Pacific Northwest Laboratory
Annual Report for 1987 to
the Assistant Secretary for
Environment, Safety, and Health
Part 5 Environment, Safety, Health, and Quality Assurance
February 1988

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

Pacific Northwest Laboratory
Operated for the U.S. Department of Energy
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Pacific Northwest Laboratory
Annual Report for 1987 to
the Assistant Secretary for
Environment, Safety, and Health

Part 5  Environment, Safety, Health,
and Quality Assurance

L. G. Faust, B. L. Steelman,
J. M. Selby, and Staff

February 1988

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

Pacific Northwest Laboratory
Richland, Washington 99352
This 1987 Annual Report from Pacific Northwest Laboratory (PNL) to the U.S. Department of Energy (DOE) describes research in environment, safety and health conducted during fiscal year 1987. The report again consists of five parts, each in a separate volume.

The five parts of the report are oriented to particular segments of the PNL program. Parts 1 to 4 report on research performed for the DOE Office of Health and Environmental Research in the Office of Energy Research. Part 5 reports progress on all research performed for the Assistant Secretary for Environment, Safety and Health. In some instances, the volumes report on research funded by other DOE components or by other governmental entities under interagency agreements. Each part consists of project reports authored by scientists from several PNL research departments, reflecting the multidisciplinary nature of the research effort.

The parts of the 1987 Annual Report are:

- **Part 1**: Biomedical Sciences  
  Program Manager: J.F. Park  
  D.L. Felton, Report Coordinator and Editor

- **Part 2**: Environmental Sciences  
  Program Manager: R.E. Wildung  
  S.G. Weiss, Report Coordinator  
  G.P. O'Connor, Editor

- **Part 3**: Atmospheric Sciences  
  Program Manager: C.E. Elderkin  
  C.E. Elderkin, Report Coordinator  
  E.L. Owczarski, Editor

- **Part 4**: Physical Sciences  
  Program Manager: L.H. Toburen  
  L.H. Toburen, Report Coordinator  
  P.L. Gurwell, Editor

- **Part 5**: Environment, Safety, Health, and Quality Assurance  
  Program Managers: L.G. Faust  
  B.L. Steelman  
  J.M. Selby  
  L.G. Faust and B.L. Steelman, Report Coordinators  
  S.K. Ennor, M.T. Upton, and J.M. Gephart, 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 the 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, editor in chief, who directed the total effort.

Members of the Scientific Advisory Committee, established in 1985, are:

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W.J. Bair, Manager  
Environment, Health and Safety Research Program
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FOREWORD

Part 5 of the 1987 Annual Report to the U.S. Department of Energy's Assistant Secretary for Environment, Safety, and Health presents Pacific Northwest Laboratory's progress on work performed for the Office of Nuclear Safety, the Office of Environmental Guidance and Compliance, the Office of Environmental Audit, and the Office of National Environmental Policy Act Project Assistance. For each project, as identified by the Field Work Proposal, articles describe progress made during fiscal year 1987. Authors of these articles represent a broad spectrum of capabilities derived from five of the seven technical centers of the Laboratory, reflecting the interdisciplinary nature of the work.
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DEPUTY ASSISTANT SECRETARY FOR ENVIRONMENT

The U.S. Department of Energy (DOE) Deputy Assistant Secretary for Environment ensures that activities and installations of the DOE and its contractors are in full compliance with DOE environmental protection policies and applicable federal, state, and local environmental standards and regulations. The Deputy Assistant Secretary for Environment provides technical support and oversight to DOE programs and ensures that all DOE-controlled activities are conducted in an environmentally responsible manner. Pacific Northwest Laboratory (PNL) has established the following three projects in support of the Deputy Assistant Secretary for Environment's mission:

- Environmental Protection, Support, and Assistance
- Environmental/Hazardous Waste Risk Assessment
- National Environmental Policy Act Assistance.
Environmental Protection, Support, and Assistance

The Pacific Northwest Laboratory (PNL) continued to provide technical assistance to the U.S. Department of Energy (DOE) Deputy Assistant Secretary for Environment through a project with the Office of Environmental Guidance and Compliance (OEG&C). Assistance from PNL included 1) the development and revision of draft technical requirements to support the revised DOE Orders concerning environmental protection, 2) development of a second field review draft of a manual entitled "Requirements for Radiological Effluent Monitoring and Environmental Surveillance for U.S. Department of Energy Operations" was completed. This manual will contain the mandatory requirements for effluent monitoring and environmental surveillance in support of revised DOE Orders on radiation protection of the public and the environment. The manual contains requirements that 1) are identified in the current (or draft) DOE environmental protection Orders, 2) are identified in other established or pending federal regulations, and 3) represent sound technical practice. Fifteen PNL technical contributors in selected areas of expertise provided the material used to prepare the draft manual. The second field review copy was distributed to the DOE Operations and Program Offices and their contractors for review and comment. Final revisions to the manual are anticipated during FY 1988 before the manual will be published as a DOE document.

RADIOLoGICAL EFFLUENT MoNITORING AND ENVIronMENTAL SURVEIllANCE MANUAL


A second field review draft of a manual entitled "Requirements for Radiological Effluent Monitoring and Environmental Surveillance for U.S. Department of Energy Operations" was completed. This manual will contain the mandatory requirements for effluent monitoring and environmental surveillance in support of revised DOE Orders on radiation protection of the public and the environment. The manual contains requirements that 1) are identified in the current (or draft) DOE environmental protection Orders, 2) are identified in other established or pending federal regulations, and 3) represent sound technical practice. Fifteen PNL technical contributors in selected areas of expertise provided the material used to prepare the draft manual. The resulting tables were completed and sent to OEG&C. These tables are intended to support the revised DOE Orders on public radiation protection and were distributed to the DOE Operations and Program Offices for a second round of reviews. These tables are based on the recommendations of the International Commission on Radiological Protection (ICRP) as found in their Publication Nos. 26 and 30 (ICRP 1977 and 1979). The final version of this document will be completed during FY 1988, and it will be published as a DOE report.

DERIVED CONCENTRATION GUIDES

W. E. Kennedy, Jr. and R. A. Peloquin

Tables of derived concentration guides (DCGs), in units of pCi/mL, were developed for public exposure to contaminated air or drinking water. These tables were based on the effective dose equivalent factors developed by the ICRP in their Publication No. 30 (ICRP 1979). The resulting tables were included as an attachment to the second field review draft of DOE Orders on radiation protection of the public and the environment. These tables will replace the concentration guides found in previous Orders.

INTERNAL DOSE CONVERSION TABLES

J. P. Corley, W. E. Kennedy, Jr., and R. A. Peloquin

Revised text and tables for a document entitled "Internal Dose Conversion Factors for Calculation of Dose to the Public" were completed and sent to OEG&C. These tables are intended to support the revised DOE Orders on public radiation protection and were distributed to the DOE Operations and Program Offices for a second round of reviews. These tables are based on the recommendations of the International Commission on Radiological Protection (ICRP) as found in their Publication Nos. 26 and 30 (ICRP 1977 and 1979). The final version of this document will be completed during FY 1988, and it will be published as a DOE report.

ENVIRONMENTAL EMERGENCY RESPONSE

J. V. Ramsdell

Technical assistance to OEG&C was provided during the DOE revision of their Environmental Emergency Response Orders on
meteorological monitoring for accident situations. Initial efforts were to develop a task description and to provide comments on an early draft version of the revised DOE Order. This task is scheduled to continue through FY 1988.

PUBLIC DOSE EVALUATION FROM OPERATING DOE NUCLEAR FACILITIES

W. E. Kennedy, Jr., K. A. Hawley, and J. P. Corley

A draft summary of the reported public radiation doses from operating DOE nuclear facilities was compiled for 1985 and 1986. The draft information was reviewed by DOE, and a paper summarizing the information was presented by C. G. Welty, Jr. (OEG&C) at the American Nuclear Society Topical Conference on Population Exposure from the Nuclear Fuel Cycle.

OTHER TECHNICAL ASSISTANCE

W. E. Kennedy, Jr., J. P. Corley, and R. D. Stenner

Through a technical assistance task, PNL further supports OEG&C by providing rapid-turnaround technical responses or reviews to priority requests from OEG&C. These requests typically are in areas that fall outside the scope of the identified tasks but have an urgency to DOE and its operations. During 1987, these special assistance activities included: 1) technical reviews of proposed EPA regulations on low-level radioactive waste disposal and decommissioning criteria, 2) technical reviews and comments on additional draft federal reports and standards, 3) presentation of papers at the Ninth Annual DOE Low-Level Waste Management Conference held in Denver, Colorado, 4) participation in a study by the National Council on Radiation Protection and Measurements concerning the development of criteria for onsite liquid discharges of radioactive materials, and 5) consulting support to the International Atomic Energy Agency concerning exempt quantities for recycle of slightly contaminated materials recovered during decommissioning.

REFERENCES


• Environmental/Hazardous Waste Risk Assessment

Pacific Northwest Laboratory (PNL) continues to provide technical guidance and support to the U.S. Department of Energy (DOE) in the environmental/hazardous waste risk assessment area. During fiscal year (FY) 1987, PNL worked with the Office of Environmental Guidance and Compliance (OEG&C) and the Office of Environmental Audit (OEA) in the area of environmental risk assessment, surveys, and evaluations of environmental problems related to hazardous and radioactive materials. The overall objective of PNL's efforts was to assist DOE in developing technical tools in support of guidance for its operations and to ensure compliance of these operations with applicable environmental regulations and standards. Major efforts during FY 1987 included 1) for OEG&C, enhancement of the Remedial Action Priority System (RAPS) for ranking inactive waste sites; 2) for OEA, development of the Multimedia Environmental Pollutant Assessment System (MEPAS) for use in ranking issues identified by the DOE Environmental Survey; 3) for OEA, technical support to the DOE Environmental Survey; and 4) technical support in evaluating Superfund sites using the RAPS methodology.

ENHANCEMENT OF THE REMEDIAL ACTION PRIORITY SYSTEM


During the year, PNL continued to enhance the Remedial Action Priority System (RAPS), a technical tool designed to evaluate the relative hazard of inactive hazardous and radioactive mixed-waste sites. RAPS uses empirically, analytically, and semianalytically based mathematical equations to project contaminant release into the environment, contaminant transport through and between multiple pathways (Figure 1), exposure to populations, and the health effects associated with exposure.

During FY 1987, the mathematical equations that form the basis of the code were successfully defended before an independent panel of technical peer reviewers selected by DOE. Specific components of the RAPS computer code were tested against actual environmental measurements obtained from two DOE installations. In addition, further enhancements were made to the code to address multiple routes of migration of contaminants from waste sites. Interim user's manuals were written, and the code was linked and downloaded to a personal computer. Lastly, the code was applied to 20 U.S. Environmental Protection Agency (EPA) Superfund sites at the joint request of EPA and DOE. Final revisions of the user's manuals will be prepared during FY 1988, a sensitivity analysis will be performed, further enhancements will be made to the code, and training sessions will be conducted for DOE.

DEVELOPMENT OF THE MULTIMEDIA ENVIRONMENTAL POLLUTANT ASSESSMENT SYSTEM


A study performed by DOE's Office of Environment, Safety, and Health concluded that the RAPS code is one of the most scientifically defensible technologies available for prioritizing sites based on relative risk, and that it could be modified to address more than just inactive waste sites. With selected additions, the code could be used to prioritize the environmental problems identified by DOE during the course of their

FIGURE 1. Pathways of Exposure to the Environment and Population
Environmental Survey. Early in FY 1987, PNL began modification of the RAPS code to accommodate releases from active facilities, including stacks, pipes, and ponds. The modified version was renamed the Multimedia Environmental Pollutant Assessment System (MEPAS). Interim user's manuals were prepared, and training sessions were provided in September on the use of the code. Ranking of problems identified as part of the Environmental Survey began in July. Preliminary rankings of more than 200 potential problems (i.e., ranking units) for 15 defense production sites will be completed early in the second quarter of FY 1988. During the remainder of FY 1988, further refinements will be made to the code, including a user-friendly shell and completion of the system documentation. Additional training courses will also be conducted for DOE and their contractor staff.

TECHNICAL SUPPORT FOR THE ENVIRONMENTAL SURVEY

The purpose of the DOE Environmental Survey is to identify and then prioritize, on a DOE-wide basis, environmental issues that require further attention. Three areas where PNL provided technical support to the Survey were: 1) technical support to the field teams, 2) field sampling and laboratory analysis efforts, and 3) technical support to the Survey Prioritization Implementation Working Group.

Technical Support to the Survey Field Teams

P. A. Eddy, V. F. FitzPatrick, J. A. Glissmeyer, and T. L. Stewart

Technical staff was provided by PNL to assist the DOE Environmental Survey Teams in the identification of potential environmental problems at DOE sites. The purpose of the Environmental Survey is to conduct an environmental evaluation of all major DOE facilities, and staff from a wide range of scientific disciplines are needed to ensure a thorough review at each site. Before conducting the site visits, team members familiarize themselves with the layout and functions of each of the sites. The Survey looks for problems that result, or could result, from the release of contaminants that could cause adverse impacts on public health or the environment. The Survey is an ongoing effort that began in FY 1986 and will continue beyond FY 1988.

The four DOE sites where PNL provided Survey team members were: Mound Plant in Miamisburg, Ohio; Savannah River Plant in Aiken, South Carolina; the Brookhaven National Laboratory, located on Long Island, New York; and the Sandia National Laboratory in New Mexico. At Mound, PNL reviewed issues relating to atmospheric releases and transport of contaminants. At Savannah River, PNL reviewed issues relating to site geology, groundwater, wastewater treatment, and surface water. At the Brookhaven National Laboratory, PNL provided a review of potential groundwater issues. Lastly, at Sandia National Laboratory, PNL provided technical review of waste treatment and surface water issues.

Environmental Survey Sampling and Analysis Program


Pacific Northwest Laboratory is one of four national laboratories collaborating on the Environmental Survey Sampling and Analysis (S&A) Program. The purpose of the S&A Program is to collect field samples and provide analytical data to assist DOE in identifying environmental problems and areas of environmental risk at DOE facilities. The key activities of the S&A Program are 1) collection of a carefully selected array of field samples from more than 40 sites specified by DOE, 2) carefully controlled quantitative laboratory analyses of the samples, and 3) reporting of the results to DOE. Work for which PNL is responsible is conducted in Richland and Columbus.

The program requires careful management and coordination because of the broad diversity of program activities, the requirement for a wide variety of laboratory and field facilities and skills at widespread geographic locations, stringent interlaboratory and interagency regulations and specifications, and the need for close cooperation and
responsiveness to the DOE Program Manager and the other three participating DOE laboratories (Argonne National Laboratory, Oak Ridge National Laboratory, and Idaho National Engineering Laboratory).

Staff at PNL began work on the program in January 1987. Ultimately, PNL will provide S&A reports describing findings from each of the assigned DOE sites on a schedule established by the DOE Program Manager. The program responsibilities have been divided into five major tasks: Site Sampling, Sample Analysis, Special Analytical Problems, Data Management, and Program Technical Assistance. Major accomplishments were achieved in each task during FY 1987.

The site sampling work was conducted at two DOE sites: the Mound Plant in Miamisburg, Ohio, and the Pinellas Plant in Largo, Florida. Field sampling is a key activity. Samples must be taken from carefully selected site locations that represent the overall nature of each location where a problem could exist. The samples must be carefully protected, preserved, and transported to the analytical laboratory with regard to strict safety and quality control (QC) considerations. Audits of the field work were conducted for DOE by EPA representatives. An additional site (Fermi Laboratory) was reviewed, and the conclusion was reached that field sampling was not warranted there.

Extensive laboratory analyses of the samples collected at Pinellas were conducted under strict QC specifications established by DOE based on the EPA Contract Laboratory Program. Participating laboratories were required to establish the prescribed EPA practices and successfully undergo extensive laboratory audits by EPA teams before conducting any analyses. All laboratories participating under PNL's program passed the audits, and several hundred analyses were conducted for specified radiochemical, inorganic, and organic constituents in water, soil, and sediment samples.

In addition to the large number of routine sample analyses, PNL has been assigned overall programmatic responsibility for conducting special analyses of samples posing unusual hazard control problems (e.g., dioxin and PCR analyses), and those requiring analytical procedures not available in most laboratories. Samples from the Pantex and Hanford sites were analyzed for other participants under the PNL program.

The S&A Program is producing large volumes of analytical data and supporting documentation. The information must be carefully preserved and organized in a format that is accessible and easy to use to meet DOE's program objectives. In this area, PNL has dual responsibilities. First, a program-wide system for data management and transfer between laboratories has been designed, and implementation assistance was provided to participants. Second, internal data management methods are being designed for reliable and efficient data collection from the PNL program's laboratories, optimal presentation for final S&A reports, and permanent archival.

Under the PNL program, staff provide technical assistance to the DOE Program Manager and conduct special program-related projects. For example, PNL facilitated production of the four-volume Environmental Survey Manual and assisted the DOE Program Manager in coordinating the program-wide QC system. Technical assistance will be reduced during FY 1988, because most of the program planning effort has been completed, and most activities are concentrated on completing site work in progress.

The S&A Program activities are expected to peak during FY 1988. The activities planned include conducting detailed planning, site sampling, and detailed laboratory analyses at one major site (Nevada Test Site); providing special assistance in hydrology consultation, site sampling, and analyses for other program participants at up to four locations; conducting field and laboratory work at additional sites as time and resources permit; conducting special analyses for additional sites on request; and preparing three final S&A reports for work completed.

Also during FY 1988, special analytical laboratory work is expected to be performed for at least five sites, and field support to other participating laboratories may be conducted for two or more sites. The data management program will continue with
emphasis on the completion of methods required for interlaboratory transfer and preparation of final DOE reports.

Technical Support to the Survey Prioritization Implementation Working Group

K. A. Hawley, B. L. Steelman, and G. Whelan

Pacific Northwest Laboratory provided input to the Survey Prioritization Implementation Working Group (SPRIG). The purpose of SPRIG is to provide technical guidance to the Survey Teams regarding the collection, analysis, and interpretation of data obtained during the Environmental Survey. A key aspect of SPRIG was to provide guidance to the teams in collecting data for use with the MEPAS methodology and to instruct the teams in the approach needed in defining the environmental problem for purposes of applying MEPAS. As the developer of MEPAS, PNL's role was to ensure that sufficient guidance was provided to the teams and the supporting contractor so that the system would be accurately and consistently applied. Staff at PNL participated in SPRIG meetings each month and took part in discussions, prepared white papers on implementation issues, and provided training for MEPAS implementation.

TECHNICAL SUPPORT IN EVALUATION OF SUPERFUND SITES USING THE RAPS METHODOLOGY


The EPA and DOE requested that PNL, using RAPS, participate in an evaluation of inactive waste site ranking systems that were being considered as potential replacements for the EPA's Hazard Ranking System (HRS). The other ranking systems were the New York State Exposure Model, the Hazardous Assessment Ranking Model II, the revised HRS, and an expert panel selected by EPA. RAPS was used to rank 20 sites that had been placed on the National Priorities List (i.e., Superfund sites).

The results of the RAPS analysis on the 20 sites illustrated the methodology's flexibility in handling a wide variety of complex problems, and its ability to provide a basis for comparison throughout the assessment process from beginning to end. RAPS also provides a structure or framework on which further investigations at a site can be based, at which point it can be used to help focus assessment exercises and indicate where problems potentially exist, why they are occurring, what effects changes can have on the assessment, where to focus available resources (i.e., time and money), and what alternatives may be most effective.

Selection of a successor for the HRS was still in progress at the end of FY 1987; however, the evaluation process did represent the first fully integrated application of the RAPS methodology to inactive waste sites.
• **National Environmental Policy Act Assistance**

The National Environmental Policy Act (NEPA) Assistance Project provides onsite technical support for several major projects being reviewed by the U.S. Department of Energy's (DOE) Office of NEPA Project Assistance. The projects under review are supported by the Office of Defense Programs and include the Waste Isolation Pilot Plant in Carlsbad, New Mexico; the proposed Special Isotope Separation Project and the Fuels Processing Restoration Project, both at the Idaho National Engineering Laboratory; and several projects supporting the Strategic Defense Initiative. Specific tasks include 1) providing guidance to DOE field office personnel regarding the interpretation and enforcement of the regulations for implementing the procedural provisions of NEPA and 2) development of NEPA policy.

**NEPA Provision Regulation Interpretation and Enforcement**

D. G. Huizenga

Through an onsite assignment to DOE Headquarters, PNL provided guidance to DOE field office personnel to better interpret and enforce regulations for implementing NEPA procedural provisions. Guidance is based on regulations issued by the Council on Environmental Quality (CEQ), 40 CFR Parts 1500-1508 (as amended), the DOE NEPA guidelines, and legal case history. The project staff work closely with personnel in the Office of Environmental Guidance and Compliance to ensure that all applicable federal, state, and local regulations are adequately addressed in the NEPA documentation under review.

**NEPA Policy Development**

D. G. Huizenga

In addition to providing technical review of special projects, the NEPA Assistance Project staff support the development of DOE NEPA policy. During FY 1987, efforts centered on developing a strategy to interface the requirements of NEPA, the Resource Conservation and Recovery Act, the Comprehensive Environmental Response, Compensation, and Liability Act, and the Superfund Amendments and Reauthorization Act. This task is being accomplished through coordination with DOE General Counsel, U.S. Environmental Protection Agency Headquarters, and CEQ.

**Reference**

Safety, Health, and Quality Assurance
DEPUTY ASSISTANT SECRETARY FOR SAFETY, HEALTH, AND QUALITY ASSURANCE

To establish and maintain an effective nuclear safety program, the U.S. Department of Energy (DOE) Deputy Assistant Secretary for Safety, Health, and Quality Assurance has assigned to the Office of Nuclear Safety (ONS) responsibility for developing and promulgating nuclear safety policy, standards, and guidance and for DOE-wide independent overview, support, and counsel in nuclear safety. The objectives of the Nuclear Safety Program are to ensure that the activities of the DOE and its contractors are in full compliance with applicable nuclear safety, health, and emergency preparedness standards and regulations, and to provide technical support to the DOE Assistant Secretary for Environment, Safety, and Health. To accomplish this, ONS has established Pacific Northwest Laboratory (PNL) as a lead lab in health physics and has established the following five projects to assist in the ONS mission.

- **Personnel Neutron Dosimeter Evaluation and Upgrade**
- **Beta Measurement Evaluation and Upgrade**
- **Health Physics Support and Assistance to the Department of Energy**
- **Department of Energy Laboratory Accreditation Program Technical Development and Application**
- **Internal Dosimetry Evaluation and Upgrade**.

The major emphasis at PNL continues to be the development of criteria, instruments, and methods to ensure that radiation exposure to occupational personnel and to people in the environs of nuclear facilities is maintained as low as reasonably achievable. Particular emphasis has been placed on improving basic personnel radiation exposure measurement and recording programs. Collectively, the above five projects make up the Health Physics Outlay Program.
PERSONNEL NEUTRON DOSIMETER EVALUATION AND UPGRADE PROJECT


This project is a continuing effort, and its primary objectives are to assess personnel neutron dosimeter capabilities and to develop improved personnel neutron dosimeters and instrument systems. It focuses on the significant problems that affect the field determination of personnel neutron dose and compliance with applicable DOE Orders and regulations.

The short-term goal of the project is to develop and implement an interim neutron dosimeter and a portable neutron spectrometer at DOE facilities. The long-term goal is to develop an effective dose equivalent system.

The project includes interfacing with regulatory and other federal agencies involved in neutron dosimetry, conducting research leading to standardization of equipment and procedures for dosimetry systems, developing spectral measurement capabilities, and transferring new technology to industry and other organizations and agencies for implementation in the field.

Research is conducted at PNL and at supporting DOE laboratories, universities, and private companies to focus the capabilities of the most appropriate organizations and individuals on neutron dosimetry upgrade. A continuing project has been identified for fiscal year (FY) 1988 through FY 1990 to improve personnel neutron dosimetry capabilities at DOE facilities. Project developments are publicized; and other agencies, organizations, and commercial vendors are encouraged to participate, where appropriate, through publications, presentations, workshops, and technology transfer meetings. The program includes training and assistance for DOE facilities that are implementing new technology.

As the DOE lead laboratory for the Personnel Neutron Dosimeter Evaluation and Upgrade Project, PNL is responsible for providing 1) research and development capabilities, 2) technical coordination of project-related subcontracted work, 3) task objectives and milestones, 4) financial administration of the project, and 5) overall management of the project.

During FY 1987, research and development or other project activities included the following principal areas: 1) combination thermoluminescent dosimeter/track-etch dosimeter (TLD/TED) development and implementation; 2) field neutron spectrometer development; 3) total dose (photon and neutron) meter development; 4) a feasibility study for a total effective dose equivalent system; 5) a feasibility study for an optically stimulated luminescent dosimeter (OSL); 6) a feasibility study for a l/v detector for low-energy neutrons; 7) optical fiber dosimetry; 8) semiconductor dosimeters; 9) superheated drop detectors; 10) neutron depth-dose characterization; 11) accelerator health physics; 12) a personnel neutron dosimeter guide for selection, processing, readout/interpretation, and calibration; and 13) workshops and technology transfer.

In addition, PNL participated in field measurements of neutron dose and spectra in DOE laboratories, Department of Defense (DOD) facilities, and commercial power reactors. New devices were used wherever practical, and PNL also participated in both interagency and international intercomparisons. All of these activities contributed to the verification...
of accuracy, the practicality of new dosimeters and instruments, and personnel experience.

Progress during FY 1987 for the Personnel Neutron Dosimeter Evaluation and Upgrade Project is discussed in the following subsections.

Development and Implementation of the Combination Thermoluminescent Dosimeter/Track-Etch Dosimeter

M. A. Parkhurst

Following the combination TLD/TED technology transfer meeting in FY 1986, research has continued for the purposes of fine-tuning equipment and procedures, validating the TED response, and promoting implementation of the TLD/TED at DOE facilities as the interim neutron dosimeter. The FY 1987 efforts in support of the combination TLD/TED included work performed by Lawrence Livermore National Laboratory (LLNL) and the University of Connecticut at Storrs (UCONN). At LLNL, characterization of the energy and angular response continued, and efforts were initiated to relate track size distribution to neutron energy. At UCONN, efforts were directed to improve the TED copolymer, to develop a more tissue equivalent polymer, and to lower the neutron energy for which the TED is effective by adding boron to the radiator. Participation by PNL and LLNL resulted in a joint European/U.S./Canadian intercomparison of the response of the TEDs to a wide range of monoenergetic neutron energies. Twelve other laboratories (see Figure 1) participated in the intercomparison, which was sponsored by the cooperative European research project called Collection and Evaluation of Neutron Dosimetry Data (CENDOS). PNL was one of five laboratories providing the irradiations. The results will be published in the near future.

Development of a Portable Field Neutron Spectrometer

L. W. Brackenbush, S. D. Miller, and W. D. Reece

In response to the requirement for neutron spectral information to improve accuracy of the neutron dosimetry, a portable field neutron spectrometer was designed and a prototype was built by PNL. The prototype, shown in Figure 2, consists of a NE-213, and tissue equivalent proportional counter (TEPC) electronics patterned after the total dose meter circuits, Ortec ADCAM 414, a multi-channel analyzer, and a Gridcase 160 lap-top microcomputer with a hard disk drive. It is compatible with IBM/PC computer hardware used at most DOE facilities. The components of the system are packaged into a unit the size of a small suitcase. Most of the software has been developed by modifying programs previously developed at PNL for the specific requirements and hardware of the spectrometer system. Emphasis was placed on user-friendliness. The raw data and analyzed spectra are displayed along with the average neutron energy and average neutron quality factor with an error estimate.

Development of a Total Dose Meter

L. W. Brackenbush

A technology transfer meeting was held in Denver, Colorado, in September 1986 for the transfer of track-etch technology and total dose meter technology. Following this meeting, efforts were continued to respond to requests for information by firms who were interested in the possibility of producing the total dose meter commercially (see Figure 3). Research continued to reduce the total dose meter noise level, reduce its power requirements, and adapt computer codes and algorithms to analyze data. Two more prototypes were built, and the development work on the total dose meter was completed. Testing the total dose meter in accordance with American National Standards Institute (ANSI) draft Standard N42.17(c) may be initiated.

(a) EG&G/Ortec Incorporated, Oak Ridge, Tennessee.
(b) Grid Systems Corporation, Mountain View, California.
(c) Information regarding the ANSI draft Standard N42.17 may be obtained from J. M. Selby, Pacific Northwest Laboratory, Richland, Washington.
FIGURE 1. Intercomparison of CENDOS-Sponsored Track-Etch Dosimeters

FIGURE 2. PNL Field Neutron Spectrometer
Feasibility of a Total Effective Dose Equivalent System

J. E. Tanner, L. W. Brackenbush, W. D. Reece, and R. I. Scherpelz

The Presidential directive of January 1987 (The President 1987) requires the determination of effective dose equivalent. However, the directive gave no guidance as to how effective dose equivalent is to be derived. A feasibility study was conducted to develop this guidance. A Monte Carlo computer code (MCNP) and the Medical Internal Radiation Dose (MIRD) committee anthropomorphic phantom (Figure 4) were used to calculate the effective dose equivalent for neutrons that are normally incident to the anterior of the phantom. The preliminary calculations demonstrated that effective dose equivalent can be significantly less than the dose equivalent evaluated at the body surface. Thus, the conservatism of present techniques can be reduced and the impact of a change in neutron quality factors lessened. Conversion factors were determined using a male phantom; a female phantom will be developed so that conversion factors can be calculated for both sexes. These conversion factors can be used in the field neutron spectrometer system. Dosimeter design and performance criteria will be developed.

Feasibility Study for an Optically Stimulated Luminescent Dosimeter

S. D. Miller

After exposure to radiation, LiF, CaF$_2$, and other II-VI group compounds emit light proportional to the exposure when stimulated by heat. The energy required to reach the conduction band can also be provided by electromagnetic energy rather than heat. In FY 1987, CaF$_2$:Mn was shown to be sensitive to 1 mR of gamma exposure when supercooled OSL readout was used. Room temperature OSL was sensitive to 100-mR gamma exposure. The phosphors were shown to be stable for OSL...
even after being heated to 300°C. Ultraviolet excimer lasers with their six wavelengths may prove to be capable of selectively emptying electron traps. Two patent applications have resulted from this study. Research to develop this technique into a practical field dosimeter system will continue in FY 1988.

Feasibility Study for a 1/v Detector for Low-Energy Neutrons
L. W. Brackenbush, G. W. R. Endres, W. O. Reece, and J. E. Tanner

Efforts were initiated in FY 1986 to develop 1/v detectors. They will fulfill the requirement for a commercial instrument for field use to accurately measure the dose or flux over the resonance energy region between 50 keV and 500 keV. The detector is surrounded by a 1/v absorber to measure the fluence and therefore the neutron dose in this region of the energy spectra.

Optical Fiber Dosimetry
G. W. R. Endres

The components for an optical fiber dosimetry readout system were ordered in FY 1987. Recent findings about the sensitivity of optical fibers to neutron radiation have shown promise in detecting fast and thermal neutrons. These fibers and their readout systems will be characterized. The response to a wide range of neutron energies and the detection limits for those energies will be determined for various types of fibers.

Semiconductor Dosimeters
L. W. Brackenbush

The Tri-Cities University Center (TUC) in Richland, Washington, is attempting to develop new, improved neutron dosimetry devices using semiconductor detectors. The TUC is investigating 1) diode device structures that collect electron hole pairs as a result of proton absorption (dose) measurement and 2) a spectrometer to determine the energy distribution of any flux of charged particles.

Superheated Drop Detectors
C. M. Stroud

A new neutron measurement system based on the physical phenomenon of superheat is in the development stage. When superheated droplets of Freon and isobutane are suspended in a solid-elastic or high-viscous liquid, they can be vaporized by a neutron or proton striking a droplet. The energy of the recoil charged particle triggers a liquid-to-gas phase change. The sound of the "exploding" droplet can be detected and recorded in real time. It is also possible that the bubbles can be collected in the medium for later measurement. A prototype superheated drop detector is being developed by Apfel Enterprises for the determination of field applicability.

Neutron Depth-Dose Characterization
R. I. Scherpelz

Neutron depth-dose profiles inside tissue equivalent phantoms are being measured by PNL for monoenergetic and continuous energy neutron spectra. Improved flux-to-dose conversion factors result from using the measured profiles of neutron flux, dose, and dose equivalent. The final report is being written. The results of this study are needed for the effective dose equivalent task.

Accelerator Health Physics

C. M. Stroud

Radiation safety programs at DOE accelerators are a part of the neutron project. Fermi has been designated the lead laboratory for accelerator health physics and is developing and prioritizing a list of radiation safety research requirements. Stanford Linear Accelerator staff are developing a manual of good practices for health physics programs at DOE accelerator facilities. Argonne National Laboratory is developing a systematic methodology for the assay of induced radioactivity in accelerator components designated for disposal or reuse.
PNL is developing a personnel neutron dosimeter guide for selection, processing, readout/interpretation, and calibration. The draft is completed.

Workshops and Technology Transfer

M. A. Parkhurst

The Eleventh DOE Workshop on Personnel Neutron Dosimetry and a working group workshop for DOE personnel involved in implementing the combination TLD/TED were planned. The combination TLD/TED workshop was held in December 1987; the Eleventh DOE Workshop on Personnel Neutron Dosimetry was postponed until 1988.

Major accomplishments of the Personnel Neutron Dosimeter Evaluation and Upgrade Project in FY 1987 were as follows:
1) Advancement of the combination TLD/TED was made such that it is scheduled for implementation as the interim dosimeter in FY 1988. 2) The PNL field neutron spectrometer was developed and proven and will be implemented simultaneously with the interim dosimeter. 3) The total dose meter was completed. Work on it may be resumed if microelectronics become available commercially for significantly reducing its size and power requirements or if further testing is required.

Significant accomplishments expected in the future are the development and implementation of the total effective dose equivalent system and an increase in the sensitivity and lowering of the lower limits of detection for neutrons using optical luminescence. Continued examination of new concepts in neutron dosimetry is expected to result in continuing improvements, if not a quantum leap in the state of the art in neutron detection.

REFERENCE

Beta Measurement Evaluation and Upgrade

This project focuses on the resolution of problems associated with field measurement of the beta dose component at U.S. Department of Energy (DOE) facilities. The change in DOE programs, including increased efforts in improved waste management and decontamination and decommissioning (D&D) of facilities, coupled with beta measurement problems identified at Three Mile Island, have increased the need to improve beta measurements. In fiscal year (FY) 1982, work was initiated to provide a continuing effort to identify problems associated with beta dose assessment at DOE facilities. The problems identified resulted in the development of this project. The investigation includes 1) an assessment of measurement systems now in use, 2) field measurements at DOE facilities, 3) the development of improved calibration and evaluation procedures, 4) the application of innovative beta dosimetry concepts, 5) the investigation of new instruments or concepts for monitoring and spectroscopy, and 6) the preparation of a “manual of good practices” to ensure an adequate and uniform beta measurement project at DOE facilities.

BETA MEASUREMENT EVALUATION AND UPGRADE PROJECT


The Beta Measurement Evaluation and Upgrade Project is designed to provide continuing identification and resolution of significant problems that affect field measurement of beta dose and to ensure that DOE facilities can comply with applicable standards. The objective of this project is to investigate and upgrade beta radiation measurements by developing improved personnel beta dosimeters and instruments used in DOE facilities.

The work performed in FY 1987 can be classified into seven major areas: 1) current practices, 2) field measurements, 3) dosimeter development, 4) instrument development, 5) beta calibrations, 6) theoretical considerations, and 7) beta workshop report. Milestones have been met on all of the subtasks in the above areas, which include efforts by subcontractors (universities, private companies, and DOE laboratories) in addition to efforts by the Pacific Northwest Laboratory (PNL) staff. Progress during FY 1987 for the tasks under the Beta Measurement Evaluation and Upgrade Project is discussed in the following subsections.

Current Practices

L. W. Brackenbush

The purpose of this task is to evaluate the current status of beta detection and beta dosimetry programs at DOE-contractor facilities and to identify specific areas where these programs might be upgraded. The report on beta measurement practices was published following a final sponsor review and incorporation of sponsor comments (Mulvehill et al. 1987).

Field Measurements

L. A. Rathbun

The purpose of this task is to characterize typical beta radiation fields at various DOE facilities. This will provide essential firsthand knowledge of the beta fields and measurement techniques currently employed. A report (Rathbun, Swinth, and Haggard 1987) covering seven sets of measurements (30 field locations) made at DOE facilities was published following final clearance and sponsor concurrence. The measurements included beta dose and spectral measurements using a variety of instruments and dosimeters. Field measurements have shown that beta/gamma dose ratios approaching 100:1 are possible with typical ratios of about 20 to 40:1. In addition, beta dose rates vary significantly over short distances, which complicates the interpretation of multielement dosimeters and large-volume detectors. Beta dose rates at several of the sites have ranged from 45 to 790 mrad/h with many of the dose rates over 100 mrad/h (Rathbun, Swinth, and Haggard 1987).
Beta Dosimeter Development

K. L. Swinth

The objectives of this task are to identify and develop new and innovative beta dosimeters for assessing beta dose and for estimating beta spectra. Kansas State University (KSU) has developed a dosimeter with a thin (approximately 17 mg/cm²) LiF chip on a graphite backing. The laboratory evaluation of the KSU thermoluminescent dosimeters (TLDs) and the evaluation of the dosimeters in a multielement badge were completed. A letter report on the laboratory evaluation was completed. Tests of the KSU TLDs in the badge show good response in terms of DOE Laboratory Accreditation Program (DOELAP) criteria for shallow dose, but the detection limit is too high (200 to 400 mrad). Use of the dosimeter in a badge would require that the badge and reader be considered as a system to meet an acceptable detection level. The laboratory evaluation indicated that acceptable field performance is feasible in terms of both the detection limit (10 mrad) and the energy response.

The laser-heated TLD system optics were improved to increase power delivery, and the software and hardware were upgraded to facilitate evaluation of the system. Calcium sulphate dosimeters obtained from International Sensor Technology (IST) are being used for the initial evaluation of reader performance. Tests have been performed on the relative light collection from the front and rear surfaces of a dosimeter chip; it appears that approximately one-half of the total light collected is collected from the front surface (40 to 60%). Tests have been performed on readability of the graphite-backed LiF chip in the laser reader. The poor infrared absorption of LiF makes the use of the dosimeter impractical; too much of the heat is transferred to the bonding agent, and the overall detection levels are too high to be practical (<1 rad).

Evaluation of thermally or optically stimulated exoelectron (TSEE or OSEE) dosimeters continued with studies of the long-term fading. Fading was significant for the OSEE mode (20% fading after two weeks in an office environment), but in the TSEE mode, fading could not be detected under ambient conditions. A two-element badge was fabricated with the exoelectron dosimeter and tested against DOELAP criteria. The only deficiency noted was in meeting the low-energy photon requirements. Further studies are under way to correct this problem. The report on exoelectron dosimetry was cleared and submitted for publication. Information from the report was presented at the annual meeting of the Health Physics Society (HPS) in Salt Lake City, Utah, in July 1987.

Visits were made to the University of Giessen, Federal Republic of Germany (FRG), and to the State Dosimetry Laboratory in Dortmund, FRG, to discuss the application of exoelectron dosimeters to personnel dosimetry. Technology for the manufacture and readout of exoelectron dosimeters has been developed in FRG, and the dosimeters are undergoing trials for application in the field.

Work continues on a study of the optically stimulated luminescence (OSL) of materials for dosimetry. Construction of an experimental reader was completed, and specific excimer lasers and arc lamps were evaluated as ultraviolet stimulation sources. An excimer laser was purchased for future studies. Tests were performed with several phosphors, and additional materials were ordered for evaluation. Tests with CaF₂ demonstrated a linear response, negligible fading over a 5-month period, and a lower detection limit of 1 R for 60Co.

Beta Instrument Development

K. L. Swinth

This task is dedicated to the development of instrumentation for beta measurements based on new and innovative ideas. The instruments must provide a correct determination of the penetrating and nonpenetrating field.

Phoswich beta-particle spectrometers were studied under contract with KSU. The experimental system provided a 90% or greater reduction in gamma-radiation sensitivity for gamma-ray energies below 1.5 MeV. The study involved the testing of various combinations of plastic scintillators, photomultipliers,
discrimination techniques, and the use of optical filters. Filters were necessary to maintain the light output for various scintillators at comparable levels.

The Phoswich Beta-Particle Spectroscopy report (Simons 1987), describing the KSU efforts to develop a phoswich spectrometer, formed the basis of a paper presented at the HPS annual meeting in Salt Lake City. The general conclusion of the paper was that the proportional-scintillation counter coincidence technique (previously studied by KSU) provided a simpler and more useful spectroscopy scheme than the phoswich. Significantly, this work demonstrated the feasibility of the phoswich, whereas previous work at another laboratory attempted to show that the use of a phoswich detector was not technically feasible.

A prototype portable probe using the proportional-scintillation counter concept has been fabricated and tested (see Figure 1). The system provides beta and photon spectra and calculates doses for the two components. Excellent separation of beta and photon components of the radiation field has been obtained. Calibration of the system must be completed before field testing can proceed.

A site review was held at Idaho National Engineering Laboratory (INEL) to evaluate progress on the thin tissue equivalent scintillator. Progress has been stalled by the apparent inability of the manufacturer to produce a satisfactory scintillator. The few samples with the proper decay time (≈200 ns) have lacked long-term stability. As a result of the review, a meeting of Bicron, PNL, and EG&G Idaho personnel was held at the annual meeting of the Health Physics Society. Their decision was that selected samples of plastic scintillators (BC-440) must be tested to determine decay time, stability of phosphors, and relative light output. Subsequently, measurements made at PNL have shown that the samples (BC-440) had a decay time of about 200 n/sec, as expected. Light output was greatest for a sample of ZnS(Ag)-loaded plastic (BC-400).

In the BC-440 samples, light output changed very little with changing fluor concentration in the samples.

Efforts continued on the study of the response of survey meters to geometry-dependent sources. It was found that some of the specially produced sources have anisotropic emission characteristics that are probably related to the source manufacturing process. New $^{90}Sr$ and $^{204}Tl$ sources were fabricated. Uniformity measurements for the new sources showed a significant improvement in the uniformity of the beta field. Correction factors determined from scans using the new sources were generally smaller. A $^{204}Tl$ source, designed like the most recent $^{90}Sr$ source, was ordered from Westinghouse Hanford Company.

A draft report on studies with the scanning system has been completed and edited. This report shows the magnitude of the correction factors (up to 500 times) for various instruments and geometries, and it details the technique used to determine the correction factors. Additional studies were performed with a thin (1-cm) ionization chamber to determine whether this will provide an improved response (smaller correction factor) for various geometries.
Computer programs to simulate the response of cylindrical ionization chambers, concentric ionization chambers, and pancake ionization chambers were developed. Data from the programs agree with experimental data, and the programs will be used to develop geometries that reduce the geometrical dependence and/or permit corrections within the instrument.

**Beta Calculations**

P. L. Roberson

The purpose of this task is to develop and maintain calibration capabilities that are unique to the beta measurement project. The lack of unique capabilities was one of the areas of deficiency identified at the 1986 Beta Workshop, held in Albuquerque, New Mexico.

Several techniques to reduce the photon contamination of the monoenergetic electron Van de Graaff beam were evaluated, but further studies were curtailed because of lack of funding. Improved holders were fabricated for the large-area beta sources, and calibrations were performed with these sources.

**Theoretical Considerations**

K. L. Swinth and W. D. Reece

The purpose of this task is to follow basic studies that affect beta dosimetry and to develop methods of calculating energy deposition from beta radiation.

The final report on the calculational studies by KSU, *Comparison of Beta-Particle Absorbed Doses in Skin and Thermoluminescence Dosimeters* (Faw 1987), was used as the basis for a paper presented at the HPS annual meeting in Salt Lake City. The calculations confirmed the desirability of a thin detector (dosimeter) and verified the inappropriate response of standard TLDs in beta fields.

A draft of the report on biological considerations for proper depth and methods for assessing dose to the skin is complete. The report verifies the appropriateness of a measurement depth of approximately 4 mg/cm², but points out the need to consider dose response as a function of irradiation area and biological end effects.

**Beta Workshop Report and Technology Transfer**

K. L. Swinth

Under this task, project progress is reviewed; new ideas are identified; and new information, methods, or instruments developed by the project are transferred to the nuclear industry.

A call for proposals was developed and proposals totaling $1.75 million were received from various institutions. The proposals were reviewed and ranked by an internal committee, and the top-ranked proposals were selected for funding. The proceedings of the beta workshop were completed and submitted for review to the sponsor. In response to comments, final revisions were made, and the report was sent out for publication.

**REFERENCES**

Faw, R. E. 1987. *Comparison of Beta-Particle Absorbed Doses in Skin and Thermoluminescence Dosimeters*. Kansas State University, Manhattan, Kansas.


• Health Physics Support and Assistance to the Department of Energy

The Pacific Northwest Laboratory (PNL) functions as the lead laboratory providing health physics support and assistance to the Health Physics Branch of the Office of Nuclear Safety (ONS). Support and assistance are provided for specific tasks or special studies that are identified as high priorities by the U.S. Department of Energy (DOE). The designation of lead laboratory in health physics, with an agreement and budget in place, provides the Branch with the additional expertise necessary to respond to the many questions and situations that arise during the operation of its numerous nuclear energy research, development, and demonstration facilities.

HEALTH PHYSICS SUPPORT AND ASSISTANCE

J. M. Selby, J. G. Stephan, and J. B. Martin

This project focuses on identifying needed improvements in occupational radiation programs and measurement technologies and on analyzing the applicability and impact of standards, regulations, and engineering or administrative actions on DOE's occupational radiation protection programs. This is accomplished by means of special technical studies. Technical assistance is also provided by PNL in the form of specific priority tasks or special studies identified and outlined by DOE/ONS. Project objectives are achieved using the capabilities and expertise of PNL, other DOE laboratories, universities, and private industry. The assistance also includes transferring laboratory-developed techniques to the field by means of DOE-sponsored workshops.

Progress during fiscal year (FY) 1987 for Health Physics Support and Assistance (HPSA) tasks is discussed in the following subsections.

SPECIAL STUDIES

J. M. Selby, L. G. Faust, and J. G. Stephan

The objectives of these tasks are to provide technical assistance in developing guidelines for implementing standards and regulations and to prepare technical reports and conduct special studies for ONS as requested by the sponsor.

Neutron Quality Factor

L. G. Faust

The International Commission on Radiological Protection (ICRP) and the National Council on Radiation Protection and Measurements (NCRP) have proposed changes to the quality factors, Q, associated with high linear energy transfer (LET) radiations: e.g., protons, neutrons, and alpha. Because of the absence of spectral data, the currently accepted values for Q will essentially be doubled if average values are used. For neutrons, the new average values for Q are 5 for thermal and 20 for fast neutrons. The DOE Ad Hoc Committee on Neutron Quality Factor reviewed a large amount of data that were used to support ICRP and NCRP recommendations and issued a report that supported the suggested changes. However, the report indicated that spectral data in the case of neutrons should be used wherever and whenever possible.

Subsequently, the Ad Hoc Committee report has undergone a peer review, which supported its findings, and at least two Committee on Interagency Radiation Research and Policy Coordination (CIRRPC) reviews, both of which suggested no change in Q. Regardless of the CIRRPC review, the Ad Hoc Committee members maintained their original conclusions to double Q for fast neutrons if spectral data are available and, if not, to use an average Q of 20, consistent with the statement of the 1985 Paris meeting of the ICRP.

Improvement of the overall data base is needed to provide better guidance regarding Q for neutrons and better application to personnel protection programs.

Annual Radiation Exposure Report

S. E. Merwin and J. B. Martin

The eighteenth annual report for the year 1986 was prepared and published.
Thirty-four charts and twenty-one tables that indicated exposure trends for the years 1978-1985 were prepared.

Assessment and Control of Dose to Fetus
D. R. Fisher, M. R. Sikov, and J. M. Selby

The Nuclear Energy Agency (Paris, France) appointed a consultant group to evaluate the biological data relevant to protection of fetus in pregnant radiation workers and to make recommendations for operational procedures to achieve satisfactory protection. A draft report entitled "The Assessment and Control of Radiation Dose to the Embryo and Fetus" was prepared. The draft report was reviewed when the consultant group met in Paris on June 24-26, 1987, and a revised draft was prepared in August 1987.

Consideration was given to recent epidemiological data from Japanese atomic bomb survivors showing increased sensitivity of the fetus to mental retardation or reduced intelligence after exposure to radiation from weeks 8 to 15 of gestation. These data are statistically consistent with a non-threshold linear dose-response relationship having a risk coefficient of 0.4 Gy⁻¹ (40% per 100 rad). However, other biological data indicate a threshold at about 0.1 Gy (10 rad, or 10 rem if Q = 1) for other biological effects of radiation on the fetus. The consultant group therefore concluded that current standards for radiation protection limiting the fetus to 0.5 rem (5 mSv) during the 9-month period of gestation are satisfactory if the dose during any 4-week period does not exceed 0.1 rem (1 mSv).

Epidemiology Studies of DOE Workers
R. J. Traub

The epidemiology studies of DOE workers were summarized. Eleven studies were identified, and 90 papers and 1100 abstracts were reviewed and summarized.

Computerized Radiation Exposure Module
EG&G, Idaho

The computer data base was developed for radiation doses received by DOE and contractor personnel. Summary information was compiled from records of the Radiation Exposure Information Reporting System (REIRS). A new computer model was developed for use with the revised REIRS requirement. The model has been completed and will be tested as soon as the FY 1986 data is received from all DOE field offices.

GUIDES TO GOOD PRACTICE
L. G. Faust, J. B. Martin, J. M. Selby, and J. G. Stephan

The objective of this project is to upgrade and revise existing guides to good practice and to develop new ones as required by the emergence of new technology, development of more accurate data, and changes in recommendations, standards, regulations, and orders.

Tritium Guide

The "Guide to Good Practice at DOE Tritium Facilities" has been rewritten, except for the health physics section. A four-member committee has been identified to develop that section. Completion of the revised draft is expected by February 1988.

Plutonium Guide

The second draft of the "Guide to Good Practices for DOE Plutonium Facilities" was submitted to DOE/Headquarters (HQ) in August for distribution and review. Comments from the steering committee and other DOE contractors are expected in November 1987. Publication of the guide is expected by March 1988.

Uranium Guide

The final draft of the "Guide to Good Practice for DOE Uranium Facilities" is nearly complete. A DOE review will occur in early 1988.
Training Guide

The second draft of the "Guide to Good Practice for Radiation Protection Training" was completed. The final draft is scheduled for completion in January 1988.

Training Manual

H. J. Moe, ANL


TECHNICAL EVALUATION OF NATIONAL AND INTERNATIONAL OCCUPATIONAL RADIATION EXPOSURE RECOMMENDATIONS, STANDARDS, AND REGULATIONS

J. M. Selby, J. B. Martin, and J. G. Stephan

The objective of this project is to provide a timely, technical evaluation of national and international occupational radiation exposure recommendations, standards, and regulations to determine their technical applicability, compatibility with DOE operations and orders, and impact on DOE operations. As appropriate, technical expertise is drawn from other DOE-contractor laboratories to assist in the evaluations.

Staff evaluated and commented on 30 standards for the following organizations:

- International Standards Organization (ISO) - 10 standards
- National Council on Radiation Protection and Measurements (NCRP) - 3 reports
- International Electrotechnical Commission (IEC) - 12 standards
- American Society for Testing and Materials (ASTM) - 4 standards
- American National Standards Institute (ANSI) - Health Physics Society Standards Committee - 1 standard.

Staff members also commented on the revision of Code of Federal Regulations 10 CFR 20 and on two reports by the Committee on Radiation Protection and Public Health of the Nuclear Energy Agency (NEA).

Technical Evaluation of the Capability of Present Instrumentation to Meet the Draft ANSI Standard N42.17


The objectives of this task are 1) to evaluate the applicability and practicability of the proposed ANSI N42.17A, B, and C standards regarding performance specification for health physics instrumentation; 2) to determine the degree of conformance to the proposed standards of selected, currently available commercial instruments; 3) to develop a formal test, evaluation protocol, and specific procedures; and 4) to lay the groundwork for establishing a permanent testing and certification laboratory.

Comments received from the ANSI N42 working group on draft ANSI N42.17A, B, and C were sent for review during the fourth quarter. A meeting of the working group will be scheduled in the next few months.

The automated instrument-testing data acquisition system was received; to complete the requisition, the vendor must demonstrate operation of the system. This demonstration is scheduled to occur in FY 1988.

The draft of the Part I report for air-monitoring testing was completed. The record describes the test procedures based on the requirements in draft ANSI N41.17B. In addition, testing on air monitors continued. Testing on general criteria, electronic criteria, and air-circuit criteria was performed. Analysis of data on completed testing was also performed, and the report on testing results is being drafted.

Additional testing for high-energy photon response for extreme-range conditions was completed. Fog, rain, shock, and response-time testing for extreme-range conditions was performed. This completes the testing to be performed on instruments under extreme-range conditions.

(a) Information regarding draft ANSI Standard N42.17 may be obtained from J. M. Selby, Pacific Northwest Laboratory, Richland, Washington.
A draft of Section 3 ("Measurement Quality Assurance") of the procedures manual for testing has been completed.

The transient generator upgrade instrumentation was delivered in August and will permit testing for instruments requiring three-phase power or instruments requiring more than 1 kWh of power.

A draft of the body of the report on implementation of instrument testing was completed and sent to committee members and other selected individuals for comments. Comments were received on the draft report and committee members met September 25, 1987 at the National Bureau of Standards (NBS).

AIR SAMPLING AND MONITORING

E. E. Hickey, J. Mishima, and K. L. Swinth

The objective of this task is to develop techniques for measuring and interpreting levels of radioactive materials in the workplace at DOE facilities. Techniques for control of material in the air and calibration of systems will also be studied and improved.

DOE Program for Improving Air Sampling and Monitoring

This task is designed to identify and resolve problems associated with work environment air sampling and monitoring, performed as part of the routine surveillance of airborne radioactivity in work locations. The working group that was established to prepare guidance for the prompt detection of plutonium in the workplace was contacted, and writing assignments were made. First drafts have been received and reviewed. A meeting of the working group was held September 30 to October 1, 1987 at Rocky Flats, Colorado, to further review and coordinate the document. A more complete draft of the guidance document was scheduled to be issued for comment in November. A tentative schedule of milestones has been developed, and the final report will be published in June 1988.

Air Monitor Development

The work on the Rocky Flats air monitor is slightly behind schedule. The tooling for casting and stamping dies for the filter detector assembly is in the process of fabrication. Testing a complete assembly should begin by the end of FY 1988.

The Workplace Transuranic Aerosol Measurement System (WOTAMS) prototype, which was scheduled to be shipped to PNL at the end of April, was not sent as planned because of software problems. Development of the computer code for the system continues. Environmental chamber temperature tests were performed. The instrument performed well except for a minor temperature drift. During early FY 1988, minor electronic and mechanical debugging will be completed.
This project provides research support for the U.S. Department of Energy (DOE) Laboratory Accreditation Program (DOELAP) for personnel dosimetry services. The research effort encompasses the development of improved calibration methods and the operation of intercomparison and measurement assurance projects for DOE laboratories. Major accomplishments for fiscal year (FY) 1987 include: 1) development of databases on the performance of thermal and high-energy neutron dosimeters, 2) determination performance criteria for angular response of personnel dosimeters, 3) operation of a calibration intercomparison program for DOE laboratories, and 4) investigation of the impact of International Commission on Radiation Units and Measurements (ICRU) Report 39 on DOE calibrations (ICRU 1985).

DOELAP TECHNICAL DEVELOPMENT AND APPLICATIONS

J. C. McDonald, F. M. Cummings, R. A. Fox, C. D. Hooker, K. L. Jones, and P. L. Roberson*

A national approach to quality assurance and accreditation of personnel dosimetry services for DOE laboratories is being implemented through DOELAP. The DOELAP program involves operating a performance testing laboratory located at the Radiological and Environmental Sciences Laboratory (RESL) in Idaho Falls and conducting a technical application program at the Pacific Northwest Laboratory (PNL). The total effort encompasses 1) development of improved accreditation methods, 2) intercomparison of DOE radiological calibration standards using round-robin exchanges of instruments and sources, and 3) determination of the impact of new regulations and standards including development of calibration techniques that are needed to meet such standards.

The FY 1987 effort included 1) development of a performance data base for thermal and high-energy neutron dosimeters, 2) development of a database for angular response of personnel dosimeters and performance criteria for dosimeter angular response, 3) operation of the DOE intercomparison program, 4) participation on the working committees that are reviewing the results of DOELAP performance tests, and 5) investigation of the impact of the recommendations of ICRU Report 39 on DOE calibrations (ICRU 1985).

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the appropriate dose equivalent assigned as a function of incident angle. The operational quantities used to assign delivered dose equivalent will significantly impact the design of future dosimetry systems.

Traditionally, dosimeter response at nonzero angles has been compared to delivered dose equivalent at perpendicular incidence. This approach results in extreme conservatism when estimating the dose equivalent in an isotropic environment. In most cases, movement of a worker within the radiation environment results in a field impinging from many directions relative to the dosimeter position. The ICRU recommends measuring individual dose equivalent for 0.007-cm and 1.0-cm depths (ICRU 1985). This is the dose equivalent below a specified point on the body at the appropriate measurement depth. If the specified point on the body is understood to be the location of the dosimeter, then a new set of dose equivalent quantities must be determined. The directional dose equivalent is an appropriate model for assigning dose equivalent at nonzero angles of incidence.

Criteria are required to determine whether dosimeter performance is acceptable at nonzero angles. These criteria can be applied regardless of the model chosen to assign dose equivalent. The International Commission on Radiological Protection (ICRP) recommends accuracy within a factor of 1.5 (ICRP 1982). Although this factor seems large, it must encompass uncertainties due to energy response, angular response, and random system variability. Criteria for angular response can be developed, consistent with existing DOE criteria for response at perpendicular incidence and with ICRP recommendations (ICRP 1982).

Two algorithms were proposed to meet the ICRP recommendations for accuracy. Each included a weighted bias representing the difference between reported dose equivalent and delivered directional dose equivalent. Weighting factors were applied to compensate for the reduction in delivered dose equivalent at angles near 90°. Dosimeters from five laboratories were evaluated using the proposed criteria. For photons, the weighted bias and standard deviation were determined using directional dose equivalent in the ICRU sphere. Available data was too limited to assign directional dose equivalent for neutrons and betas. Calculating and measuring directional dose equivalent have been proposed as part of future research efforts to supplement existing data.

Intercomparison Progress

F. M. Cummings and C. D. Hooker

The intercomparison of radiation calibration standards in DOE facilities continued with the shipment of radiation-measuring instruments and a beta calibration source set.

During FY 1987, there were nine requests for the instrument sets and five for the beta set. Of those laboratories requesting the intercomparison sets, results were reported for five of the participants using the instruments and for two participants using the beta set. The sets are scheduled up to a year in advance. Those participants who did not report results failed to do so because last-minute scheduling problems arose in personnel and facility availability. The average and one standard deviation of the ratios of participant results to PNL calibration values were 0.98 ± 0.04 for gamma measurements. Those ratios for the gamma measurements varied from 0.94 to 1.07.

Overall, the participation and results during FY 1987 indicated an improvement in the agreement among laboratories over the FY 1986 results.

ICRU-39 Impact Studies

J. C. McDonald

In 1985, ICRU issued a new ICRU Report 39. This document recommends changes in the units of occupational radiation measurement used within DOE, but more important, it will require extensive changes in the radiation measurement program.

The ICRU Report 39 includes definitions of four new quantities for monitoring radiation to the trunk of the body. These quantities are meant to supersede and replace the previously employed quantities, dose equivalent index, shallow and deep-dose
equivalent index, shallow and deep-dose equivalent, some of which are used in the current or draft DOE Orders. The new quantities refer to the two basic measurement situations in radiation protection: environmental area monitoring and individual monitoring. These measurements are carried out by instruments and dosimeters, respectively.

Basically, all occupational radiation measurements are to be made using one of the four units, depending on whether the measuring device is a dosimeter or an instrument and whether the purpose of the measurement is to determine the penetrating or nonpenetrating components of dose equivalent.

The previous dose equivalent unit was related to exposure in air and corrected to dose equivalent on a phantom using correction factors called C values. The new units are related to air kerma and corrected by specific dose equivalent correction factors for each of the four units using the ICRU sphere as a standard.

The radiation units previously recommended by the ICRU and currently used by DOE include the Roentgen, the rad, and the rem. In the old system, these units were used interchangeably, because they were all approximately equal for x-rays and gamma rays. In the new system, this is no longer true because of the conversion factors necessary to calculate dose equivalent from exposure (C factors). Although the new units are somewhat more complex, they are more accurate because they take into account the radiation that is backscattered from a person's body.

To determine the effect of the changes in applying the new units to phantom radiation, the C values used in the DOE Lap program as identified in the DOE Lap manual must be compared to the "unified conversion factors" reported by the Federal Republic of Germany and the United Kingdom (Wagner et al. 1985). This comparison shows an increase of 10 to 25%, with the greatest increase associated with low-energy photons. Preliminary measurements of shallow C factors for a phantom simulating the ICRU sphere show good agreement with the values of Wagner et al. (1985).

Immediate action by DOE is needed to determine the potential impacts of ICRU Report 39 on dosimeter and instrument designs, on development of correction factors to ensure continued use of a standard slab phantom at DOE, on changing the standardizing of all instrument and dosimeter calibration procedures, and on preparation of documentation such as manuals of good practice and handbooks.

Supplemental Tasks

R. A. Fox, J. C. McDonald, F. M. Cummings, C. D. Hooker, K. L. Jones, and P. L. Roberson

Several liaison trips were made to RESL in Idaho Falls. Progress of the DOE Lap testing program was discussed, and plans were made for developing new testing categories. A specification was written and agreed upon regarding the uncertainties in the delivery of dose.

The PNL calibration facilities were upgraded with several improvements including a new k-fluorescence x-ray generating assembly. This new x-ray source is expected to increase the dose equivalent rate capability and provide a cleaner x-ray spectrum.

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• Internal Dosimetry Evaluation and Upgrade

This multilaboratory research project was established to provide enhanced capabilities to U.S. Department of Energy (DOE) and DOE-contractor laboratories in evaluating and tracking internal radiation doses from intakes of radionuclides by workers. The project has six principal objectives: 1) to identify current problems and deficiencies in dose-assessment practices, 2) to recommend improved methods of calculating doses to internal organs and tissues for protecting workers and for determining compliance with radiation protection standards, 3) to recommend uniform methods for compliance with DOE Orders and federal regulations and for international scientific guidance with internal dose assessment, 4) to evaluate the accuracy and precision of bioassay laboratory measurements and the appropriateness of draft American National Standards Institute (ANSI) Standard N13.30, “Performance Criteria for Radiobioassay,” 5) to assist DOE in establishing a bioassay laboratory accreditation program, and 6) to develop improved analytical techniques for in vitro and in vivo bioassay measurements.

INTERNAL DOSIMETRY EVALUATION AND UPGRADE PROJECT


This project is a multilaboratory research effort. Internal dosimetry is the science of determining radiation doses to organs and tissues from internally deposited radioactive materials. It involves analysis of the intake of radioactive materials, their redistribution in body fluids, tissues, and organs, and their rate of excretion from the body. Estimating intake also involves measurement of radionuclides in the body by external counting and measurement of radionuclides in bioassay samples.

Studies to improve internal dose assessment are in progress at the Pacific Northwest Laboratory (PNL) and several other supporting DOE laboratories and universities. An Internal Dosimetry Expert Group was formed to provide guidance to DOE and DOE-contractor laboratories regarding compliance with proposed revisions to DOE Orders 5480.1A (DOE-RL 1981) and 5484.1 (DOE 1981). An ad hoc Internal Dosimetry Advisory Group prioritizes the tasks needed to perform this work and provides direction and guidance. The Advisory Group reviewed and scored 33 research proposals from other institutions and provided recommendations to DOE for funding priorities.

The following sections describe progress during fiscal year (FY) 1987 on selected tasks.

Reference Man Database

K. F. Eckerman, ORNL

A project is in progress at Oak Ridge National Laboratory (ORNL) to revise the Reference Man (ICRP 1975) database. The Reference Man database is a fundamental starting point for internal dose calculations; it contains generic anatomical and physiological data for the human.

Chemical and Radiological Toxicities of Uranium

K. F. Eckerman, ORNL

The chemical toxicity and biokinetics of uranium are being studied under subcontract with ORNL. This task involves a review of recent data and potential changes in guidelines for occupational exposure that may be implied by those data.

Ultrasonic Measurement Techniques

A. L. Anderson, LLNL

New ultrasound methods are being developed at Lawrence Livermore National Laboratory (LLNL) to precisely determine the chest-wall thickness and fat content of subjects counted for plutonium and other transuranics in the lung. The task involves generating ultrasonic images followed by computer image processing and tissue characterization.
Detection of Beta-Emitters in the Skeleton

G. R. Eisele, ORAU

A task to determine methods, procedures, and the accuracy and precision of direct in vivo measurements of strontium and neptunium in bone is in progress at Oak Ridge Associated Universities (ORAU). The bremsstrahlung spectrum from such beta-emitters in bone is difficult to quantify. ORAU is developing calibration factors and studying the effect of geometry on detection efficiency. Yorkshire swine that are administered strontium serve as the model for direct counting experiments.

Reevaluation of the Human Plutonium Injection Data of 1945-46

W. D. Moss, LANL

A task is nearing completion at Los Alamos National Laboratory (LANL) to review, interpret, and correct notebook records on the original Langham plutonium injection data on human subjects. The purpose of this work is to develop a new excretion model for plutonium that will permit better estimates of workers' plutonium depositions based on bioassay excretion data and better correlation between human and animal excretion data. The task will explain why the old Langham power-function model previously overestimated workers' plutonium depositions.

Research Tasks at PNL

Several different research tasks are under way at PNL. One task involves collecting and evaluating data on the particle-size distribution and solubility of uranium metal oxides in the work environment of DOE uranium metal-working facilities to determine the effects of particle-size distribution and solubility on dose to internal organs. Another task involves review of current work by the International Commission on Radiological Protection (ICRP) and National Council on Radiation Protection and Measurements (NCRP) task groups on lung modeling. A pilot study was also initiated during FY 1987 to develop improved methods for determining the absorbed fraction of beta energy emitted by radionuclides in small organs. Progress on other major PNL tasks is reported in the following sections.

Technical Evaluation of Draft ANSI Standard N13.30 (Radiobiology)


This task involves two rounds of bioassay laboratory performance testing to evaluate the adequacy of draft ANSI Standard N13.30 "Performance Criteria for Radiobiology."(a) Participants include both in vitro (excreta analysis) and in vivo (external counting) measurement laboratories. Analytical measurement results are being evaluated for bias, precision, and minimum detectable amount.

The pilot study report on in vivo testing was published (Robinson et al. 1986). The report showed a diversity in laboratory measurement performance and that poor measurement results were often a result of having chosen less-than-optimum methods. The report also recommended a number of revisions to the performance criteria of the draft ANSI standard. The second round of in vivo testing was begun in FY 1987 to evaluate revised in vivo performance criteria. It will be completed during FY 1988. Lung and whole body calibration phantoms are being sent to facilities with active in vivo counting laboratories for measurement performance testing.

The final report on in vitro testing was completed and is "in press." This report verified the appropriateness of the performance criteria in the draft ANSI standard for in vitro measurements. It also showed that the performance criteria are achievable, but that optimum methods are not always chosen by analytical laboratories.

(a) Information on draft ANSI Standard N13.30 may be obtained from Roscoe Hall, E. I. duPont de Nemours & Co., Savannah River Plant, Aiken, SC 29801.
The analytical performance of fecal bioassay measurements was studied and a draft report prepared. An artificial fecal matrix was developed for use in performance testing. Samples spiked with $^{239}\text{Pu}$ were distributed to nine bioassay laboratories. It appears from this work that the performance criteria are appropriate and well within the capabilities of analytical laboratories.

The influence of point-source versus uniformly distributed radioactive source material in the lung phantom was studied during FY 1987 (Scherpelz and Maclellan 1987). The point source introduces unacceptable bias into the measurement process, and a uniformly distributed source was recommended. Other work in progress involves the preparation of a three-volume procedures manual for in vitro and in vivo testing, a report on the financial impacts of accreditation, and a plan for pilot accreditation testing.

**Measurement of Transuranics in Workers**

H. E. Palmer, N. Cohen, NYU, and G. S. Kephart, WHC

The purpose of this task is to develop better methods for measuring internal transuranic radionuclide contamination in radiation worker. It involves a statistical evaluation of the sensitivity of in vivo detector systems for measuring transuranics in the lung, and a study of the ratio of $^{239}\text{Pu}$ to $^{241}\text{Am}$ in wounds by measuring the L x-rays with a Si(Li) detector. In addition, realistic human calibration phantoms are being constructed using human bone specimens that contain naturally metabolized $^{241}\text{Am}$. Phantom parts are being put together at PNL and the New York University Medical Center.

Previously, the $^{239}\text{Pu}$ and $^{241}\text{Am}$ concentrations in deep wounds were determined only by analysis of excised tissue. A study performed during FY 1987 showed that a Si(Li) planar detector provides sufficient photopeak resolution to distinguish between the 20.16 keV uranium L x-rays from $^{239}\text{Pu}$ decay and the 20.78 keV neptunium L x-rays from $^{241}\text{Am}$ decay (see Figure 1). The energies measured (and therefore the absorption coefficients of the two x-rays) are similar; thus, the ratio of the peaks for a source embedded in tissue remains approximately the same for the two x-rays to a depth in tissue of at least 6 mm. Figure 2 shows the $^{239}\text{Pu}$ to $^{241}\text{Am}$ ratios plotted against the resulting ratio of the two L x-ray regions at the skin surface and at two different depths in tissue. These curves may be used to determine the $^{239}\text{Pu}$ to $^{241}\text{Am}$ ratio in wounds. Measurement results on deep wounds agree with results obtained by radiochemical analysis of excised tissue.

The in vivo calibration phantoms produced to date include a head phantom (half-skull containing $^{241}\text{Am}$), an arm, and a leg phantom (see Figure 3). The torso phantom is in progress and will be completed during FY 1988. These phantoms have been useful for calibrating in vivo detector systems for measuring $^{241}\text{Am}$ and $^{239}\text{Pu}$ in the skeleton. The completed set of calibration phantoms will be available for use by other facilities.

**Resonantly Enhanced Collisional Ionization**

G. K. Gerke, B. A. Bushaw, and T. J. Whitaker

Resonantly Enhanced Collisional Ionization (RECI) is a promising technology for analyzing radioactive materials, such as plutonium, americium, thorium, uranium, and radium, with high measurement sensitivity at low cost. The objective of this task is to develop the technology for a small, inexpensive instrument capable of measuring extremely small quantities of radionuclides in biological samples. The focus this year has been to compare the potential limits of detection for two different detection schemes.

The RECI process requires two dye lasers to sequentially excite the atom of interest through two resonance steps to a high-lying Rydberg state where collisions with a buffer gas ionize the atom (see Figure 4). Calcium, a spectroscopic analog of uranium, was used during early developmental testing.

The first detection scheme involved a simple wire collector that was capable of operation in proportional mode for increased gain. Detection limits and the sample retention time on the filament were determined. An
FIGURE 1. Overlay of Separate $^{239}$Pu and $^{241}$Am Source Measurements with a Si(Li) Detector

FIGURE 2. Comparison of $^{239}$Pu to $^{241}$Am Ratio with Ratio of Counts in the $\gamma$ Photopeaks at Different Depths in Tissue
FIGURE 3. Human Body Calibration Phantom Parts

FIGURE 4. Preliminary Testing of RECI Components
80-ng(a) sample of calcium on a rhenium filament heated to approximately 1700°C was found to have a retention half time of approximately 20 min. With a signal-to-noise ratio of 103, and with pulsed heating immediately prior to scanning across the selected peak, the minimum detectable amount was estimated to be 800 fg(b) calcium.

The second detection scheme involved a thermionic diode. When the sample filament was heated to temperatures necessary to atomize the calcium, enough electrons were generated to provide a space-charge-limited regime in which a positive ion could be detected as a current flow between the sample filament and a collector plate. The two dye lasers excited the atoms between the filament and the plate, and 10 torr of buffer gas collisionally ionized the Rydberg states. A minimum detectable amount of 160 fg was demonstrated. With further progress, a detection limit of 10 fg is expected. Work during FY 1988 will involve measurement of uranium using the thermionic diode detection. The expected detection limit for uranium is 1 fg.

(a) 1 ng = 10^{-9} grams.
(b) 1 fg = 10^{-15} grams.

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