THE NIOSH RADIATION DOSE RECONSTRUCTION PROGRAM: ORIGIN, GOALS, SCOPE, AND RESULTS

During the past 65 years, hundreds of thousands of people have been employed in nuclear weapons-related activities for the U.S. Department of Energy and its predecessor agencies. Many of these workers, as is normal in any population group, have developed cancer, and, in some cases, their cancers may have been due to radiation exposures they received in the course of these activities. In 2000, the President signed legislation requiring that, upon submission of a claim for compensation from people involved in this type of work, their records would be reviewed and assessed to estimate the probability that this was the case. As noted in the papers that follow, the process for documenting whether their cancers were, or could be, attributable to radiation exposures associated with their work requires extensive reviews, evaluations, and assessments of the dose on an individual case basis. This is commonly referred to as "dose reconstruction." One of the major features of the program is that its implementing legislation requires that the dose reconstructions be performed in a manner that is favorable to the claimant.

The responsibility for overseeing the Radiation Dose Reconstruction Program is delegated to the U.S. Department of Health and Human Services with day-to-day operations being assigned to the National Institute for Occupational Safety and Health (NIOSH). In 2002, NIOSH contracted with the Oak Ridge Associated Universities (ORAU) Team to provide dose reconstruction and other services in support of the program. The 15 papers contained in this special issue provide a review of the collection, processing, and management of the required data, the methods being used to perform the associated assessments, their scientific bases, and the role played by the health physics and radiation safety profession in this effort.

Other objectives of this special issue include sharing the associated technical information with the professional scientific community; subjecting the work to the peer-review process of a well-respected scientific journal; gaining the valuable independent feedback that such reviews would provide; and producing papers that would be readily available to answer questions from current or prospective claimants, members of Congress, representatives of Federal, state, and local government agencies, and members of the public and media. It is also hoped that this special issue will serve as a valuable resource for use in training and education.

In undertaking this task, every effort has been made to cover all significant aspects of the program and to present them in a logical, coherent, and comprehensive manner, with a minimum of duplication. To enable readers to locate additional information on key topics, cross-references to other papers in this same issue have been inserted into the text of many of the papers.

A synopsis of each of the 15 papers is presented below. For purposes of organization, they are divided into five groups.

GROUP 1: BACKGROUND INFORMATION

Radiation Dose Reconstruction Program of the National Institute for Occupational Safety and Health: Overview—James W. Neton, John Howard, and Larry J. Elliott

Neton and his coauthors describe what is commonly cited as the NIOSH Radiation Dose Reconstruction Program. As they note, the processing of each claim requires the reconstruction of the doses received, and a determination (by the U.S. Department of Labor) of whether the worker was "at least as likely as not" to have sustained his or her cancer due to occupationally related radiation exposures received in the course of employment in the nuclear weapons program. Although some dose assessments are straightforward, experience soon revealed that there were many complexities and challenges inherent in this effort. These include missing, non-interpretable, or undocumented records; a wide variety of external and internal exposure conditions; and highly variable workloads and conditions. Additional effort was required to develop the necessary infrastructure to ensure that all claims could be processed in an efficient and timely manner; documenting that all assessments are equitable and consistent; and ensuring that each claimant receives the "benefit of the doubt" in cases in which the available information is inadequate to differentiate among several plausible exposure scenarios. The authors emphasize that every effort has been, and continues to be, made to ensure that the dose assessments

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are performed using well-established scientific methods, combined with the implementation of a claimant-favorable approach.

The NIOSH Radiation Dose Reconstruction Project: Managing Technical Challenges—Matthew P. Moeller, Ronald D. Townsend, and David A. Dooley

Townsend, who is director of the prime contractor, Oak Ridge Associated Universities; Moeller, who is director of one of the subcontractors, Dade Moeller & Associates; and Dooley, who is director of the other subcontractor, MJW Corporation, review the primary technical challenges faced in managing this organization, and in meeting the emerging demands of the project. From the time the program was initiated, operations were behind schedule because the awarding of the contracts was not completed until two years after the Congressional legislation for implementation of the program had been passed. Primary among the challenges were the needs for continuous planning, integration, and conflict resolution. These basic requirements were exacerbated by the tremendous amounts of data to be processed, the breadth of the methods for individualized dose reconstruction that needed to be developed, and the demands on the infrastructure to support the project. The most complex and continuing challenges have been to establish an open program, prepare credible technical documents, and generate understandable, defensible, and claimant-favorable dose reconstructions in a timely manner.

Responsibilities and Activities of the Advisory Board on Radiation and Worker Health—Paul L. Ziemer

Ziemer presents a detailed review of the activities of the Advisory Board on Radiation and Worker Health, which plays a major role in the Radiation Dose Reconstruction Program. The Board has the responsibility of advising the Secretary of the U.S. Department of Health and Human Services on (1) the development of guidelines for dose reconstructions and the determination of the probability of causation; (2) the validity and quality of dose reconstruction efforts performed for the program; and (3) whether there are additional classes of employees who qualify to be added to the Special Exposure Cohort (SEC). The SEC includes workers who were exposed to radiation but for whom it is not feasible to estimate their doses, yet there is a reasonable likelihood that they were sufficiently high to have endangered their health. Another responsibility of the Board is to establish methodologies for auditing the dose reconstruction program to ensure the validity and quality of the dose estimates. As part of this effort, the Board ultimately expects to sample and audit approximately 2–3% of the completed dose reconstructions.

Scientific Issues in Radiation Dose Reconstruction—Richard E. Toohey

On the basis of a detailed review, Toohey identified more than 180 issues that pertained to the scientific bases of the Radiation Dose Reconstruction Program. For purposes of analyses, he separated these issues into three categories: (1) data issues, (2) dosimetry issues, and (3) compensation issues. Data issues include the use of coworker information; changes in site operations over time; variations in operations within different facilities at a given site; and episodic exposures and incidents. Dosimetry issues include specific questions related to external doses (for example, the sensitivity of the personal monitors, dependence of their responses on geometry, the energy of the radiation, and the accompanying uncertainties) and to internal doses (for example, inhalation and ingestion models, intake and ingestion rates, dose coefficients, and modeling uncertainties). Compensation issues include uncertainties in the risk models, use of the upper-bound 99^{th} percentile value for assessing claims (which is claimant favorable compared to more likely than not $>50^{th}$ percentile test), and considerations related to dose reconstruction assessments for compensation vs. the worker's official dose of record. One of Toohey's more significant observations, based on the preceding considerations and the roles they played in estimating the probability of causation, is that the application of well-established scientific methods does not always yield an outcome that is most favorable to the claimant.

GROUP 2: DATA COLLECTION AND SUPPORTING STUDIES

Data Collection, Processing, Validation, and Verification—Deborah L. Martin, Jennifer L. Hoff, Roger A. Gard, Richard J. Gregosky, Hobert W. Jones, Cheryl A. Kirkwood, Donald G. Morris, Tracey E. Shinsato, and Cheryl L. Willott-Moore

Martin and her coauthors describe the team and methodologies that were created to collect, organize, store, and manage the voluminous amounts of information, data, and records that have been vital to the success of the NIOSH Radiation Dose Reconstruction Program. The data destined for review, evaluation, and analyses reside in documents located in one or more of the >300 covered Atomic Weapons Employer and U.S. Department of Energy facilities (including contractor sites); the file cabinets in somebody's office; or in repositories such as the National Archives and Records Administration facility. Once the data have been obtained and verified, they are securely stored in readily usable formats on an individual claimant basis and compiled in a manner in which they can be readily retrieved for a specific site, facility, time period, occupational environment, and individual worker, while every aspect of these operations is simultaneously being conducted under strict quality control oversight. This paper provides insights into this essential aspect of the dose reconstruction program.

Development of Site Profiles for Dose Reconstruction Used in Worker Compensation Claims—Judson L. Kenoyer, Edward D. Scalsky, and Timothy D. Taulbee

This paper, which serves as a source of information on *occupational* exposures, is one of two that relate to the development of what are called "site profiles." The other (by Rollins, which is described immediately below) provides information on ambient *environmental* exposures. As Kenoyer and his coauthors emphasize, one of the basic principles in reconstructing occupational doses is that personal dosimeter data and measured intakes (e.g., estimated through urinalyses, whole body counting and breathing zone air sampling) should serve as the fundamental sources of information. This, however, is not always possible because the worker's exposure records may be incomplete or missing, or perhaps the individual was not monitored based on directives and guidelines at the time. To fill these voids, profiles have been prepared for each of the major U.S. Department of Energy sites, the goal being to provide a general overview of each facility located on that site, the types of radiation sources employed, and the radionuclides involved, supported by details of the processes to which they are, or were, being subjected. Each profile is designed to enable the dose reconstructors to make intelligent and consistent decisions in estimating internal and external doses in cases where a complete set of monitoring data for workers is unavailable.

Ambient Environmental Profile for the Savannah River Site—Eugene M. Rollins

As a follow-up to the paper by Kenoyer et al., Rollins presents an in-depth "case study" of the site profile development process, focusing on the *ambient environmental* dose profile for the Savannah River Site. In this case, the principal sources of radionuclide contaminants were airborne releases from onsite operations, and radioactive fallout from atmospheric nuclear weapons tests in the United States and elsewhere. As such, the major intakes by onsite workers were through inhalation during periods of time they were outdoors. To assess the accompanying doses, airborne concentrations of specific radionuclides were estimated on the basis of monitoring records of their releases from individual facilities on the site, and contributions due to resuspension of earlier depositions from the soil. External doses were estimated on the basis of releases of noble gases and contributions from radioactive materials deposited within the site environment. The resulting intakes and ambient radiation exposures were then used to estimate the dose rates to those organs of interest during specific time intervals. Particularly challenging was the necessity to account for the confounding effects of atmospheric nuclear weapons testing, the lack of spatial and radionuclide resolution, and the insensitivity of sampling methods to certain radionuclides that served as significant contributors to dose.

GROUP 3: DOSE RECONSTRUCTION

Internal Dose Reconstruction under Part B of the Energy Employees Compensation Act—Elizabeth M. Brackett, David E. Allen, Scott R. Siebert, and Thomas R. La Bone

As Brackett and her coauthors state, the primary objective of the internal dosimetry program is to estimate the annual dose equivalent that was delivered to the affected organ of a worker from all occupational intakes between the time of initial employment and the date the cancer was diagnosed. Neither the committed dose, nor the effective dose, is of interest. Based on the Integrated RadioEpidemiological Program requirements, all input doses must be those for the organ in which the cancer was diagnosed, expressed in terms of annual dose, and classified according to the energy of the radiation involved. One of the major challenges is the necessity to include any potential doses that could have been received, but were unmonitored or undetected. Playing primary roles in filling these voids are the previously discussed site profiles, which provide vital information on the processes, radionuclides, and types of radiation sources with which a worker was likely involved. Other challenges include the inability to collect follow-up samples, and, in many cases, a general lack of information regarding the specific duties the worker performed and/or the location within a facility and/or site where he or she worked. Brackett and her coauthors provide multiple examples of how these issues were addressed.

Establishing Bounding Internal Dose Estimates for Thorium Activities at Rocky Flats—Brant A. Ulsh, Bryce L. Rich, Melton H. Chew, Robert L. Morris, Mutty Sharfi, and Mark R. Rolfes

Ulsh and his coauthors present an interesting example of how the science of dose reconstruction was used to determine whether the limited thorium activities at the

U.S. Department of Energy Rocky Flats facility presented significant and unquantifiable risks to workers, and therefore constituted a valid basis for being added to the Special Exposure Cohort (SEC). The historic difficulty in analyzing for thorium intakes, using the available methods for conducting in-vitro bioassays, complicated the task. Other important considerations were the long biological retention time for thorium, and its relatively high dose per unit intake. Through interviews with numerous former workers who were closely involved in the thorium handling activities and documentation of the quantities of thorium handled and the types of processes conducted, supplemented by reviews of logbooks, monthly reports, and other monitoring records, sufficient evidence was obtained to place an upper bound on the doses the workers could have plausibly received. Based on this information it was determined that thorium dose reconstructions could be performed with sufficient accuracy, and that these thorium activities did not present a valid basis for addition to the SEC.

Development of Rapid Methods for Assessing Doses from Internally Deposited Radionuclides—Edward F. Maher, Keith A. McCartney, Brian D. Mize, Lin-Shen C. Sun, and Scott R. Siebert

During the early phases of the dose reconstruction program, all calculations for internally deposited radionuclides were performed using the Integrated Module for Bioassay Applications (IMBA) software. It soon was recognized, however, that associated limitations delayed the processing of claims, primarily because this program required separate calculations for each radionuclide, depending on its physical, chemical, and biological characteristics, and the mode of intake. To resolve these difficulties, a concerted effort was undertaken to develop what are called the Chronic Annual Dose Workbook (CADW) tools. These tools not only have the capabilities for calculating internal doses, using the IMBA software as a base, but they also permit an analyst to combine up to 255 separate intakes for any combination of radionuclides, intake modes, and absorption rates into a single dose calculation. This yields a tremendous savings in computational time, and the output is displayed in a format that is compatible with the Integrated RadioEpidemiological Program used for compensability determinations. This is one of several examples of new computer tools that, while developed for the NIOSH Radiation Dose Reconstruction Program, will find applications throughout the health physics and radiation safety profession.

External Dose Reconstruction under Part B of the Energy Employees Compensation Act—Steven E. Merwin, Matthew H. Smith, Robert C. Winslow, Keith A. McCartney, Jack J. Fix, Timothy D. Taulbee, and Gregory L. Macievic

As explained by Merwin and his coauthors, the reconstruction of doses from external sources involves a variety of challenges. These range from accounting for the uncertainties in, and interpretation of, the doses that were recorded to estimating those for workers who were not monitored. The latter group included, particularly during the early years, most of those employed at Atomic Weapons Employer facilities; those involved in "low-risk" activities at Department of Energy facilities in which plutonium and uranium were handled; and transient workers who were employed by subcontractors not subject to site monitoring requirements. Even for those workers who were monitored, the reported data were subject to a range of errors. Examples were doses missed due to the limits of detection associated with personal dosimeters and doses incurred through occupationally related x-ray examinations. In addition, it was necessary to account for the relationship of the dose to the energy of the emissions (i.e., photons, electrons, and neutrons) from the external sources. Having overcome these hurdles, it was then necessary to convert the recorded doses into organ doses, depending on the cancer type and location. These authors conclude by providing examples of how the available information and guidance were used in reconstructing the doses from such sources.

Reconstruction of Doses from Occupationally Related Medical X-Ray Examinations—Vernon E. Shockley, Ronald L. Kathren, and Elyse M. Thomas

Many of the workers submitting claims for compensation received occupationally related medical x-ray examinations in the course of their employment. To ensure that this component of their dose records is adequately evaluated, it is necessary to estimate the contributions from these procedures, prominent among which were radiography and photofluorography of the chest, and radiography of the pelvis and the lumbar, cervical, and thoracic portions of the spine. Shockley and his coauthors review the factors that must be considered, and how and in what ways they can influence the dose. Those having a major impact are the voltage and electric current applied to the x-ray tube; the presence or absence of filters to absorb the lower energy x rays (and "harden" the beam); and the presence or absence of collimators to restrict the size of the beam. Another key factor was whether the specific body organ for which the dose is being assessed was in, on the periphery, or outside the primary beam. Complicating the task were the continuing changes and improvements in medical x-ray equipment during the multiple decades that workers were employed.

GROUP 4: EVALUATION OF CAUSATION OF CANCER

Interactive RadioEpidemiological Program (IREP): A Web-Based Tool for Estimating Probability of Causation/Assigned Share of Radiogenic Cancers—David C. Kocher, A. Iulian Apostoaei, Russell W. Henshaw, F. Owen Hoffman, Mary K. Schubauer-Berigan, Daniel O. Stancescu, Brian A. Thomas, John R. Trabalka, Ethel S. Gilbert, and Charles E. Land

Kocher and his coauthors provide an in-depth review of the models and assumptions incorporated into the Interactive RadioEpidemiological Program (IREP), which is a Web-based computer code used to evaluate causation of cancers diagnosed in individuals who were exposed to ionizing radiation. The quantity calculated in IREP is referred to as the "probability of causation/assigned share" (PC/AS). As will be noted, the PC/AS is calculated on the basis of an estimate of the excess relative risk associated with given radiation exposures. A defining characteristic of IREP is that it accounts for many sources and kinds of uncertainty in calculating probability distributions of the excess relative risk and PC/AS. Approaches to accounting for uncertainties in the various risk models and parameter values are emphasized, and limitations of the code are discussed. On the bases of the accompanying discussion, it is clear that, as a tool for use in adjudicating claims for compensation, IREP operates at the interface of science and a policy that will ensure that the outcomes will be favorable to the claimants.

GROUP 5: COMMENTARY AND CONCLUSION

Implications of Claimant-Favorable Approaches Used in Dose and Probability of Causation Calculations under EEOICPA—Steven E. Merwin, Donald N. Stewart, Matthew H. Smith, Kenneth D. Potter, and Stuart L. Hinnefeld

In their review of the technical aspects of the NIOSH Radiation Dose Reconstruction Program and associated compensation decisions, Merwin and his coauthors have revealed several interesting outcomes. These are primarily attributed to the combined effects of the numerous accompanying claimant-favorable approaches, assumptions, and parameters that are incorporated into the program. While these are designed to ensure that essentially all claims with merit are compensated, they have also lead to a substantial number of claims being compensated even though the associated cancers were highly unlikely to have been attributable to radiation exposures in the workplace. This, in turn, has yielded a compensation rate of approximately 30% even though epidemiological studies and accompanying analyses have shown that the rate of radiation-induced cancers in the workers is, at most, only a few percent. This point is typically not understood, nor accepted, by claimants and various other stakeholders, and it is rarely appreciated and reported by the media.

The National Institute for Occupational Safety and Health Radiation Dose Reconstruction Program: Commentary and Conclusions—James W. Neton and Larry J. Elliott

Neton and Elliott introduce the final paper by observing that, in many respects, dose reconstruction can be best described as *health physics archaeology*. Continuing, they list four underlying principles that have governed the NIOSH Radiation Dose Reconstruction Program from its inception: (1) all activities should be supported by well-established scientific methods, modified to meet the need for a claimant-favorable decision; (2) application of these methods should be consistent and uniform; (3) every effort should be made to perform the dose reconstructions in a timely, efficient, and equitable manner; and (4) the program should be conducted in a transparent manner while maintaining the privacy of the workers and claimants. Illustrating the first two principles, the authors describe the prominent roles played by the latest national and international consensus standards developed by, for example, the National Council on Radiation Protection and Measurements and the International Commission on Radiological Protection. In support of the last two principles, they discuss the strategic approaches used and the development of new computer tools for increased efficiency, as well as the openness and personalized nature of interactions with workers and claimants, which are highlighted by the "claimant favorability" policy.

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Last but not least, we want to thank the many members of the dose reconstruction team who devoted hours of their time, often during vacations and holidays, to the preparation of the individual papers. They were an inspiration to us all.

Dade W. Moeller
Richard E. Toohey
Associate Editors, Health Physics