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Development of Dose Coefficients for Radionuclides Produced in Spallation Neutron Sources

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Project Title:
Development of Dose Coefficients for Radionuclides Produced in Spallation Neutron Sources

May 15, 2003

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TRP Research Area: Transmutation Sciences

Academic Year 1 – (August 1, 2001 – July 31, 2002) Funding: \$160,000

Academic Year 2 – (August 1, 2002 – July 31, 2003) Funding: \$160,000

Academic Year 3 - (August 1, 2003 – July 31, 2004) Funding Request: \$160,000

Abstract

A research consortium comprised of representatives from several universities and national laboratories has been established as part of this on-going project to generate internal and external dose conversion coefficients for radionuclides produced in spallation neutron sources. Information obtained from this multi-year study will be used to support the siting and licensing of future accelerator-driven nuclear initiatives within the U.S. Department of Energy complex, including the Spallation Neutron Source (SNS) and the Advanced Fuel Cycle Initiative (AFCI) Projects. Determination of these coefficients will also fill data gaps for several hundred radionuclides that exist in Federal Guide Report No. 11 and in Publications 68 and 72 of the International Commission on Radiological Protection (ICRP).

Work Proposed for Year 3:

Representatives from the Working Group established in Year 1 have developed and verified a methodology to develop dose coefficients from radionuclides produced during the spallation process. Dose coefficients have been generated using this methodology for a select few radionuclides. Personnel built on the progress of year one and categorized 81 radionuclides into three distinct groups during Year 2. In addition, dose coefficients were generated for radionuclides that fell into Category 1. During Year 3, the main concentration of the consortium's time will be devoted to obtaining nuclear data that will allow dose coefficients to be calculated for Category 2 and 3 radionuclides and to calculate dose coefficients for those in Category 2.

Background and Rationale

The U.S. Department of Energy (DOE) was authorized by Congress in 2001 to create the Transmutation Research Program (TRP) to address pressing nuclear-related issues facing the nation such as nuclear energy and waste management concerns, declining U.S. nuclear infrastructure, global nuclear leadership, and national defense. Other national and international accelerator programs such as the SNS project located at the Oak Ridge National Laboratory (ORNL) are expected to benefit from the knowledge and data obtained from research activities within the TRP program.

The TRP program will need to assess the health risks associated with the operation of each of their accelerator-driven nuclear facilities for both NEPA and PSAR development. Quantifying the radiological risks to workers will have to be addressed during the design and siting of each of these facilities. U.S. Environmental Protection Agency (EPA) Federal Guidance Report No. 11 "Limiting Values of Intake and Air Concentration and Dose Conversion Factors for Inhalation, Submersion, and Ingestion", developed two derived guides, Annual Limit on Intake (ALI) and the Derived Air Concentration (DAC), to be used to control radiation exposure in the workplace. The ALI is the annual intake of a radionuclide which would result in a committed effective dose equivalent of 0.05 Sv/yr for stochastic effects, or a committed dose equivalent to an individual organ or tissue of 0.5 Sv/yr for deterministic effects, to Reference Man (ICRP 1975). A DAC is that concentration of a radionuclide in air which, if breathed by Reference Man for a work-year, would result in an intake corresponding to its ALI (EPA 1988). Therefore, ALIs and DACs can be used for assessing radiation doses due to accidental ingestion and

inhalation of radionuclides and are used for limiting radionuclide intake through breathing of, or submersion in, contaminated air.

In addition to determining ALIs and DACs, in many situations it is useful to know the committed dose equivalent to an organ or tissue per unit intake, the committed effective dose equivalent per unit intake, the dose equivalent rate per unit air concentration of radionuclide, or the effective dose equivalent rate per unit air concentration of radionuclide. These dose coefficients (DCs) allow simple determination of radiation dose associated with various exposure scenarios, and ultimately, assessing the health risks to workers in a nuclear facility.

Even though the ALIs, DACs, and DCCs calculated in Federal Guidance Report No. 11 adhere to the derived limits in Publication 30 (ICRP 1979), which incorporate current knowledge of radionuclide dosimetry and biological transport in humans, the report is not exhaustive in reference to anthropogenic radionuclides. Unfortunately, many of the rare radionuclides produced during the spallation process are not addressed in current radiation protection standards. There may be as many as 660 radionuclides that would be produced in either the target or blanket of the APT for which no data exists in Federal Guide Report No. 11 or in Publications 68 and 72 of the ICRP. The number of radionuclides that need to be studied is expected to increase if those produced in the target and blanket from an Accelerator-Driven System (ADS) and SNS activities are also considered.

It is the intent of the current research to develop a methodology and generate internal and external dose coefficients for radionuclides produced in spallation neutron sources. Results from this study will expand the ALI and DAC data of Federal Guidance Report No. 11 in order to include radionuclides produced by current technology, such as that used in the TRP and SNS programs.

Research Objectives

There are four research objectives for Year 3 of this project. They are to:

- Expand the number of participants and the role of the existing TRP DC Working Group
- Further refine a reproducible methodology to determine internal and external DC and incorporate checks into currently used computer codes
- Complete an exhaustive search for nuclear decay data for radionuclides missing such data
- Generate internal and external DC values for radionuclides in Category 2 and Category 3

There are four goals for Year 3 of this project:

- Generate DCs for radionuclides that could be created from spallation neutron sources which have been placed in category 2
- Generate results that will be considered for inclusion in future ICRP Reports
- Create additional opportunities for students to present project results at national professional conference
- Search for and evaluate nuclear data needed to produce dose coefficients for category 3 radionuclides

Technical Impact

Results from the proposed work will be invaluable to individuals and organizations responsible for ensuring the safety of their workers in accelerator facilities, and the national and international radiation safety profession in general. The DCs generated as part of this study can be used to support the siting and licensing of future accelerator-driven nuclear initiatives within the U.S. DOE complex, including the SNS and APT projects. As mentioned previously, determination of these coefficients will also fill data gaps that exist in Federal Guide Report No. 11 and in ICRP Publications 68 and 72.

From a much larger perspective, the establishment of the multi-university/national laboratory consortium as part of this project will further enhance the technical infrastructure of the TRP. The proposed composition of the consortium would also appear to make it an excellent resource for radiation safety issues facing the TRP in the future. Finally, students selected to participate on the project will have the opportunity to work with a number of leaders in the health physics community on this important activity.

Research Approach

Each of the above objectives will be accomplished through the completion of specific tasks. Tasks associated with each objective are identified below:

Objective 1 - Expand the number of participants and the role of the existing TRP DC Consortium

Work performed under this project has continued to draw upon the experience and expertise residing at a number of respected health physics academic programs across the United States and representatives from DOE national laboratories. Faculty and students from the following academic institutions are currently participants in the consortium: Georgia Institute of Technology, Idaho State University, University of Florida, and the University of Nevada, Las Vegas (UNLV). Oak Ridge National Laboratory (ORNL) also has representation on the Consortium.

Efforts were initiated in Year 2 to add representatives from other countries to serve as members on the TRP DC Consortium. For example, faculty and students from Tbilisi State University in Tbilisi, Georgia have participated in a number of project activities and

have been invited to formally become members of the Consortium. In fact, one such student is currently enrolled in the Department of Health Physics at UNLV. Project personnel will continue to work to expand the number of participants and role of the existing TRP DC Consortium in a reasonable manner.

A TRP DC Working Group was established in Year 1 to direct and oversee consortium activities. The following individuals will serve on the Advisory Group in Year 3:

Phillip Patton ,UNLV, Project Coordinator
Richard Brey, Idaho State University
Keith Eckerman, ORNL
Tom Gesell, Idaho State University
Nolan Hertel, Georgia Tech
Samson Pagava, Tbilisi State University
Mark Rudin, UNLV

The Project Coordinator will be responsible for scheduling and hosting all of the meetings of the TRP DC Working Group in Year 3. It should be emphasized that Working Group members and all participating members of the consortium will work collaboratively to complete all tasks associated with the project. UNLV personnel will host future working group meetings periodically to continually encourage collaboration and ensure project activities are completed in a timely manner. The current proposal requests funding for three UNLV graduate students, summer salary for the Project Coordinator. In addition, funding is requested to host TRP DC Working Group meetings in Year 3.

Objective 2 - Further refine a reproducible methodology to determine internal and external DCs

A methodology was developed by TRP DC Working Group in Year 1 to determine internal and external DCs. The first step involved obtaining radiological data from the ENSDF nuclear physics database developed at Brookhaven National Laboratory for selected radionuclides. Examples of data collected included decay modes, decay energy levels, and radiation energies and intensities. The ENSDF data was downloaded into an EDISTR input file. The EDISTR batch file executed the necessary steps and formatting codes that prepared input files (NDX and RAD) for the Dose Calculation (DCAL) program, which can be used to calculate the DCs. However, the methodology can be somewhat cumbersome and difficult to use. The primary problem has been the difficulty associated with properly formatting the NDX and RAD input files for use in DCAL. Project personnel will continue to work closely with Keith Eckerman of ORNL who wrote DCAL and is a member of the Working Group to correct this problem.

The metabolic models and data from ICRP Publications #30 and #66 will be applied in order to use the best technology available and to maintain consistency with current standards. These ICRP publications define the committed dose equivalent in a target

organ, T , from activity in a source organ, S , for each type of radiation, i , of a particular radionuclide, j , as:

$$H_{50,T}(T \leftarrow S)_i = 1.6 \times 10^{-10} U_s SEE(T \leftarrow S)_i \quad \text{Sv} \quad \text{Eq. 1}$$

where U_s is the total number of transformations of radionuclide, j , in source organ, S , over 50 years following intake of the radionuclide and SEE is the specific effective energy per gram for radiation type, i , absorbed in target organ, T , per transformation in source organ, S , modified by a quality factor. For all types of radiation emitted by radionuclide j , Eq. 1 becomes:

$$H_{50,T}(T \leftarrow S)_i = 1.6 \times 10^{-10} \left[U_s \sum_i SEE(T \leftarrow S)_i \right]_j \quad \text{Sv} \quad \text{Eq. 2}$$

Therefore, the development of the DCs involves determining U_s and $SEE(T \leftarrow S)$ values. For consistency with Federal Guidance Report No. 11, dose coefficients will be evaluated for an adult male with the target tissues of gonads, breast, lung, red marrow, bone surface (endosteum), thyroid, remainder, and total committed effective dose equivalent.

The DCAL program utilizes the ICRP #30 gastrointestinal tract model and the ICRP #66 lung model to calculate the number of transformations per Bq in each target organ over fifty years. This requires knowledge of the physical and metabolic data (i.e. radioactive half-life, inhalation class, and the fraction of stable element reaching the body fluids following ingesting) for each radionuclide. Since DCAL can also calculate $SEE(T \leftarrow S)$ values, it is able to determine the committed dose equivalent in a target organ, T , using Eq. 2. Furthermore, the committed effective dose equivalent can be determined by:

$$H_E = \sum_T w_T H_{50,T} \quad \text{Eq. 3}$$

Once the committed dose equivalent to all target organs and the committed effective dose equivalent are determined, values of the ALI and DAC can be calculated for each radionuclide.

Objective 3 - Generate internal and external DC values for selected radionuclides

The TRP DC Working Group has completed a prioritization of radionuclides projected to be released via air emissions or in the inventory of a mercury target after a long irradiation period. Only radionuclides with a half-life greater than 1 minute are considered, the list is narrowed from 540 radionuclides to approximately 81. UNLV students classified these 81 nuclides into three categories. Dose coefficients were generated for six quality assurance radionuclides as well as for radionuclides in Category 1 by all groups, since the appropriate nuclear data were available. Dose coefficients were not calculated for Category 2 nor Category 3 radionuclides. It is these two categories that will be addressed in Year 3 of the grant. Currently, students from UNLV, Idaho State,

and Tbilisi State University in the Republic of Georgia, are investigating nuclear data sources to determine the availability of needed nuclear data. After obtaining the needed nuclear data, dose coefficients for these categories will be calculated.

Capabilities at the University and National Laboratories

Due to the nature of the proposed project, there are no large equipment needs at this time. Much of the work is performed with computers and every effort is made to ensure that personnel are using state-of-the-art computer systems and software to ensure timely completion of the project. The project will continue to rely on expertise provided by members of the TRP DC consortium and Working Group.

Project Timeline (August 1, 2003 – July 31, 2004)

| <u>Year 3 Activities</u> | <u>Completion Date</u> |
|---|------------------------|
| Determine which radionuclides in Category 2 have needed nuclear data to calculate DCs | November 2003 |
| Working Group Generate DCs for Second Set of Radionuclides | June 2004 |
| Working Group Crosschecks DC Results | August 2004 |
| Generate Annual Report | September 2004 |

Deliverables

The following deliverables will be completed during Year 3 of the project:

Monthly Progress Reports (Monthly) – The principal investigator will submit reports on a monthly basis that identify administrative, technical, and budget issues associated with the project.

Annual Report (July 31, 2004) - The principal investigator will generate an annual report that outlines project activities performed during FY 2004.

Professional Meeting Presentations/Publications (July 31, 2004) - It is expected that the results of this study will be presented and/or published at selected professional meetings and in the scientific literature. Abstracts or manuscripts generated, as part of this study will be sent to the TRP/UNLV program for review.

Annual Reports and any professional meeting presentations, technical publications, or student theses will also be developed and delivered to the TRP/UNLV program at the end of the FY 2004.

Phillip W. Patton

Academic Rank

Assistant Professor (tenure-track), Department of Health Physics

Degrees

B.S., Physics, 1990

Augusta College, Augusta, Georgia

M.S., Nuclear Physics, 1993

University of Georgia, Athens, Georgia

M.S., Health Physics 1998

University of Florida, Gainesville, Florida

Ph.D., Health Physics, 2000

University of Florida, Gainesville, Florida

Years of Service

3 years; Original appointment – November, 2000

Other Related Experience

- Graduate Research Assistant, University of Florida, Gainesville, FL, 1996-2000

- Graduate Research/Teaching Assistant, University of Georgia, Athens, Georgia, 1990-1993

Principal Publications of Last Three Years

DA Rajon, PW Patton, AP Shah, CJ Watchman, and WE Bolch, "Surface area overestimation within 3D digital images and its consequences for skeletal dosimetry" *Med Phys* **29** (5) 682-708 (2002).

PA Patton, DW Jokisch, DA Rajon, AP Shah, BA Inglis, SL Myers, and WE Bolch, "Skeletal dosimetry via NMR microscopy: Investigations of sample reproducibility and signal source" *Health Phys.* **82** (3): 316-326 (2002).

PA Patton, DA Rajon, AP Shah, DW Jokisch, BA Inglis, WE Bolch. "Site-specific variability in trabecular bone dosimetry: considerations of energy loss to cortical bone." *Med. Phys.* **29** (1): 6-14 (2002).

WE Bolch, PA Patton, DW Jokisch, DA Rajon, AP Shah, SL Myers, and BA Inglis, "Considerations of marrow cellularity in 3D dosimetric models of the trabecular skeleton" *J. Nucl. Med.* **43** (1) 97-108 (2002).

DA Rajon, DW Jokisch, PW Patton, AP Shah, CJ Watchman, and WE Bolch, "Voxel effects within digital images of trabecular bone and their consequences on chord length distribution measurements" *Phys. Med. Biol.* **47** (10) 1741-1759 (2002).

WE Bolch, PW Patton, AP Shah, DA Rajon, and DW Jokisch, "Considerations of anthropometric, tissue volume, and tissue mass scaling for improved patient specificity of radionuclide S values in the skeleton." *Med Phys.* **29** (6) 1054-1070 (2002).

MG Stabin, KF Eckerman, WE Bolch, LG Bouchet, and PW Patton, "Evolution and status of chord-based bone and marrow dose models" *Cancer Biotherapy and Radiopharm* **17** (4) 427-434 (2002).

DA Rajon, DW Jokisch, PW Patton, AP Shah, CJ Watchman, and WE Bolch, "Voxel effects within digital images of trabecular bone and their consequences on chord length distribution measurements" *Phys. Med. Biol.* **47** 1-19 (2002).

DW Jokisch, PW Patton, DA Rajon, BA Inglis, and WE Bolch, "Chord distributions across 3D digital images of a human thoracic vertebra" *Med. Phys.* **28** (7): 1493-1504 (2001)

DW Jokisch, LG Bouchet, PW Patton, DA Rajon, and WE Bolch, "Beta-particle dosimetry of the trabecular skeleton using Monte Carlo transport in 3D digital images" *Med. Phys* **28** (7): 1505-1518 (2001)

DA Rajon, DW Jokisch, PW Patton, AP Shah, and WE Bolch, "Voxel size effects in 3D NMR microscopy performed for trabecular bone dosimetry" *Med. Phys.* **27** (11): 2624-2635 (2000)

"NMR Microscopy for Skeletal Dosimetry: An Investigation of Age, Gender, and Marrow Cellularity on Dose Estimates" University of Florida PhD Thesis, Department of Nuclear and Radiological Engineering, (2000).

Scientific and Professional Societies

Sigma Xi Scientific Research Honor Society Member (1999 - Present)

Alpha Nu Sigma Honor Society Member (1996 - Present)

American Association of Physicist in Medicine Member (1996 - Present)

Health Physics Society Member (1996 – Present)

American Nuclear Society Member (1996 - 2000)

Honors and Awards

Health Physics Fellow, 1997

United States Achievement Academy

Mark J. Rudin

Academic Rank

Associate Professor (with tenure) and Chair, Department of Health Physics

Degrees

B.S., Health Sciences, 1983

Purdue University, West Lafayette, Indiana

M.S., Health Physics, 1985

Purdue University, West Lafayette, Indiana

Ph.D., Health Physics, 1989

Purdue University, West Lafayette, Indiana

Years of Service

10 years; Original appointment – August 1993, Promotion to Associate Professor and Tenure – July 1999

Other Related Experience

- Technical/Administrative Assistant, U.S. Department of Energy-Headquarters (DOE-HQ), Office of Environmental Restoration and Waste Management (EM), Office of Research and Development (EM-54); June 1992-June 1993.

- Senior Program Specialist/Project Engineer, EG&G Idaho, Inc., Buried Waste Integrated Demonstration (BWID) Systems Analysis Project, Idaho National Engineering Laboratory (INEL), Idaho Falls, Idaho; August 1989 - August 1993.

- Instructor, Department of Health Physics, Idaho State University; Pocatello, Idaho;

Principal Publications of Last Three Years

Rudin, M.J.; Richardson, W.M.; Dumont, P.G.; Johnson, W.H. In situ measurements of transuranics using a calcium fluoride scintillation detection system. *Journal of Radioanalytical and Nuclear Chemistry*, 248:445-448; 2001.

Johnson, W.H.; Rudin, M.J. Distribution of radionuclides in Gypsum Wash sediments. *Toxicological and Environmental Chemistry* 79:73-80; 2001.

Twichell, D.C., Cross, V.A., Rudin, M.J., Parolski, K.F., and Rendigs, R.R., Surficial geology and distribution of postimpoundment sediment in Las Vegas Bay, Lake Mead, Open File Report 01-70, March, 2001.

Johnson, E.A.; Rudin, M.J.; Steinberg, S.M.; Johnson, W.H. The sorption of selenite on various cement formulations. *Waste Management* 20(7):509-516; 2000.

Rudin, M.J.; Johnson, W.H. The influence of flood source placement on radiation exposure during quality assurance testing. *Journal of Nuclear Medicine Technology*. 28:88-93; 2000.

Scientific and Professional Societies

Health Physics Society

Academic Education Committee

Chair, Fellowships Subcommittee

Member, HPS Accreditation Subcommittee

Lake Mead Chapter of the Health Physics Society

Statement of Current and Pending Support – Phillip Patton

Academic Year (Fall 03 – Spring 04): Will be responsible for teaching a minimum of 9 credit hours of coursework per semester within the Department of Health Physics and performing service at the college, university, and professional level during the academic year. Dr. Patton was the principal investigator for the TRP DC project in FY 03. Dr. Patton is also a co-author on the following National Institutes of Health (NIH) proposal:

Advances in Skeletal Dosimetry Through Microimaging, funded by NIH – Patton portion - \$54,096

Statement of Current and Pending Support – Mark Rudin

Academic Year (Fall 03 – Spring 04): Will be responsible for teaching a minimum of 6 credit hours of coursework per semester within the Department of Health Physics and performing service at the college, university, and professional level during the academic year. Note that Dr. Rudin receives a release of 3 credits of teaching per semester because he is chair of the department. Dr. Rudin was a co-principal investigator of the TRP DC project in FY 02. Dr. Rudin is also currently supported under the following projects:

Geophysical Mapping and Sediment Collection in Lake Mead, USA funded by the U.S. Geological Survey - \$476,100

Monitor and Assess Water Quality; Characterize Existing Conditions and Identify Numerical Criteria to Protect Existing Higher Water Quality in Lake Mead National Recreation Area funded by the National Park Service - \$26,450.