theft, malicious mischief, and plant sabotage.

Oil Spill Combustion

W. Wakamiya, S. E. Petty

Combustion is one method that may be used for oil spill cleanup in ocean waters. When crude oil is burned, the resulting residue is more easily removed and much smaller in volume than with other cleanup processes. Also, combustion reduces the spreading of the oil spill. The suitability of using combustion depends on the integrity of the vessel, geographical position of the accident, atmospheric conditions, available manpower, and the type of crude oil. Oil type is important because burning characteristics depend on the oil's composition.

One objective of this project was to verify a proposed model that described how well various crude oils burn. The model was based on specific gravity and boiling temperature measurements obtained from ASTM distillation curves. Large-scale (2-m pool of oil) burning tests of crude oils were conducted to verify the proposed model.

Another objective of this project was to evaluate the effects of heat addition on burning rates. Coils were placed into the oil to add energy. Data were generated on the differences in burning rates caused by additional heat input.

Seven world crude oils, listed in Table 2.1, were tested. These oils were selected because they encompass the spectrum of crude oil commonly transported in ocean waters. The seven crude oils were burned three times each. Local Oklahoma crudes were also tested to verify trends found in the data from the world crude burns. Overall, 27 test burns were completed. Each world crude oil was burned once without heat addition and twice with heat addition. These two methods of combustion reflected the two major objectives of the experimental program.

Table 2.1. Crude Oils Tested

Crude Oil	API Gravity	Producing Country
Saharan Blend	44.3	Algeria
Attaka	43.2	Indonesia, East Kalimatan
Es Sider	37.0	Libya
Labuan	36.0	Malasia, Sabah
Ekofisk	35.8	Norway
Isthmus/Mayan Blend	33.0	Mexico
North Slope	26.8	USA

Samples were combusted in a 2-m burning pan. An initial oil layer of 5 cm was floated on a 32-cm column of water. The entire apparatus was submerged in water to maintain a constant temperature. The following instruments were used in obtaining data:

- four in-pool radiometers
- two in-pool thermocouple rakes (34 total thermocouples)
- two external narrow-angle radiometers
- two external wide-angle radiometers
- one level controller (used for burning-rate calculations)
- one anemometer and weather station (for ambient temperature, relative humidity, and barometric pressure).

In all, 47 channels of data were taken every 4 sec during a typical test burn.

Since the experimental work was completed during the months of June and July, ambient conditions were warm, 31°C (88°F). These conditions would not normally occur in typical ocean oil-spill incidents; however, by using a sensible heat correction factor, the proposed theoretical model was modified to reflect experimental conditions.

The following conclusions emphasize major results found during this experimental program.

- All crude oils will combust if a temperature profile can be established and completely contained in the oil layer.
- Experimental results indicate that the proposed model did not accurately predict combustibility of crude oils.
- Entrainment appears to play a significant role in combustion of crude oils. Light-end crude fractions, entrapped in lower crude oil layers, are mass transfer limited until they contact the steep temperature profile region. At that point they are propelled violently toward the burning surface. These light ends, as they accelerate to the surface in vapor form, carry with them heavier fractions. These heavy fractions, which have boiling temperatures much higher than the oil surface temperature, are combusted as they are propelled into the high temperature flame zone. A relatively constant surface temperature of 220°C supports this entrainment theory. Entrainment has been photographically documented on several burns.
- Burning rates for crude oils tested ranged from 3.00 to 4.62 mm/min.
- Burning rates of the crude oils tested were basically unaffected by heat addition. Graphically, burning rate is a very weak function of heat addition. However, all crude oil ignited more easily when energy was added.
- Establishment of a temperature profile within a crude layer on water is necessary in order to sustain combustion. Once the oil layer burns to a point where the temperature profile extends through the oil/water interface, combustion will cease. This depth defines the minimum depth.
- The flame extinction point is reached at the minimum thickness where the energy passing through the oil/water interface is approximately equal to the energy reradiated from the flame back to the oil pool's surface.

The experiments suggested several areas for further study. These experiments are necessary to substantiate current research and to clarify the direction of future research on crude oil combustion.

One area of research would determine if the results can be applied at cooler ambient conditions (0° to 5°C). One major parameter that may change with lower ambient temperatures, assuming sufficient oil depth and negligible weathering, is the ease of ignition. Ignition may be more difficult at cooler temperatures because ignition is basically a vapor-phase phenomenon, and volatilization decreases with decreasing ambient temperatures. Data should indicate that once ignited (provided a minimum oil depth exists) removal percentages of crude oil by combustion will be approximately the same values as those obtained in this study.

The current program concludes that as long as a minimum oil depth exists, a crude oil will burn. Only when significant amounts of energy pass into the supporting water phase will combustion cease. Two additional areas require future research:

1. Determine if it is possible to insulate thin oil slicks from the supporting

water column by a relatively nonconductive medium.

2. Determine if solid primers can supply adequate energy to initiate temperature gradients in the oil necessary for sustaining combustion. Ignition may be the most significant parameter affecting combustion of crude oils. Liquid primers, due to evaporative cooling, may not have been successful in the past because of their inability to provide an adequate heat flux to initiate the required temperature gradient.

Fuel Conservation by the Application of Spill Prevention and Failsafe Engineering

J. L. Goodier, R. J. Siclari, P. A. Garrity

The need for a spill prevention guideline manual was shown from a series of nationwide plant surveys directed toward spill prevention, containment, and countermeasure evaluation, coupled with spill response action activities. From Federally accumulated statistics for oil and hazardous substance spills, the authors culled information on spills of hydrocarbon products. Federal statistics indicate that an average of 1450 on-land oil spills are reported to the authorities annually. In 1978 7,289,163 gal of oil were accidently discharged from on-land operations. In 1979, this figure was reduced to 3,663,473 gal. These figures are derived from reported spills; it is highly possible that an equal amount was spilled and not reported. Spills effectively contained within a plant property that do not enter a navigational waterway need not be reported. Needless to say, there is a tremendous annual loss of oil products because of accidental spillage during transportation, cargo transfer, bulk storage, and processing.

As an aid to plant engineers and managers, Federal workers, fire marshalls, and fire and casualty insurance inspectors, the document is offered as a spill prevention guide. The manual defines state-of-the-art spill prevention practices and automation techniques that can reduce spills caused by human error. Whenever practical, the cost of implementation is provided to aid equipment acquisition and installation budgeting. To emphasize the need for spill prevention activities, historic spills are briefly described after which remedial action is defined in an appropriate section of the manual. The section on plant security goes into considerable depth since to date no Federal agency or trade association has provided industry with guidelines on this important phase of plant operation for petroleum handling facilities. The intent of the document is to provide finger-tip reference material that can be used by interested parties in a nationwide effort to reduce loss of oil from preventable spills.

Within the past ten years there has been considerable advancement in the technologies of spill prevention, spill containment, and failsafe engineering. The Federal government through the U.S. EPA has published spill prevention criteria developed from historic spill investigations and field surveys of industrial and Federal installations. To date there has been no consolidated effort to define and publish information that will guide plant management and engineers in the application of spill prevention and failsafe engineering. This guideline manual is intended to extend cryptic criteria statements into a practical publication that explains "how" and "why."

The U.S. Department of Energy's interest in the spill prevention program stems largely from a desire to materially reduce the needless loss of energy products from accidental discharges. The additional benefit that will be derived is a reduction in polluting incidents that contaminate the inland and coastal waters of the United States which can cost from $10 to $100 per gallon to clean up. Much of the oil spilled was refined product. Naturally, the more advanced the refining of crude oil progresses, the more expensive the spill becomes. The cost from exploration, recovery, transportation, and processing is then lost with the product.

Eventually this manual will be due for revision to include technological advances. In this respect suggestions, comments, and even technological input are solicited from any possible source.

Additionally, unique spill prevention measures introduced in surveyed plants are recorded for the benefit of other plant facilities. Whenever practical a recommended or suggested practice is supported by a brief description of a spill incident to support and stress the need for corrective action. More than 100 illustrations and 24 tables were collected from equipment suppliers for inclusion in the manual to clarify the written word. Photographic material and illustrations were provided with the full knowledge of intended use with the authority to reproduce. The response of equipment suppliers was in fact so voluminous that less than one-third of the illustrations supplied could be used. Although the names of manufacturers and products are used freely, the document is not intended as an endorsement of one or any group of products.

• Liquefied Petroleum Gas (LPG) Research Assessment

The project's objective is to evaluate safety and environmental control issues relating to the processing, transportation, storage, and use of liquefied petroleum gas (LPG). The resulting information will support the DOE/EV Environmental and Safety Engineering Division in developing an LPG research and development plan as part of the DOE Liquefied Gaseous Fuels (LGF) Safety and Environmental Control Assessment Program. Information provided by PNL and its subcontractors was compiled and edited into a preliminary report describing the LPG industry and its principal facilities and systems. Over twenty assessments were prepared that identify R&D needs resulting from LPG safety and environmental control concerns. A state-of-the-art review of LPG release prevention and control was contributed to the LGF Assessment Program Second Status Report.

Liquefied Petroleum Gas (LPG) Safety and Environmental Research and Development

J. G. DeSteese, D. N. Gideon[a], P. J. Anderson[b]

The overall objective of this project is to evaluate safety and environmental control issues relating to the production, transportation, storage, and use of liquefied petroleum gas (LPG). The resulting information will assist the DOE/EV Environmental and Safety Engineering Division in developing a research and development (R&D) program plan that addresses LPG safety and environmental concerns.

This project has involved the efforts of two subcontractors. Battelle Columbus Laboratories (BCL) provided system descriptions of LPG transportation by pipeline, rail, and truck, and an assessment of the state-of-the-art of release prevention and control in the LPG industry. The Institute of Gas Technology (IGT) contributed descriptions of production, import/export, and peakshaving plants together with barge and ship transportation systems. Both subcontractors and PNL identified and evaluated R&D needs and recommended R&D program elements that address LPG safety and environmental concerns.

A methodology was developed to rank the identified concerns according to their priority. A complete response strategy for LPG accident scenarios includes release prevention, release detection, release control, vapor control, fire prevention, fire detection, fire control, and damage control. Each element of this strategy represents required action in the event that the previous element fails to control an accidental release. On this basis, R&D needs applying to release prevention are considered to have the highest priority. Over twenty LPG safety and environmental concerns were identified. Effort is continuing to substantiate these concerns and plan appropriate R&D approaches that may lead to their solution or mitigation.

A report was completed by BCL that presents a state-of-the-art summary of release prevention and control methodology in the LPG industry. A summary of release prevention and control methods and regulations was provided for pipeline, railroad, and truck transportation and consumer storage. The accident record for each of these elements was considered together with design and construction practices, operations, maintenance, and research and development activities. An overall conclusion of this study is that regulatory requirements and the dissemination of advisory information, respectively, are the basic current approaches to release prevention and release control in the transportation, storage, and use of LPG.

(a) Battelle Columbus Laboratories
(b) Institute of Gas Technology

This report was published in the Second Status Report of the DOE/EV Liquefied Gaseous Fuels Safety and Environmental Control Assessment Program (Gideon 1980).

Reference

Gideon, D. N. 1980. "State-of-the-Art of Release Prevention and Control Technology in the LPG Industry." Report V in Liquefied Gaseous Fuels Safety and Environmental Control Assessment Program Second Status Report. Vol. III, DOE/EV-0085.

• Environmental Control Technology for Shale Oil Wastewaters

The capabilities and limitations of conventional treatment and disposal technology are being evaluated for shale oil wastewaters. Laboratory studies (bench-scale) are being conducted to assess the effectiveness of several physical, chemical, and biological processes for removing pollutants from shale oil wastewaters. Preliminary cost estimates based on bench-scale studies ranged from $11 to $25/1000 gal of in-situ retort water treated by sedimentation, steam stripping, biologically activated carbon, chemical coagulation and filtration, and activated sludge. Bench-scale studies on evaporation of in-situ retort water indicate that a higher quality effluent can be produced at a lower cost ($7/1000 gal) using this process rather than the series of processes given above. The condensate produced by evaporation has very low concentrations of inorganic constituents, including arsenic and other heavy metals, and can be readily treated to remove organic residuals.

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

B. W. Mercer, W. Wakamiya

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.

Estimated Costs of Physical-Chemical and Biological Treatment

Preliminary cost estimates are given in Table 2.2 for physical-chemical and biological treatment processes consisting of liquid-solids separation, steam stripping, biological activated sludge, chemical coagulation and filtration, and activated carbon adsorption. A range of cost is given rather than a single cost because of uncertainties in scale-up factors derived from bench-scale data. These preliminary estimates, however, are often useful in the initial decision process to select or reject a specific process or process train for further study. For example, a process may be too costly compared to alternatives under the most optimistic assumptions. The cost estimates reported here were developed for a waste-water reuse objective where the finished effluent is used for cooling purposes (e.g., recirculated through a cooling tower). The effluent has not been demineralized since it may be possible to concentrate it several-fold in the cooling tower without scaling problems. Use of a highly saline water in a cooling system will, however, require the use of corrosion resistant material. The presence of a small ammonia residual (e.g., 100 to 200 mg/ℓ) will also preclude the use of copper or copper alloys. The major

Table 2.2. Preliminary cost estimates for Retort Water Treatment

Processing Step	Cost Range $/1000 gal
1. Suspended Solids Separation	0.07 - 0.20
2. Steam Stripping	4.82 - 12.13
3. Activated Sludge	3.09 - 5.65
4. Coagulation-Filtration	0.55 - 0.64
5. Activated Carbon Adsorption	2.25 - 6.13
TOTAL	10.78 - 24.75

objectives of the treatment steps are: 1) to remove biodegradable organics that may cause fouling of the cooling system; and 2) to reduce the odor of the retort water to an acceptable level downwind from the cooling tower. Suspended matter and ammonia are removed from the raw water to permit biological treatment, and biological solids are removed by coagulation and filtration to avoid plugging of the activated carbon columns.

Ultimate disposal costs for the cooling tower blowdown are not included and may be substantial if this waste is classified as hazardous because of residual toxicant concentrations (e.g., arsenic and selenium). The above wastewater treatment costs will add from $0.45 to $1.04/barrel of oil produced at a 1:1 volume ratio of retort water to oil. The major cost factors in these estimates are: 1) steam consumption for ammonia stripping; 2) acid addition for pH control and aeration time for activated sludge treatment; and 3) activated carbon exhaustion rate. Cost reductions are possible through the use of alternative methods; however, these would require further study. Acid consumption, for example, in activated sludge treatment may be reduced but not eliminated by adding waste flue gas with CO_2 to the air injected in the aeration basins.

Heavy Metals and Boron in Treated Effluents

Effluents from various treatment steps in the bench-scale studies were analyzed for elemental content by neutron activation and plasma emission spectroscopy. The results of these analyses for heavy metals and boron are presented in Table 2.3 for an in-situ retort water. An 80% reduction of arsenic was achieved through the ferric hydroxide-manganese dioxide scavenging step, but little additional removal was achieved by activated sludge and activated carbon. Effective copper removal was observed particularly by activated carbon. An increase in manganese was observed following the $Fe(OH)_3$-MnO_2 scavenging step, which is believed due to incomplete precipitation of the manganese. Other metals, cadmium (<0.01), zinc (<0.03), and nickel (<0.8) were below detection limits in the untreated retort water.

Bench-Scale Evaporator Test

A 25-GPD evaporator was operated continuously for a period of 136 hr (5.6 days) after a sump concentration factor of 25 had been reached. The evaporator used was a vertical, flat plate, falling-film unit. The feed entered through a filter and was heated to near boiling in a constant temperature bath. Evaporation occurred as the sump charge (5 ℓ) was continuously recirculated over the outer surfaces of a 15-cm-wide by 91-cm-high by 3.8-cm-deep hollow panel having 2730 cm^2 of heat transfer surface (0.157-cm-thick titanium sheet). The rate of circulation was 30.3 ℓ/min. Plant steam, fed to the inside of the panel through a pressure regulator, was the heat source for evaporation. The steam formed from evaporation of the concentrate was collected as distillate from a condenser. The heating steam pressure, sump pressure, ambient pressure, sump temperature, and distillate production rate were monitored continually during the above processing period.

The wastewater was pretreated by air sparging in 30- to 40-gal batches at 93°C before feeding to the evaporator. The period of sparging was determined by pH change. When pH remained constant after two successive readings taken a half hour apart, sparging was discontinued and the wastewater transferred to the evaporator feed tank. This normally occurred around a pH of 10.

The average composition of the evaporator inputs and outputs during the five days of continuous operation are given in Table 2.4. The overall heat transfer coefficient across the evaporator panel was 2610 $J/m^2 \cdot s \cdot {}^\circ K$ and the temperature difference between steam and evaporating liquid was 4.6°C. Heat transfer remained relatively constant during the last 72 hours of operation. Inspection of the heat transfer panel after shutdown of the unit disclosed a uniform chocolate-brown film estimated to be less than 0.003 cm thick. Rinsing of the panel, after reinstallation in the evaporator, with 5% sulfuric acid at 88°C recirculating at 30.3 ℓ/min removed the coating in 1.5 hr.

Bench-scale studies on biological and activated carbon treatment of the retort water evaporator condensate were conducted. Biological treatment by activated sludge was effective for removing between 35% and 45% of the total organic carbon (TOC) and chemical oxygen demand (COD). The TOC and COD removal levels were near 35% at a solids retention time of 15 days in the activated sludge units, and were near 45% at a solids retention time of 30 days. The hydraulic retention time was 8 hr in

Table 2.3. Heavy Metals and Boron in Retort Water Effluents

Effluent	Concentration, ppm						
	As	B[a]	Cu[a]	Fe	Mn	Mo[a]	Se
Untreated Retort Water	4.1	108	0.33	8	0.2	8.4	0.30
Steam Stripper	4.1	110	0.21	5	0.2	8.2	0.34
$Fe(OH)_3$-MnO_2 Scavenging	0.8	71	0.08	5	2.0	7.7	0.26
Activated Sludge	0.6	107	0.10	5	2.0	7.1	0.18
Activated Carbon	0.6	106	0.01	5	1.3	6.8	0.14

[a]Determined by plasma emission spectroscopy. All others were determined by neutron activation.

Table 2.4. Average Composition of Bench Model Evaporator Inputs and Outputs During Five Days of Continuous Operation

Note: All values in mg/l except conductivity (μmhos/cm) and pH (units).

Constituents	Feed as Received	Feed, 200°F Air Sparged	Distillate	Sump Concentrate
NH_3	1,620	176	224	—
Conductivity	17,830	16,100	1,260	437,000
pH	9.0	9.9	7.4	10.4
Total Inorganic Carbon	2,390	1,380	162	17,200
Total Organic Carbon	1,830	2,050	549	42,300
Total Residue, 103°C	15,300	19,300	34	446,700
Total Volatile Residue	2,580	3,850	21	98,100
Total Nonfilterable Residue, 103°C	148	157	1	3,460
Volatile Nonfilterable Residue	103	92	—	800
Alkalinity ($CaCO_3$)	11,920	9,380	666	105,000
Concentration Factor	—	1.4	—	29.1
Na^+	5,830	7,080	1.1	150,000
Mg^{++}	7.0	8.9	0.1	16.9
Ca^{++}	5.2	5.8	1.3	5.2
COD	7,150	7,850	1,820	—

than 99% removal of TOC was achieved with combined activated sludge each case. Greater and activated carbon treatment to breakthrough at 110 bed volumes of carbon column effluent. Greater than 98.4% TOC removal was achieved with activated carbon adsorption to breakthrough at 90 bed volumes of carbon column effluent. The untreated retort water evaporator condensate contained 570 mg/ℓ TOC and 1680 mg/ℓ COD.

• Geothermal Liquid Waste Disposal

Three disposal techniques are being used at geothermal sites around the world: direct discharge to surface waters, deep-well injection, and ponding. Several other techniques are considered viable options. Additional research and development is needed to reduce the uncertainties and to minimize the potential adverse environmental impacts of disposal.

State-of-the-Art Review: Liquid Waste Disposal for Geothermal Energy Systems

L. J. Defferding

The objective of this project was to review the state-of-the-art of disposal methods that are available for liquid wastes from geothermal energy systems. The project was completed and a final report was published: "State-of-the-Art of Liquid Waste Disposal for Geothermal Energy Systems: 1979" (Defferding 1979).

The work includes reviews of the state-of-the-art of geothermal liquid waste disposal, and evaluates surface and subsurface disposal methods with respect to technical, economic, legal, and environmental factors.

The disposal of geothermal liquid effluents could affect the environment in an adverse manner. Disposal is not only complicated by the wide variability of waste fluid properties (e.g., temperature, pH, and chemical constituency), but also by the large volumetric flows involved. The task of waste disposal is also affected by such site-specific variables as geology and environmental setting, by legal requirements, and by unknown economic factors.

Three disposal techniques are currently in use at numerous geothermal sites around the world: direct discharge into surface waters, deep-well injection, and ponding for evaporation. Our review showed that effluents are directly discharged into surface waters at Wairakei, New Zealand; Larderello, Italy; and Ahuachapan, El Salvador. Ponding for evaporation is employed at Cerro Prieto, Mexico. Deep-well injection is being practiced at Larderello, Ahuachapan; Otake and Hatchobaru, Japan; and at The Geysers in California. All sites except Ahuachapan (which is injecting only 30% of total plant flow) have reported difficulties with their systems.

The report also includes a review of disposal techniques used in related industries. The oil industry's efforts to dispose of large quantities of liquid effluents have been quite successful as long as the effluents have been treated prior to injection.

This study has determined that seven liquid disposal methods--four surface and three subsurface--are viable options for use in the geothermal energy industry (see Table 2.5). However, additional research and development is needed to reduce the uncertainties and to minimize the adverse environmental impacts of disposal.

Reference

Defferding, L. J. 1979. State-of-the-Art of Liquid Waste Disposal for Geothermal Energy Systems. PNL-2404, Pacific Northwest Laboratory, Richland, Washington.

Table 2.5. Evaluation of Geothermal Liquid Waste Disposal Techniques

TECHNICAL ASPECTS

Disposal Method	Experience with Method	Equipment	Importance of Geology and Underground Hydrology	Interaction with Processes	Useful By-products	Reliability	Cost
Direct Release to Surface Waters	In Use (a)	Readily available	Minimal	Very low	No	High	Low
Treatment and Release to Surface Water	Minimal	Special Materials May be Needed	Minimal	Moderate (1)	Possibly	Moderate	Moderate
Closed-cycle Ponding	In use (b)	Special Materials (Pond Liners) Needed	Minimal	Very Low	Possibly	High	Low (3)
Consumptive Secondary Use	Experimental	Readily Available	Minimal	Significant (1)	Yes	High	Low
Injection into Producing Horizon	In use (c)	Special Equipment (Pumps) Needed	High	Significant (1)	Possibly	Moderate (2)	Moderate (4)
Injection into Nonproducing Horizon	Experimental	Special Equipment (Pumps) Needed	High	Significant (1)	Possibly	Moderate	Moderate (4)
Treatment and Injection	Experimental	Special Materials May be Needed	Moderate (1)	Significant	Possibly	Moderate to High	Moderate

LEGAL ASPECTS

Disposal Method	Geothermal Laws	Environmental Laws	Water Rights Laws	Land Use Laws
Direct Release to Surface Waters	Yes	Yes	Yes	Minimal
Treatment and Release to Surface Water	Yes	Yes	Yes	Minimal
Closed-cycle Ponding	Yes	Yes	Yes	Yes
Consumptive Secondary Use	Yes	Yes	Yes	Yes
Injection into Producing Horizon	Yes	Yes	No	No
Injection into Nonproducing Horizon	Yes	Yes	No	No
Treatment and Injection	Yes	Yes	No	No

ENVIRONMENTAL AND SAFETY ASPECTS

Disposal Method	Occupational Safety	Water Pollution	Air Pollution	Noise Pollution	Toxic Substance Disposal	Solid Waste Disposal	Induced Seismicity	Land Subsidence	Comments
Direct Release to Surface Waters	Excellent	Moderate	Yes	Yes	No	No	No	Potential	Low cost, good potential for low-temp., direct-heat applications
Treatment and Release to Surface Water	Good	Low	Yes	Low	Potential	Yes	No	Potential	Cost of treatment must be kept low
Closed-cycle Ponding	Good	Low Potential	Yes	Yes (5)	Potential	Some	No	Potential	Needs reliable liners and low-cost land in arid regions
Consumptive Secondary Use	Good	No	Low Potential	Low	No	No	No	Potential	Shows potential for medium- to low-temperature waters
Injection into Producing Horizon	Good	Moderate Potential	Low	Low	No	Low	Low Potential	Low	Very popular, but potentially has some problems
Injection into Nonproducing Horizon	Good	Moderate Potential	Low	Low	No	Low	Low Potential	Potential	Used primarily where producing zones are highly fractured
Treatment and Injection	Good	Low	Yes	Low	Potential	Yes	Low Potential	Low	Solid disposal may be a big problem

(a) Wairakei, New Zealand; Ahuachapan, El Salvador; Iceland; Klamath Falls, Oregon
(b) Cerro Prieto, Mexico
(c) Ahuachapan, El Salvador and Larderello, Italy

(1) Temporary backup systems needed
(2) Has shown moderate reliability except in highly permeable zones
(3) Depends on liner and land costs
(4) Depends on permeability of receiving zone (lower permeability increases cost)
(5) Good designs reduce noise output

• Compressed Air Energy Storage (CAES)

The objectives of this project are to identify potential environmental problem areas associated with the implementation of Compressed Air Energy Storage (CAES) technology, to assess the potential impacts of these concerns, and to identify or highlight the need for technologies to prevent or control adverse impacts. Research efforts in FY 1980 consisted primarily of preliminary assessments of probable subsurface effects such as alteration of hydrological and geochemical conditions, geologic phenomena, and initiation of an assessment of the legal and regulatory issues associated with CAES technology.

Compressed Air Energy Storage Environmental Control Concerns

M. A. Beckwith

Compressed air energy storage (CAES) is a technology for storing excess off-peak electrical energy in thermo-mechanical form and for recovering it later for peak-demand period generation of electricity. During periods of low electricity demand, excess base load generating capacity is used to power an air compressor train at the CAES facility. The compressed air it generates is then stored underground in porous media, such as aquifers; in caverns mined from hard rock; or in solution-mined salt formations. During daily peak-load periods, the compressed air is released, mixed with fuel, and burned in a modified combustion turbine.

As the lead laboratory for research sponsored by the Department of Energy in compressed air energy storage, Pacific Northwest Laboratory (PNL) established the Environmental Control Concerns Program. The objectives of the program include identification of the environmental factors (air-and water-borne releases, effects on geologic stability, and aesthetic, regulatory, and land-use considerations) associated with the development of CAES; quantification of the environmental impacts of these factors (where possible) and establishment of a data base useful for planning and siting CAES facilities; and identification of environmental control practices or areas of research leading to improved control practices.

During FY 1980, research was initiated in issue areas identified during work performed in FY 1979. Research efforts included preliminary assessments of the 1) potential for induced seismic activity associated with CAES caverns mined from hard rock formations; 2) potential geochemical effects on aquifers utilized for CAES; 3) probable legal and regulatory issues involved in CAES development; and 4) potential environmental effects of mined waste disposal. The issue of alteration of local groundwater hydrologic conditions was also addressed; plans for subsequent required research was the primary result of this effort in FY 1980. Research potentially related to CAES was also reviewed for applicability to the program. Support on environmental regulatory matters was also provided to the CAES Technology Development Program at PNL.

Research activities of FY 1980 were based primarily on the results of the initial surveys conducted in FY 1979. Similarly, the research of FY 1980, while somewhat qualitative, will serve as the basis for more quantitative subsequent studies. Program activities of FY 1981 will involve more direct environmental support to the field test phase of the CAES Technology Development Program. It is anticipated that the program will develop much of the data required for complying with current environmental regulations and for making decisions regarding this developing technology.

• Analysis of Nuclear Fuel Cycles

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 technologies that control or eliminate the discharge of noxious materials to the environment can be developed and demonstrated in a timely fashion. The objective of this program is to identify areas in developing nuclear fuel cycles where 1) inadequate consideration is being given to environmental controls, and 2) 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. The following tasks are being performed:

- Overview of the Gas-Cooled Fast Breeder Reactor
- LWR Improvements Overview
- Environmental Readiness Document (ERD) for Advanced Isotope Separation
- Environmental and Safety Overview for LMFBR
- Thorium/Uranium Environmental Control Technology.

Overview of the Gas-Cooled Fast Breeder Reactor

M. A. Lewallen, A. M. Nolan

The objective of this task was to assess the expected environmental effects of operation of a Gas-Cooled Fast Breeder Reactor (GCFBR) to identify any improved environmental control technology that requires development for this type of reactor.

Estimates of radioactive effluents expected from normal operation of a GCFBR were used to determine long-term impacts on the surrounding human population. Fifty-year collective dose equivalent commitments resulting from a one-year release were estimated and compared to those resulting from operation of a Light Water Reactor (LWR) and a high temperature gas-cooled reactor (HTGR).

The results of the comparison are shown in Tables 2.6 and 2.7 for gaseous and liquid releases, respectively. The GCFBR is expected to produce much smaller radiological impacts on the surrounding human population than either the LWR or the HTGR. Thus, it appears that environmental control technology developed for radioactive effluent control for the GCFBR is adequate.

Table 2.6. Fifty-Year Collective Dose Equivalent Commitments (Man-Rem) for a One-Year Gaseous Release from the GCFBR, HTGR, and LWR

	Collective Dose Equivalent Commitment by Reactor Type		
Affected Organ	GCFBR	HTGR	LWR
Total Body	2.7 - 3[a]	1.4 + 0	1.2 + 1
Gastrointestinal Tract	2.7 - 3	1.4 + 0	1.2 + 1
Thyroid	6.4 - 3	1.4 + 0	3.2 + 1
Bone	8.0 - 4	4.3 - 1	4.3 + 0
Lung	2.7 - 3	1.6 + 0	1.2 + 1

(a) 2.7×10^{-3}

Table 2.7. Fifty-Year Collective Dose Equivalent Commitments (Man-Rem) for a One-Year Liquid Release from the GCFBR, HTGR, and LWR

	Collective Dose Equivalent Commitment by Reactor Type		
Affected Organ	GCFBR	HTGR	LWR
Total Body	8.0 - 4[a]	4.4 - 1	2.5 - 1
Gastrointestinal Tract	1.0 - 2	2.4 - 2	3.6 - 2
Thyroid	4.7 - 4	9.1 - 4	3.2 + 0
Bone	6.6 - 4	5.8 - 1	1.3 - 1
Lung	6.8 - 5	4.6 - 2	3.2 - 2

(a) 8.0×10^{-4}

Light Water Reactor (LWR) Improvements Overview

M. A. Lewallen, R. L. Aaberg

The objective of this task was to evaluate the potential environmental effects of proposed changes that improve uranium utilization of light water reactors (LWR). The results of the analysis are contained in Impacts of Uranium Utilization Improvements on Light Water Reactor Radionuclide Releases (Aaberg 1980). The results are summarized in Table 2.8.

Higher burnup is the most promising method to improve uranium efficiency because it involves minimal changes to reactor structure and operating procedures. Greater nuclide inventory is the most obvious outcome of this change. The source term for releases increases proportionally to the uranium loading and burnup achieved.

Table 2.8. Methods of Increasing Uranium Utilization and Estimated Effect of each on LWR Radionuclide Releases

	Release Effect[a]
Increased Burnup:	
Higher Radionuclide Inventory	+3
Higher Fuel Failure Rate from:	
Pellet Clad Interaction	+2
Fuel Rod Internal Pressure	+1
External Clad Corrosion	+1
Fuel Assembly Dimensional Changes	0
More Reactive Geometries	0
Fuel Management and Plant Operation	
Low Leakage Fuel Management	0
Axial Blanket	0
Power Coastdown	0
6-Month Cycles	0
BWR Spectral Shift	+1
Thorium Corner Rods in BWRs	+1

(a) +3 Certain increase
+2 Probable increase
+1 Possible increase
0 Negligible effect

A higher incidence of fuel failures from pellet-clad interaction (PCI) is also possible with higher burnups. Limitations on the fuel may also be imposed by fuel rod internal pressure and external clad corrosion.

Spectral shift and thorium corner rods in boiling water reactors (BWR) also change the character of the nuclide source inventory, but the differences will cause only small changes in effluents. Changes in fuel management and plant operation such as low-leakage fuel management, axial blankets, power coastdown, and six-month cycles have a negligible effect on environmental releases.

Reference

Aaberg, R. L. 1980. Impacts of Uranium Utilization Improvements on Light Water Reactor Radionuclide Releases. PNL-3584, Pacific Northwest Laboratory, Richland, Washington.

Environmental and Safety Overview of Liquid Metal Fast Breeder Reactor

M. A. Lewallen, D. L. Brenchley

The objective of this task was to recommend specific actions the Environmental and Safety Engineering Division (ESED) of the DOE Office of the Assistant Secretary for Environment should take with respect to its overview function in the Conceptual Design Study (CDS)[a] for a Liquid Metal Fast Breeder Reactor (LMFBR).

The scope of this work was limited to literature review of the Fast Flux Test Facility (FFTF), Clinch River Breeder Reactor (CRBR), and Prototype Large Breeder Reactor (PLBR) projects. The findings and recommendations are listed below; the first five are considered Priority I and the second five Priority II.

1. Monitoring at FFTF--A program should be implemented to monitor the performance of environmental control technology at FFTF. This is currently the only opportunity in the United States to review and evaluate the performance of large-scale equipment that might be later specified for commercial LMFBRs. This monitoring project would involve inspecting control equipment and evaluating performance. Such a monitoring program is essential to the Environmental and Safety Engineering Division.

2. Tritium Control--Tritium control technology developed for LWRs should be reviewed to determine if it can be applied to the LMFBR design proposed in CDS. Although total emissions from LMFBRs are less than for LWRs, the guideline of controlling emissions to as low as possible still seems applicable. Recent experimental studies indicate that tritium yields are an order of magnitude greater than previously reported. Most of the tritium is collected in the sodium purification cold traps in the primary and secondary loops. However, if more stringent regulations are applied, then additional control systems must be considered.

3. Hydrogen Monitoring and Control--Hydrogen monitoring and control methods should be reviewed to determine if these methods can be used during the conditions postulated for a hypothetical core-disruptive accident. The hydrogen is produced when sodium comes into contact with concrete, and it poses a potential explosion hazard. The current approach is two-fold. First, steel liners are used to protect the concrete in the event of a spill. Second, analytical studies by FFTF and Clinch River Breeder Reactor (CRBR) staff indicate that natural mechanisms will tend to prevent hydrogen buildup in the event of a spill. Nuclear Regulatory Commission (NRC) staff, however, recommend the use of hydrogen control systems.

4. Licensing--The ability to obtain a license for the environmental control technology specified in the CDS should be determined. In the past, the NRC staff and the Department of Energy (DOE) have often differed on the basic safety and implementation approach. FFTF has received operational approval from NRC, but several points on CRBR were unresolved when that review was terminated by Presidential action in 1977. One area of contention is the use in the reactor cavity of sacrificial materials that do not produce large volumes of hydrogen and other gases in the event of a core disruptive accident or large sodium spill. NRC favors such an approach. Neither FFTF nor CRBR designs contain this feature.

5. Sodium Purification--Cold trap sodium purification technology should be reviewed to determine if the control efficiency of tritium and other radionuclides can be improved by design and/or process changes. Cold traps are used in the primary and secondary sodium loops to control oxygen levels and thus reduce corrosion throughout the system. The oxygen is removed as disodium oxide. Many radionuclides are also removed in the cold traps, but few studies have been conducted to determine removal mechanisms or changes that might increase control efficiency.

(a) This work is being performed by the Reactor Research and Technology Division, Office of Nuclear Energy Programs, U.S. Department of Energy.

6. Sodium Leaks--The technology available for sensing and controlling sodium leaks should be reviewed, including methods for suppressing sodium smoke and preventing its release into personnel areas. Sodium is very reactive with air or water and, since millions of pounds of sodium are used, there is an ongoing concern about leaks. One key to eliminating large spills is detecting and controlling small leaks.

7. Sodium Wastes--The desirability of treating sodium wastes offsite should be evaluated. This has been mentioned as a possibility, presumably for safety reasons. This waste is a concern for two reasons. First, the sodium is highly reactive and hence, caution is necessary, especially for onsite treat ment. Second, the waste contains radionuclides because much of it comes from the sodium cold traps.

8. Activity Limits--The need to place a limit on the maximum activity that can be stored in any part of the Radioactive Argon Processing System at one time must be assessed. This would limit the amount of radiation that could be released in the event of a leak or equipment failure. This is a practical safety point that has been previously recommended by NRC for FFTF.

9. Decommissioning--Special considerations, if any, need to be determined for the decommissioning of a plant. Activated corrosion products plate-out and diffuse into system components; this may make decontamination and subsequent decommissioning more difficult. FFTF staff say that current technology and experience are available to decommission a facility such as FFTF.

10. Shielding--The shielding and maintenance practices associated with the primary sodium loop should be reviewed. Millions of pounds of sodium containing ^{22}Na, ^{24}Na and activated corrosion products are present in this system. While no new technology seems to be required to meet standards, it is a concern unique to LMFBR and, as such, the ESED staff must be in a position to review the system.

Thorium/Uranium Environmental Control Technology

M. A. Lewallen, S. A. Weakley

The objectives of the thorium/uranium environmental control technology project are to: 1) identify the major waste effluents associated with the mining, milling, and refining of thorium and low-grade uranium; 2) identify existing environmental control technologies for these effluents and determine their costs and the current levels of control; and 3) identify environmental control technologies that could be used to meet more stringent control standards and determine their costs as a function of the level of control. All three of these objectives are completed for thorium and have been reported on (Blahnik et al. 1980). Cost results are summarized in Table 2.9. The lower cost figures are for state-of-the-art environmental control technology at each site.

Table 2.9. Cost Range of Environmental Control for the Mining, Milling, and Refining of Thorium Resources

Location	Approximate Cost Range [a,b] (Cost/lb Thorium Produced)
Lemhi Pass	$ 0.63 - 40.65
Hall Mountain	0.28 - 16.35
Wet Mountain	0.34 - 18.96
Palmer, Michigan	0.46 - 2.13
Bald Mountain	4.29 - 26.22
Conway Granite	0.43 - 4.56
Stockpile Refinery[c]	0.15 - 1.98

(a) Maximum cost is for the more effective, but usually more complex, methods and includes up to a 200% contingency on estimates.

(b) Minimum cost represents the base technology, which is usually the most available, lowest cost, and simplest to employ (e.g., equipment constructed of mild steel, easy to move soil, good onsite availability of construction materials, no special protection from the environment, low contingency, etc.)

(c) Does not include mining and milling environmental control costs.

Reference

Weakley, S. A., et al. 1980. Economic and Environmental Impacts of Thorium Mining, Milling and Refining. PNL-3253, Pacific Northwest Laboratory, Richland, Washington.

• Analysis of Fusion Fuel Cycles

The objective of this task is to undertake an independent review and analysis of current fusion facilities that have or will generate tritium wastes and effluents to the environment. Consideration is given to those fusion facilities that are in operation or under construction. These include the magnetic fusion facilities: Tokamak Fusion Test Reactor (TFTR), the Tritium Systems Test Assembly (TSTA), and the Fusion Materials Irradiation Test Facility (FMIT). Facilities in the Inertial Confinement Fusion area will also be reviewed and analyses made of the tritium control problems. Based on these analyses, experimental data needs to support the environmental control technology of fusion facilities will be evaluated.

A Survey of Tritium Wastes and Effluents In Near-Term Fusion Research Facilities

W. E. Bickford, D. A. Dingee,
C. E. Willingham

The objective of the survey of tritium wastes and effluents in near-term fusion research facilities is to develop and evaluate the experimental data needed to support the environmental control technology in those facilities.

Tokamak Fusion Test Reactor

The Tokamak Fusion Test Reactor (TFTR) at the Princeton Plasma Physics Laboratory, Princeton, New Jersey is designed to demonstrate fusion energy production from the pulsed burning of deuterium and tritium in a magnetically confined toroidal plasma. The Preliminary Safety Analysis Report (PSAR) for the facility has identified routine generation of radioactive wastes in the solid, liquid, and gaseous form. Several areas identified have yet to be quantified because of lack of operational experience.

Leakage of process cooling water from pump seals, flange leaks, etc. will present a problem owing to activation of corrosion products of copper and stainless steel. The total equilibrium activity in the water is estimated at 5.3×10^{-7} μCi/cc from copper and 4.6×10^{-9} μCi/cc from stainless steel. The volume of water leaked is expected to be small, and collection and decontamination procedures used in the nuclear industry should suffice.

The use of zirconium/aluminum getter surfaces in the torus for tritium pumping also needs further analysis. The original design called for the use of Zr/Al pumps located in the tritium vault to pump tritium during D-T pulses. The new concept would add getters in the torus itself, occupying a significant portion of the surface area available. The use of this concept offers significantly reduced tritium inventories available for routine permeation and release to the environment. However, the regeneration characteristics of the panels are uncertain. If removal is required, control measures for removal, handling, processing, and possibly shipping must be considered.

Tritium Systems Test Assembly

The Tritium Systems Test Assembly (TSTA) under construction at Los Alamos Scientific Laboratory (LASL) is designed for development and demonstration of technologies related to the deuterium-tritium fuel cycle in fusion power plants. The facility essentially consists of a gas process loop to handle a flow of up to 500 moles per day of DT. On-site tritium inventories will be approximately 200 gr. No actual fusion processes will occur in the facility. Instead, they will be simulated by the injection of helium and other impurities into the fuel stream. As such, no activation products are generated and tritium will be the only radionuclide of concern.

One of the prime functions of TSTA will be the development and demonstration of control technology for tritium. As such, the estimates on design goals for tritium release during operation are just that. However, the technology to be used is based on existing experience in U.S. tritium handling facilities. Rigid quality control on equipment and plumbing for primary containment is coupled with the use of secondary containment (glove boxes, etc) and the processing of glove box atmospheres. Catalytic oxidation of tritium to water in effluent streams and storage on molecular sieve beds have proved very successful in actual use. The TSTA facility will go one step further in providing an emergency tritium cleanup system (ETC) for large releases within the building. This is again based on catalytic oxidation to water and storage of condensates in water tanks or on molecular sieve beds.

The design goals for TSTA tritium releases, taken from the facility PSAR, are given in Table 2.10. If these design goals are met, chronic exposures due to airborne releases from TSTA will be minimal. Assuming half the vacuum system release from Table 2.10 goes up the stack, the expected annual release ranges from 60 to 95 Ci/yr. The dose equivalent (DE) can then be calculated using the following assumptions:

- 96 rem/Ci for tritium in oxide form
- 75% of tritium inhaled is absorbed
- 63% of intake on skin
- 2.64×10^{-4} m^3/s breathing rate
- $\bar{x}/Q = 10^{-4}$ s/m^3 for TSTA site.

The dose equivalent for release of 100 Ci/yr is then

$$DE = (1.38) \times (96 \frac{rem}{CI}) \times (100 \frac{Ci}{yr}) \times (2.64 \times 10^{-4} \frac{m^3}{s}) \times (10^{-4} \frac{s}{m^3}) = 0.35 \text{ mrem/yr}$$

Table 2.10. Design Goal Tritium Releases

Subsystem	Release
Isotope Separation	20 Ci/yr as gas to room air and up exhaust stack
Fuel Cleanup	60 Ci/yr to Tritium Waste Treatment (TWT)
Vacuum System	80 to 150 Ci/yr to room air and TWT system
Glove boxes, pumps, etc.	20 Ci/yr to TWT

In comparison, the PSAR for the facility conservatively estimates 100% of all tritium inhaled is absorbed, assuming release of 200 Ci/yr. This gives a DE of 0.8 mrem/yr for someone standing near the TSTA building year round.

Dose calculations for the design bases accident give no credit to operation of the ETC system. A release of 100 gr is assumed in the PSAR to result in an exposure of 4.7 rem. The design basis for the ETC in a 100 gr release in the facility is to limit releases to ~0.12 Ci over a 24-hour period. This would significantly reduce the accident consequences.

Waste generation for the TSTA facility during routine operation is estimated in the PSAR as 50 to 200 m^3 of solids, consisting mostly of paper, rags, gloves, etc. This should include water on molecular sieve beds from waste treatment and pump oils on vermiculite. Only very low tritium concentrations would be discharged to the sewer, estimated in the PSAR at less than 2 kg/week. The higher activity water from waste treatment streams would be stored on molecular sieve as mentioned and placed in 30-gal (113-ℓ) drums. These drums will in turn be placed in asphalt-lined 50-gal (208-ℓ) drums for disposal at the Los Alamos waste disposal site. This disposal method has proven satisfactory in the past, so no additional control measures are foreseen.

An independent review of waste volumes produced of contaminated molecular sieve beds and oil on vermiculite from vacuum pumps indicates that the volume produced will easily be within the 50 to 200 m^3/yr predicted by LASL for TSTA operation. With LASL generating an average total of 5700 m^3/yr of contaminated wastes, the operation of TSTA does not present an unacceptable burden on existing waste handling operations.

Fusion Materials Irradiation Testing Facility

The Fusion Materials Irradiation Testing Facility (FMIT) being built on the Hanford Reservation near Richland, Washington will use a high-energy deuteron beam to produce neutrons by a stripping reaction with flowing liquid lithium. Material samples will be exposed to the neutron flux for damage studies.

Radioactive gases will be generated during FMIT operation by activation of air in the irradiation test cells and around the linear accelerator and beam transport system and by production of tritium in the lithium target stream. The test cell air tritium results from the ^{14}N (n, ^{3}H) reaction. Only small amounts of ^{3}H are actually generated, about 2 x 10^{-9} Ci/sec.

Activation of accelerator air results from high-energy neutrons interactions with the atmosphere in the shielded accelerator room and beam transport tunnel. The production rate of tritium is very small, approximately 1.5 x 10^{-4} of the test cell production rates.

Tritium is produced in the target stream by deuteron and neutron reactions with lithium at a rate of 54 Ci/day. The total amount of tritium released to the environment will be about 0.06 Ci/yr. Tritium getter units, probably zirconiumaluminum will be installed so that the vacuum system can minimize the release of tritium to the environment.

Inertial Confinement Fusion

A review of the NOVA and ANTARES projects under way at Lawrence Livermore Laboratory (LLL) and at LASL respectively, was done to evaluate the tritium and activation product concerns. These projects consist of large pulsed laser driver systems (40 to 300 KJ in about a nanosecond pulse width) impinging a specially designed fusion target. The fusion neutron yields are expected to be substantial so there will be environmental concerns.

During FY 1980 the project done for the Environmental Control Technology centered on concerns with tritium handling. Table 2.11 shows the quantities of tritium under consideration.

Procedures which are proposed for handling the routine fabrication and transport of the tritium targets are judged to be adequate. They include:

Table 2.11. Tritium Use in Currently Planned Inertial Fusion Test Facilities

	Quantity of Tritium in Use		
	In Fabrication	In Targets (500/yr assumed)	As Waste
NOVA	2g (20,000 Ci)	200 mg (2 Ci)	Assumed to be all from targets
ANTARES	2g (Est.) (20,000 Ci)	100 nanogram (1 mCi)	Assumed to be all from targets

- using monitors capable of detecting single pellet release
- treating vacuum debris through molecular sieves
- operating areas at partial vacuum
- using adequate stack heights for release
- using moisture barrier paints in areas where tritium is present
- constantly circulating air in all areas where tritium is handled
- using inert atmospheres to avoid oxidation/explosions

Accidents were also considered. A PNL independent analysis confirmed the LLL and LASL estimates to within a factor of 2 or so. These results are reproduced in Table 2.12. The most serious accident is seen to be a potential exposure of an operating crew to a tritium release into the fuel fabrication area, where concentrations could reach 72 MPC. However, the leakage would be immediately detected by monitors in the air allowing for evacuation and cleanup operations. The actual exposure to operating staff is expected to be within maximum permissable limits. To prevent leakage of tritium from a target fabrication accident from leaking into other

Table 2.12. Accidental Tritium Dose Estimates

	LLL Estimates	PNL Estimates
Handling Releases (2 Ci/month up 30-m stack)	0.2 mrem/yr	0.18 mrem/yr
Potential Maximum Release of Unburned Tritium (1000 Ci/yr up 30-m stack)	2.7 mrem/yr	1.2 mrem/yr
Instantaneous Release of all Tritium in Fuel Fabrication (20,000 Ci up 30-m stack)	416 mrem	160 mrem
Release of One Pellet Tritium into Fuel Fabircation Area (2 Ci in ~5000 m^3)	72xMPC	72xMPC

rooms, a target room will be designed for a 2-hour holdup prior to discharging up the 30-m stack.

It is to be noted that much of the information regarding Environmental Control Technology to be applied to Inertial Fusion was developed by LLL. It is assumed in this analyses that LASL will apply the same technology.

3 Operational and Environmental Safety

OPERATIONAL AND ENVIRONMENTAL SAFETY

- **DOE Decommissioning Criteria Development**
- **Environmental Protection Support**
- **Handbooks on Effluent and Environmental Monitoring**
- **Environmental Data Reporting System**
- **Personnel Dosimetry Calibrations**
- **Health Physics Lead Laboratory**
- **Analysis of Criticality Safety**

The responsibility of the Department of Energy (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 Pacific Northwest Laboratory's Operational and Environmental Compliance Program contributes to these objectives through projects in the nuclear and nonnuclear areas. Nonnuclear research and development is assuming growing significance and in the future will constitute a major portion of the program. During 1980 the major emphasis continued to be 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.

• DOE Decommissioning Criteria Development

This project was begun in the third quarter of FY 1979 to prepare a guide on the development and use of decommissioning criteria by Department of Energy (DOE) staff and contractors. The guide is for use both in the planning and implementation of decommissioning operations and in the certification of decommissioned DOE facilities and sites. A working draft of the Guide was prepared and forwarded for sponsor review in FY 1980. An extension of this effort to nonradiological hazardous materials was begun in the last quarter of FY 1980 with the development of a questionnaire for DOE contractor sites to identify and quantify nonradiological waste inventories.

Criteria Development for DOE Decommissioning Operations

D. H. Denham, J. P. Corley, R. O. Gilbert, G. R. Hoenes, J. D. Jamison, R. E. Jaquish, B. J. McMurray, E. C. Watson

The primary objective of this project is to prepare guides for the development and use of specific criteria by DOE and its contractors in conducting decommissioning operations. These guides are intended to provide a uniform basis for assessing hazardous waste inventories, developing environmental risk analyses, making decisions for further decontamination, monitoring for compliance with Federal standards, and certifying decommissioned sites. The study was initially concerned with radioactive contaminants, but has been expanded to include the identification and quantification of other contaminants.

An overall decommissioning effort (other than the actual remedial action) is expected to involve a series of 15 to 20 steps, some of which may be repeated. A flow plan for these steps, shown in Figure 3.1, includes the elements thought to be required to perform the complete cycle. Three decision points are shown: comparison of the calculated doses with DOE-provided dose criteria (occupational and environmental), comparison of the site survey data with the calculated maximum acceptable contamination levels (based on dose criteria and pathway analyses), and comparison of the certification survey results with the design objectives.

The approach used in the draft Radiological Guide is to determine acceptable levels for residual environmental contamination based on the maximum annual dose to an individual via all environmental pathways. It is not within the scope of this guide to provide specific numerical dose limits; however, we recognize that without such limits it is difficult to maintain focus and perspective. Therefore, we propose to compare the maximum individual dose with three possible control levels: maximum, design objective, and *de minimis* (see Figure 3.2). The maximum limit for environmental exposure is the current DOE standard of 500 mrem/yr for individuals in uncontrolled areas. At the other extreme, we define a *de minimis* level of 1 mrem/yr to the maximum individual as the minimum dose of concern. Between the maximum limit and the *de minimis* level is a design objective level, defined as the maximum acceptable dose for designing a decommissioning program at a given facility. A specific value for the design objective level is deliberately not shown, but will fall within a range between the maximum limit and the *de minimis* level. The design objective level will be site-specific based on the "as low as reasonably achievable" (ALARA) concept. A suggested methodology for determining site-specific numerical guidance, based on maximum annual individual dose, is included in the guide.

A working draft of the *Radiological Guide for DOE Decommissioning Operations* was prepared by PNL and forwarded to the sponsor for internal review. It includes:

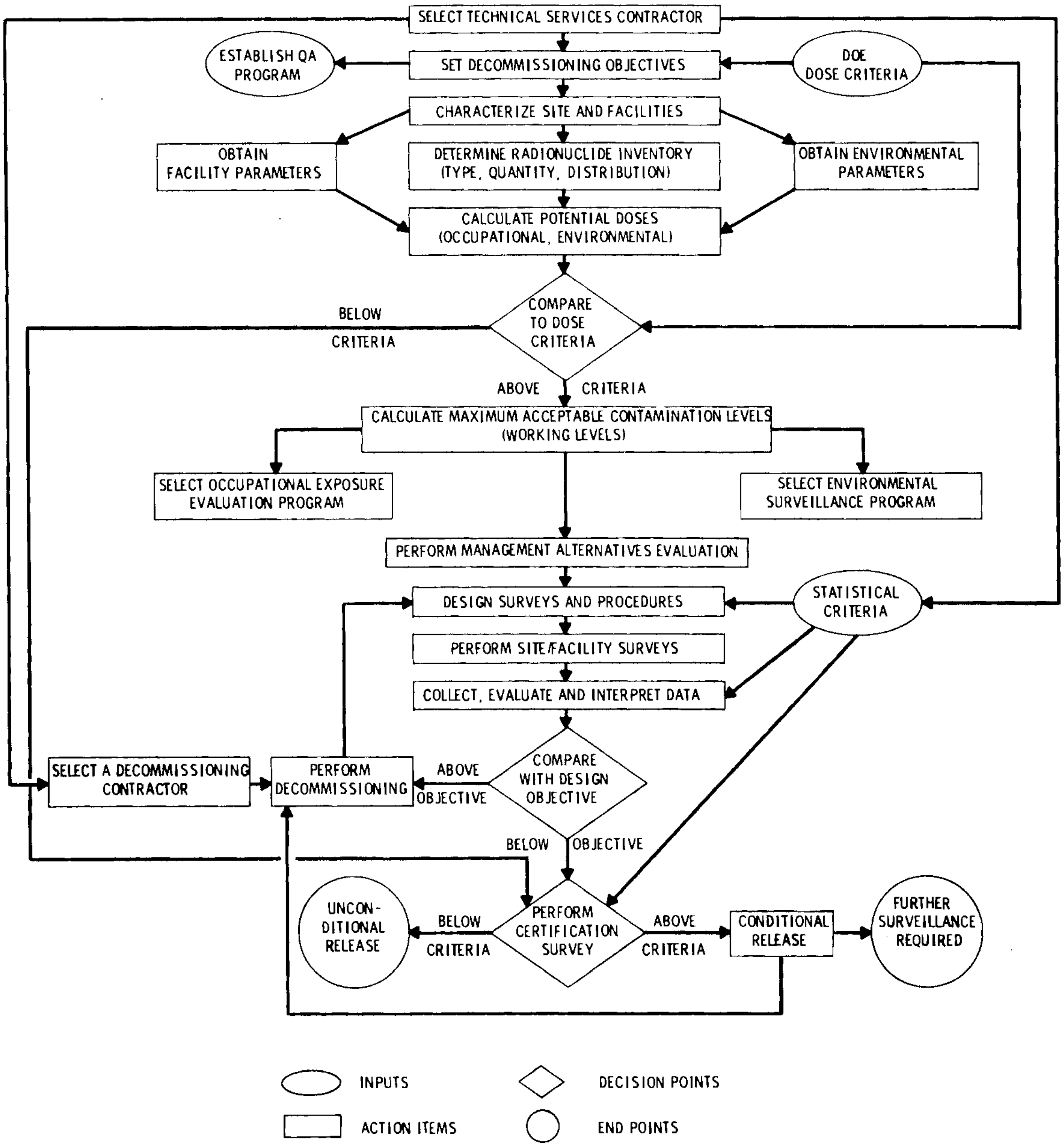

Figure 3.1. Radiological Decommissioning Plan Flow Chart. It is assumed that this process will be documented and that quality control measures will be applied to all sampling and measurements based on the quality assurance program.

1. a listing of basic radiation standards and guiding principles to be met for DOE decommissioning operations

2. recommendations for site characterization, including statistical design, sampling techniques, and instrumentation performance criteria, and review and evaluation of similar methods derived by Oak Ridge National Laboratory under Nuclear Regulatory Commission (NRC) contract for confirming radioactivity levels

3. selection and evaluation of methods for estimating occupational radiation exposures during decommissioning operations and for estimating environmental exposures before, during, and after decommissioning operations, including unplanned releases

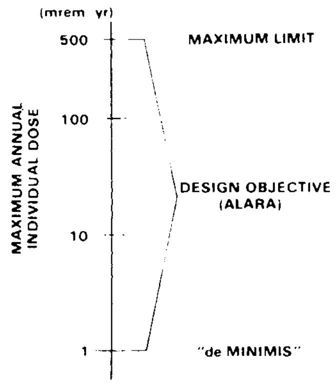

Figure 3.2. Relationship of Design Objective Maximum Annual Dose for Decommissioning to DOE Limit and *de Minimis* Level

4. recommendations for generating and maintaining records and for quality assurance procedures.

During FY 1980, PNL conducted a workshop for the exchange of information among PNL task leaders, a special DOE Task Force, and other DOE site contractor personnel; representatives of the Environmental Protection Agency and NRC were included as observers. The workshop focused on the draft Radiological Guide, identifying the PNL approach to the development of radiological criteria for DOE decommissioning operations.

The PNL team for this project also provided review of and consultation on DOE decommissioning requirements for the old New Brunswick Laboratory site in New Jersey. At DOE Headquarters' request, similar assistance was provided throughout the fiscal year on other decommissioning projects.

• Environmental Protection Support

This project was initiated at mid-year. Assistance in planning was provided for a Department of Energy (DOE) and contractor staff information meeting in early FY 1981 in compliance with the Resource Conservation and Recovery Act. A questionnaire to clarify the extent and content of quality assurance provisions in effluent and environmental monitoring programs was prepared and distributed to DOE sites as part of an emergency preparedness questionnaire distributed under another project. A draft section on quality assurance was provided for possible inclusion in a revised DOE Orders chapter. A review of available documentation for DOE sites on the methodology used to calculate environmental dose was partially completed, and a questionnaire for possible site distribution was drafted. A questionnaire to DOE sites to determine existing inventories of nonradiological materials in waste storage sites was prepared.

Environmental Protection Support and Assistance--DOE/OESD

J. P. Corley, P. J. Cowley, G. W. Dawson, R. E. Jaquish, E. C. Watson

The objective of this program is to provide technical support to the Environmental Protection and Public Safety (EP&PS) Branch of the Operational and Environmental Safety Division (OESD), with the capability and flexibility to respond to the most pressing needs and changing priorities.

Defined as initial task areas were:

1. reviews and comments on proposed legislation, regulations, draft DOE Orders, and other guidance
2. assistance with Branch-sponsored conferences and information meetings
3. review of and recommendations on environmental and effluent data reporting requirements
4. review of and recommendations for improving the methodology used to assess environmental dose
5. review and definition of quality assurance requirements for environmental and effluent monitoring programs
6. assistance in the management of hazardous toxic materials
7. assessment of the need for and feasibility of a follow-on program for DOE environmental impact statements
8. assessment of the current state of environmental radiological monitoring capabilities in emergency situations.

For FY 1980, items 7 and 8 were funded separately.

DOE Information Meeting on RCRA Compliance

Assistance was provided to the EP&PS Branch in planning the program and arrangements for an information meeting for DOE and site contractor staff scheduled for early FY 1981. The focus of the meeting was on DOE compliance plans and problems with the Resource Conservation and Recovery Act regulations due for enforcement by the Environmental Protection Agency in November, 1980.

Quality Assurance Requirements for Environmental and Effluent Monitoring

The scope and extent of specific quality assurance requirements for environmental and effluent monitoring have been difficult to determine from routine DOE site reports. As part of an emergency preparedness questionnaire to the sites, prepared under the Health Physics Support project, a module specifically addressed to quality assurance was prepared and included. No responses had been returned by the end of FY 1980.

• Handbooks on Effluent and Environmental Monitoring

An updating of the *Guide for Environmental Radiological Monitoring at DOE Installations* was submitted to the Department of Energy (DOE) Environmental Protection Branch for comment. Issue of the draft *Guide for Effluent Monitoring at DOE Installations* was again delayed because of further regulatory requirements. An analysis and evaluation of CY 1978 annual environmental surveillance reports from DOE nuclear sites was submitted to the Environmental Protection Branch. A draft Executive Summary of 1978 environmental impacts from all DOE nuclear sites was 90% completed.

Handbooks of Recommended Practices for Environmental and Effluent Monitoring and Reporting

J. P. Corley, B. V. Anderson, G. W. Dawson, D. H. Denham, R. E. Jaquish, L. C. Schwendiman

The objectives of the project are to provide:

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

2. evaluations and summaries of DOE sites' annual environmental reports and programs for use by the Operational and Environmental Safety Division.

Environmental Surveillance Guide

The usefulness of the Environmental Surveillance Guide, previously prepared under this project, continued to be demonstrated by referencing of and requests for the document. A revised edition was submitted to the sponsor for comment and eventual issue as a DOE document. The organization and regulations were updated, and a new quality assurance chapter was added.

Effluent Monitoring Guide

Continuing uncertainty as to eventual regulatory requirements stemming from the 1977 amendments to the Federal Water Pollution Control Act and Clean Air Act caused further delay in issuing the draft guide. Sections on criteria and on specific monitoring methods may need revision. By agreement with the sponsor, final draft revisions and a workshop for DOE field office and contractor staff were postponed to FY 1981.

Environmental Reports Evaluation

Analysis of the CY 1978 annual environmental reports and supporting surveillance programs for the 29 DOE nuclear sites reporting was completed and a letter report submitted to the sponsoring branch. Evaluations and comparisons were made against both the requirements of former ERDA Manual Chapter 0513 (being reissued as DOE Orders 5480.1, Chapter XVIII) and the Environmental Surveillance Guide, ERDA-77-24.

DOE Executive Summary of Environmental Impacts

A draft executive summary of CY 1978 environmental impacts from all 29 DOE nuclear nuclear sites, for issuance as a DOE document, was 90% completed. Supplemental information from several sites is still needed. The CY 1977 summary included site maps, brief site and operations descriptions, tabulations of radiation doses to individuals and populations (those within an 80-km radius), and quantities of both radioactivity and nonradioactive pollutants released. Several changes of format were made for clarity.

• Environmental Data Reporting System

A draft interim report on the content and routing of existing environmental data reporting was prepared, including a discussion of alternative approaches to use of a computerized data base and recommendations for further efforts.

Environmental Data Reporting System for DOE Sites

J. P. Corley, P. J. Cowley

The environmental data reporting system between DOE site contractors, field offices, and the Environmental Protection and Public Safety Branch was analyzed, including the contents of each type of report, responsibility for preparation, and routing. The extent of computerization of this effort at DOE sites was not analyzed, but alternative approaches to the use of computer data bases were studied. The need for improved telecommunications became increasingly apparent as this effort progressed. Recommendations for routine report content and for the direction of future efforts were incorporated in a draft interim report.

• Personnel Dosimetry Calibrations

A base of technical information will be acquired and developed for evaluating the calibration, design and performance of dosimeters used at Department of Energy (DOE) facilities. A technical document will be prepared to guide DOE and DOE contractors in selecting appropriate personnel dosimetry calibrations. Draft criteria presented by the American National Standards Institute (ANSI 1978) will be used as a guide for establishing recommended dosimeter calibration and irradiation procedures.

Technical Guidelines for Personnel Dosimetry Calibrations

R. C. Yoder, C. D. Hooker, R. A. Fox,
J. W. Courtney, R. T. Hadley, J. M. Selby

The purpose of this project is to assemble information to guide DOE and DOE contractors in selecting methods for personnel dosimetry calibrations. Personnel dosimetry performance, a major concern of radiation protection officials, is strongly influenced by dosimeter calibration techniques. The calibration enables the response of a personnel dosimeter to radiation to be correlated with the radiation dose received by an individual. Errors and uncertainties arising in the calibration are propagated through the entire personnel dosimetry system, often causing incorrect assessments of personnel radiation doses. The judicious selection and correct implementation of calibration methods can significantly aid dosimetry performance.

Calibration information for this project is being derived in two phases. The first phase, nearly complete, was the predominant project activity in FY 1980 and consisted of developing a variety of well-calibrated radiation fields for use in dosimetry performance investigations. Uncertainties in the use of these radiation fields were investigated and potential errors were minimized. The second phase concerns the accumulation of response and performance data for the dosimeters used by DOE contractors. Dosimeters will be irradiated using the radiation fields and calibrated using the information developed in the first phase. This second phase is scheduled to begin early in FY 1981.

This project is being conducted in conformance with criteria presented in the draft standard American National Draft Standard Criteria for Testing Personnel Dosimetry Performance, ANSI N13.11 (ANSI 1978). Although the draft standard does not directly address dosimeter calibrations, calibration methods must be selected and employed to be compatible with the irradiation techniques used for dosimeter performance evaluations. The performance tests specified in the draft standard reflect several concepts that have not been routinely incorporated in many calibration programs.

The preparation of a document detailing the information obtained in the project will constitute phase three. This document will serve as a guide for developing and performing dosimeter calibrations that enhance personnel dosimetry performance. The information presented in the document will reflect implementation of the ANSI N13.11 draft standard and will help improve personnel dosimetry by influencing the design of future dosimeters.

Optimization of Calibration Techniques

This phase has been the major project activity for FY 1980. Table 3.1 presents the radiation fields that have been assembled for the project. Intercomparisons and calibrations for gamma-ray, x-ray, beta, and fast neutron dosimetry have been obtained from the National Bureau of Standards. Special devices for the precise irradiation of large numbers of dosimeters have been obtained. Additionally, variables influencing the degree of uncertainty in calibrations have been studied. A process control system has been obtained and put in use. This system will monitor, correct, and control calibration variables that can adversely affect the quality of calibrations and dosimeter performance irradiations. Another important part of this phase, recently completed, was the

Table 3.1. Available Radiation Field for Irradiating Personnel Dosimeters

Filter X-Rays (Polyenergetic):

National Bureau of Standards Technique	Assigned Energy, keV
L-G	15
L-I	21
L-K	26
MFC	32
MFE	34.5
MFG	42
MFI	64
MFK	84
MFM	111
MFO	140
HFE	70
HFG	117
HFI	167
HFK	210

K-Fluorescence X-Rays (Near Monoenergetic):

Irradiator Element	Assigned Energy, keV
Zr	16.1
Cd	23.7
La	34.3
SmGd	43
Ta	58
Pb	78
U	100

Gamma-Ray Source:	Energy, keV
^{137}Cs	662
^{232}U + daughters	240 to 2614

Beta-Particles Source:	Energy, meV
^{90}Sr/^{90}Y	2.29, 0.549
^{106}Ru/^{106}Rh	3.54
^{85}Kr	0.67

Neutron Source:	
^{252}Cf	Fast Neutron Spectrum

measurement of factors relating exposure to dose equivalent. These measurements were essential for validating the selection of appropriate factors that have been considered for inclusion in the ANSI draft standard (Yoder et al. 1979).

Development of a Dosimeter Performance Data Base

In this second phase of the project, DOE contractor laboratories will be requested to submit personnel dosimeters to be irradiated in accordance with techniques developed in the first phase. A primary dosimeter calibration will be provided to each dosimeter processor. The performance of the dosimeters when evaluated with the primary calibration data will be compared with the corresponding performance based on each contractor's normal calibration data. The information derived in this phase will indicate the relative merits of different calibration regimes for accurately assessing dose equivalent under specified conditions.

Preparation of a Calibration Procedure Manual

The irradiation and calibration techniques used in the study will be documented. The resulting information will permit a uniform approach to radiation calibrations by DOE laboratories.

References

American National Standards Institute. 1978. Draft American National Standard Criteria for Testing Personnel Dosimetry Performance. ANSI N13.11, New York, New York.

Yoder, R. C., W. T. Bartlett, J. W. Courtney, C. D. Hooker, J. P. Holland and B. T. Hogan. 1979. Confirmation of Conversion Factors Relating Exposure and Dose-Equivalent Index Presented in ANSI N13.11. PNL-3219, Pacific Northwest Laboratory, Richland, Washington.

• Health Physics Lead Laboratory

Pacific Northwest Laboratory functions as the lead laboratory providing health physics support and assistance to the Division of Operational and Environmental Safety, Department of Energy (DOE), on special studies principally associated with the analysis of impact of standards, regulations, and engineering and administrative actions on occupational and environmental exposure. Support and assistance are also provided for other specific tasks or special studies identified by DOE as priorities. The designation of lead laboratory in health physics, with an agreement and budget in place, provides the Division with the additional expertise necessary to respond to the many questions and situations that arise during the operation of their numerous nuclear energy research, development, and demonstration facilities.

Health Physics Support and Assistance to the Department of Energy

L. G. Faust, J. M. Selby

Personnel Dosimetry Records Repository

J. J. Fix

A personnel radiation exposure repository and reporting system was begun by the U.S. Atomic Energy Commission (AEC) in 1968 for AEC employees and contractors. During the intervening years, the repository has fulfilled its original purpose of providing exposure overviews and information for the annual report covering the government's research facilities (now under the Department of Energy (DOE)).

In 1980, a 2-year study was begun to identify feasible alternatives for upgrading the repository data base and its uses. Input for evaluating the status of the facility-specific personnel dosimetry records and their relationship to the repository records has been received from all major DOE facilities. Three topical reports have been identified covering: 1) personnel dosimetry practices at DOE facilities, 2) an overview of DOE's radiation exposure repository, and 3) alternatives to provide an upgraded system for reporting exposure information.

Assessment, Analysis, and Recommendations for Personnel Neutron Dosimetry

L. W. Brackenbush, *Ad Hoc* Headquarters Committee

This task, begun last year, was completed with the issuance of the document *Personnel Neutron Dosimetry at DOE Facilities*, PNL-3213. The document underwent two peer reviews by dosimetry experts, and extensive revisions. The final document incorporates many of the ideas and conclusions reached at a special neutron dosimetry workshop held in Seattle, July 17-18, 1980. These include:

- establishing a lead laboratory to direct the necessary research
- optimizing current dosimetry programs and systems
- performing research leading to the development of new types of dosimeters and neutron detection mechanisms
- establishing a neutron dosimetry "think tank" to suggest new areas of research and development and to provide guidance to DOE at least until the lead laboratory is established

- establishing adequate calibration techniques and facilities
- sponsoring symposia, workshops, and intercomparison studies.

In addition, the document contains descriptions of current personnel neutron dosimeters in use at DOE laboratories, and information about a wide variety of neutron detectors that could be developed into useful dosimeters.

Field Testing, Calibration, and Standardization Techniques for Improved Neutron Spectrometry

L. W. Brackenbush, R. I. Scherpelz

All personnel neutron dosimeters in use today are highly energy dependent; hence, to properly evaluate the dosimeter results, it is necessary to know something about the neutron energy spectra where the dosimeters are used. The purpose of this task is to evaluate several types of neutron spectrometers that could be used by health physicists to determine neutron energy spectra in work locations. To carry out this task, the following objectives were established:

1. Assemble and calibrate three neutron spectrometer systems to a range of neutron energies from thermal to 20 MeV.
2. Field test the systems in neutron spectra typical of the work areas where personnel are exposed at selected DOE facilities.
3. Develop standardized techniques and procedures for use of the spectrometer systems in the field.

Three types of spectrometers were selected: 1) a multisphere or Bonner sphere spectrometer, 2) a ^{3}He spectrometer, and 3) an NE-213 liquid scintillator spectrometer. The multisphere spectrometer is the standard type used by health physicists; it is useful over a broad range of energies and intensities, but has poor resolution. The ^{3}He spectrometer is quite sensitive, has good resolution, and is useful in the energy range of 20 keV to 1 MeV. However, neutrons above 1 MeV cause serious problems in unfolding the data. The NE-213 liquid scintillator is a proton recoil device useful from perhaps 100 keV to 20 MeV or more.

A multisphere spectrometer and a ^{3}He spectrometer were assembled from commercially available components, then calibrated by exposures at the filtered neutron beam facility at the National Bureau of Standards and the cyclograaff accelerator at Lawrence Livermore Laboratory. Serious delays were encountered in assembling the NE-213 liquid scintillator spectrometer.

Some field measurements were made with the multisphere spectrometer and the ^{3}He spectrometer systems in plutonium fuel fabrication and storage facilities and a fast breeder reactor at Hanford. As shown in Figure 3.3, the spectra were essentially spontaneous fission spectra, with a greater number of low-energy neutrons in facilities with more shielding.

Because of the assembly delays, the field measurements at DOE facilities were delayed, and emphasis was shifted to the development of unfolding codes, data analysis, and documentation of standard operating procedures. The multisphere data are analyzed by the computer code LOUHI, a large, relatively complex code available at Lawrence Livermore Laboratory. A much less complex code being developed is small enough to operate on the multichannel analyzer/minicomputer systems available at most DOE sites. A very simple code, HESPEC, has been written to analyze the data from ^{3}He spectrometers. The NE-213 spectrometer data are analyzed by the code FORIST, which is available from the code center at Oak Ridge.

A Guide to Reducing Radiation Exposures to as Low as Reasonably Achievable (ALARA)

R. L. Kathren, R. C. Yoder, A. E. Desrosiers, N. P. Nisick, Ad Hoc Headquarters Committee

The ALARA (As Low As Reasonably Achievable) concept has wide application and serves as the basis for sound health physics programs. The ALARA objective is to reduce personnel and environmental radiation exposures to the lowest levels commensurate with sound economics and operating practices. Realistic numerical goals can be set and achieved, and represent one aspect of an ALARA program. However, the success of an ALARA program is measured by many factors, including such intangibles as dedication to the concept of dose reduction.

This study, begun in 1976, has resulted in two documents, Technical Guidelines for Maintaining Occupational Exposures as Low as Practicable--Summary of Current Practices (August 1978, PNL-2664) and A Guide to Reducing Radiation Exposure to as Low

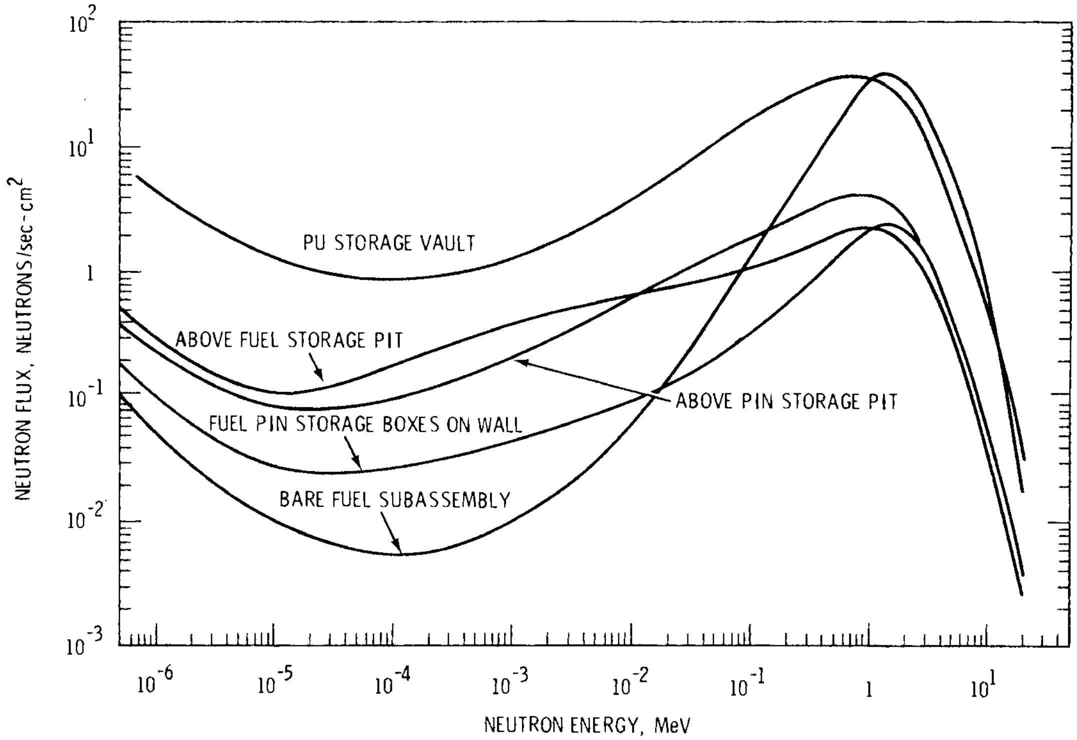

Figure 3.3. Neutron Spectra Measured by Multisphere Spectrometer at Plutonium Fuel Fabrication Facility

as Reasonably Achievable (ALARA) (April 1980, DOE/EV/1830-T5). The latter report contains guidance for ALARA programs through discussion of the following topics: risk, cost, and benefit; management and organization; education and training; radiological design; measurement of radiation in the field; operational health physics; environmental protection; emergency preparedness; and program evaluation.

Special Air Sampling Study at the Paducah Gaseous Diffusion Plant

J. M. Selby, R. P. Shaw, J. A. Glissmeyer, L. G. Faust, C. M. Unruh, R. L. Kathren, L. C. Schwendiman

A general short-term air sampling study was conducted in April 1980 at the Union Carbide Gaseous Diffusion Plant in Paducah, Kentucky. The purpose of the study was to develop additional information on potential occupational exposure to airborne hydrolysis products of UF_6 during transfer operations. Of interest in the study were the products of this rapid hydrolysis: UO_2F_2 (a solid) and HF (a gas).

Sixty-nine air particulate samples (for UO_2F_2) were taken during a 24-hr period. Six HF samples were collected and analyzed during the same period.

Personal lapel samples, breathing zone samples, and room air samples were collected during typical work activities. The samples were counted at Union Carbide facilities under supervision of Battelle personnel and then recounted at Battelle's Pacific Northwest Laboratory facilities. The two sample evaluations showed reasonably good correlation. All sample results indicated that airborne concentrations of the hydrolysis products of UF_6 were well below maximum permissible concentrations. Evaluation is still in progress and will be incorporated in the final report to be issued by DOE.

Radiation Survey of Bartlesville Energy Technology Center

J. M. Selby, R. P. Shaw, J. M. Taylor,
C. D. Hooker, B. J. McMurray

In response to a request from the Bartlesville Energy Technology Center (BETC), received via DOE Headquarters, a team consisting of five PNL staff members and one DOE/DOES staff member was formed to perform a complete radiation survey of BETC. The survey, completed on June 18, 1980, included measurements of direct radiation and surface contamination in numerous areas of BETC. Measurements of ^{3}H, ^{14}C, and alpha, beta, and gamma radiation were made by smear and direct surveys. The hot cell, accelerator room, laboratories, and associated ventilation systems were surveyed in detail. Preliminary inventories of sealed sources and various waste containers were also taken, and a set of environmental samples was collected.

Based on the results of the radiation survey, it was recommended that:

- certain exhaust systems (including several fume hoods) be removed and disposed of
- a complete source inventory be conducted
- it be determined whether concentrations of transuranic elements in packaged solid waste were less than 10 nCi/g
- liquid wastes stored onsite be identified and an inventory determined
- approximately 1.5 yd^3 of solid waste previously disposed of be repackaged and shipped offsite for proper burial
- a complete radiation survey of miscellaneous laboratory hardware items be performed.

Characterization of DOE Facility Emergency Preparedness

E. E. Oscarson, F. J. Borst,
A. E. Desrosiers, M. L. Smith

In 1970, a study was initiated at the request of the U.S. Atomic Energy Commission and the Advisory Committee on Reactor Safeguards to characterize emergency preparedness capabilities at nuclear sites. The primary emphasis of that study was the capability of then-current instruments to cope with emergency conditions. Five reports (BNWL 1552, 1635, 1742, 1857, and 1991) were issued based on the study.

As a result of the lesson learned from Three Mile Island, the Department of Energy (DOE) has requested an extension of the previous study to characterize current emergency capabilities and to upgrade the five reports where necessary. The program involves the development of a questionnaire that has been sent to all DOE contractors, coupled with site visits, where necessary, to clarify the response; analysis of the data; publication of a report summarizing current DOE emergency planning and capabilities and evaluating strengths and weaknesses; and revision of the five previous reports, as necessary.

The questionnaire being used is more extensive than the one used previously. An extensive revision process was necessary to incorporate information required by several organizations at DOE Headquarters. The questionnaires were sent to the field offices in August 1980. We anticipate that data analysis and site visits will commence early in 1981.

• Analysis of Criticality Safety

Under this program, data have been collected on more than 400 nuclear criticality safety infractions that occurred at DOE nuclear facilities covering a period of some six years. The program initially included 100 violations but was broadly expanded to include more than 400 in FY 1979. With this broader, more complete data base, a more definitive evaluation of the status of overall criticality safety is possible. The causes of the infractions were then assigned frequency values in a fault tree. The most frequent causes were identified and studied to ascertain possible areas of improvement in criticality safety. Estimates also were made of the probabilities for inadvertent criticality. Preparation of the final report summarizing the work was begun.

Analysis of Criticality Safety

R. C. Lloyd, E. D. Clayton

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

Under this program, data on nuclear criticality safety infractions have been collected from a number of DOE facilities located throughout the United States. The types of facilities include: a gaseous diffusion enrichment plant, fuel reprocessing plants, reactor fuel storage facility, weapons production plant, and several research and development laboratories.

The data collected include, among other things, details of over 400 violations of criticality safety limits or procedures with emphasis on determining cause and actual or potential severity of the incident.

Such information provides a data base from which to estimate basic event probabilities to be used in a fault-tree analysis of criticality safety, wherein the undesirable event is the unintentional occurrence of criticality. Thus, an estimate of the probability of a criticality accident can be calculated.

During the course of this work, each of the violations was assigned a number from 0 to 5 representing the severity, or potential severity, of the event. An important item of concern also is the duration of time that the infraction exists before its detection and correction. The MFAULT Code (Pelto and Purcell 1977) allows recovery modeling by using a duration of fault time.

It is assumed that the time to correct the infraction or fault is small compared with the duration of the fault. The probability for criticality as a function of the duration time of the infractions also has been studied. A study also has been made to ascertain areas of improvement in criticality safety according to assigned causes. This was done by calculating the accident probability as a function of the improvement factor of the cause. Work has begun on a summary report, but a final evaluation and review will be made of the calculations and assumptions before the report is issued.

Two reports on a similar but less comprehensive study have been made to date (Lloyd, Heaberlin, and Clayton 1979; Lloyd, et al. 1977). The collected data were analyzed with the ACORN and MFAULT computer codes (Carter 1977; Pelto and Purcell 1977). From these analyses, the probability of the inadvertent occurrence of criticality was estimated and the most likely contributing events identified. With this knowledge, suggestions were made to effect further improvements in criticality safety control.

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4 Human Health Studies

HUMAN HEALTH STUDIES

- **Statistical Health Effects**
- **Radioisotope Customer List**

Statistical analyses of the health of Hanford workers have been conducted at PNL for several years. The principal focus has been the study of the mortality data of contractor employees. Recent accomplishments have been the analysis of an updated file of worker deaths and the application of advanced methods of analysis to this unique data set. The Hanford Environmental Health Foundation is associated with PNL in this continuing study.

• Statistical Health-Effects Study

The main purpose of this program is to analyze the mortality of Hanford workers and to determine the effects of radiation exposure in this population. A secondary objective is the development of improved methodology for assessing health effects of chronic low-level exposure to harmful agents or substances, particularly in an occupational setting. In the past year we have presented published results of updated analyses, presented papers in two areas of methodological research, and have worked with staff of the Hanford Environmental Health Foundation to improve data collection procedures.

Statistical Health-Effects Study

E. S. Gilbert

The primary objective of this program is to analyze the mortality of Hanford workers and particularly to assess the effect of radiation exposure in this population. An important element is clear communication of both methodology and results in order to promote a better understanding of the problems involved in drawing conclusions about the effects of low-level exposures. To this end, results of the analysis of our recently updated files as well as a description of our methodology have been presented at a number of forums.

A second objective is the development of methodology appropriate to the analysis of data on low-level chronic exposures experienced by occupational populations. Two areas of research are currently being pursued. The first is a comparative investigation of methods of evaluating health risks due to occupational exposures, while the second is a study of the potential biasing influence of variables other than radiation.

Updating of the working master file at Pacific Northwest Laboratory was completed at the end of 1979. Various analyses have been performed on this new file, and procedures used to create this file have been documented. Several refinements have been made in our computer programs, and both our files and our programs have been converted for use on the VAX computer.

Initial results of a comparative investigation of various procedures for analyzing occupational exposures were presented at the annual meeting of the American Statistical Association in August 1980. Questions of interest concern the advantages and disadvantages of using an external population for comparison, the development of expressions for the power of various procedures for detecting risks of various magnitudes, and the relative merits of various analytical techniques and approaches to handling the dosimetry data.

The impact on mortality of variables other than radiation (such as length of employment, job category, employment status, etc.) has been evaluated, using computer programs developed for exposure analysis. Such variables are frequently correlated with exposure and can easily bias results when exposure is studied in an occupational setting. Such biases can be particularly severe when deaths are not related to the population at risk (proportional mortality analysis). The results of this research were presented as a poster session at the annual meeting of the Society for Epidemiological Research in June 1980.

We have continued to respond to others who have analyzed the Hanford data. Such response has included two letters to the editor concerning analyses by Mancuso, Steward, and Kneale, and an analysis by Gofman.

Joint efforts with the staff of the Hanford Environmental Health Foundation, who are responsible for the data collection, are under way to evaluate the potential usefulness of the data now in the file or under consideration for future acquisition, the adequacy of quality control procedures, and methods of maintaining files for greatest utility and accessibility. Other questions that are being explored are the completeness of Social Security Administration ascertainment of deaths and the quality of death certificate diagnosis. The first meeting of the Advisory Committee to the Hanford Health and Mortality Study was held in Richland in June 1980.

• Radioisotope Customer List

Radioisotope Customer List

J. S. Burlison

The purpose of this program is to prepare and distribute the annual document entitled List of DOE Radioisotope Customers with Summary of Radioisotope Shipments FY 1979. This document lists the FY 1979 commercial radioisotope production and distribution activities of the Department of Energy (DOE) facilities at Argonne National Laboratory, Brookhaven National Laboratory, Hanford Engineering Development Laboratory, Idaho Operations Office/Aerojet Nuclear Co., Los Alamos Scientific Laboratory, Mound Facility, Pacific Northwest Laboratory, Oak Ridge National Laboratory, Rocky Flats, Savannah River Plant/DOE, and United Nuclear Industries, Inc. The report was distributed in June 1980.

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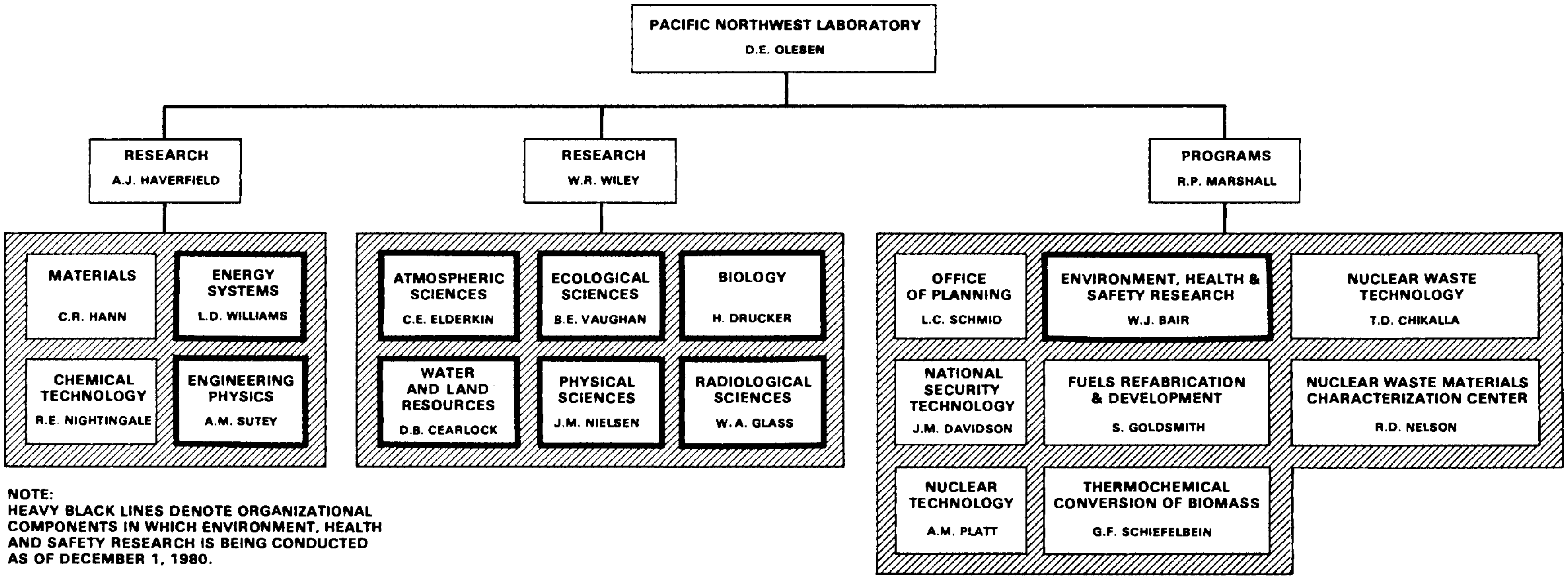

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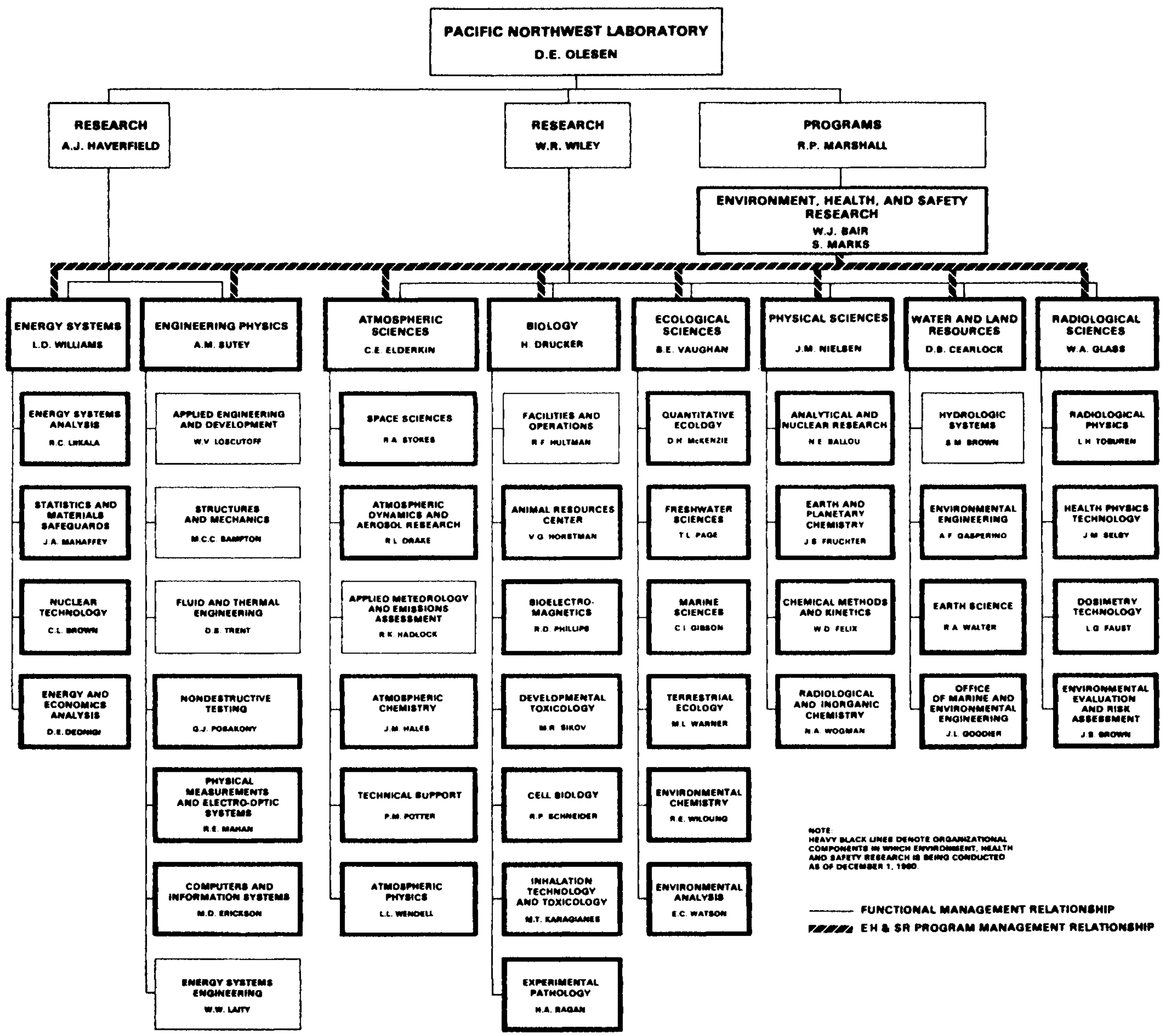
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