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Development of Dose Conversion Coefficients for Radionuclides Produced in Spallation Neutron Sources

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Project Title:

Development of Dose Conversion Coefficients for Radionuclides Produced in Spallation Neutron Sources

August 11, 2001

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Texas A&M University
University of Florida
University of Tennessee

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AAA Research Area: Systems Integration: Safety/Dosimetry

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

Year 2 - \$160,000

Year 3 - \$160,000

Abstract

A research consortium comprised of representatives from several universities and national laboratories will be established as part of this 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 Accelerator Production of Tritium (APT) projects. Determination of these coefficients will also fill data gaps for several hundred radionuclides that exist in Federal Guidance Report (FGR) No. 11 and in Publications 68 and 72 of the International Commission on Radiological Protection (ICRP). This proposal discusses the overall research collaboration in general and the University of Nevada, Las Vegas (UNLV) funded portion of the research to be implemented by Phillip Patton and Mark Rudin in particular.

Background and Rationale

The U.S. Department of Energy (DOE) was authorized by Congress in 2001 to create the Advanced Accelerator Applications (AAA) program 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. Besides investigating transmutation as a viable alternative of long-term waste management, the AAA program is continuing to develop the technology base of alternative tritium production options, including the completion of the APT design and development activities. 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 AAA program.

The AAA 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 conversion coefficients (DCC) 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 FGR 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 the Accelerator-Driven Test Facility (ADTF) and SNS activities are also considered.

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

Research Objectives

There are four research objectives for Year 1 of this project. They are to:

- Establish a research consortium comprised of representatives from several universities and national laboratories.
- Develop a prioritized list of radionuclides produced during the spallation process that will be considered as part of the study.
- Further Georgia Tech's work on developing a reproducible methodology to determine internal and external DCC.
- Generate DCC values for selected 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 DCCs 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 for approximately 600 radionuclides that exist in FGR 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 AAA program. The proposed composition of the consortium would also appear to make it an excellent resource for radiation safety issues facing the AAA program 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: Establish a research consortium comprised of representatives from several universities and national laboratories.

The proposed work will 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 will initially be invited to participate in the consortium: Georgia Institute of Technology, Idaho State University, Texas A & M University, University of Florida, and the University of Nevada, Las Vegas (UNLV). The following DOE national laboratories will also be invited: Los Alamos National Laboratory (LANL) and Oak Ridge National Laboratory (ORNL). There is every expectation that the number of academic institutions/national laboratories may grow as the project evolves.

A Technical Advisory Group will be established to direct and oversee consortium activities. The following individuals will be invited to serve on the Advisory Group:

Phillip Patton ,UNLV, Project Coordinator
Wesley Bolch, University of Florida
Brent Boyack, LANL
Steve Chase, U.S. Department of Energy
Keith Eckerman, ORNL
Nolan Hertel, Georgia Tech
John Poston, Texas A&M

The Project Coordinator will be responsible for scheduling and hosting the initial meeting of the Technical Advisory Group. The first meeting will be held in Las Vegas, NV, at the beginning of FY 02. Items to be addressed during this meeting include, but are not limited to, further defining the scope of the consortium, outlining the roles and responsibilities of working group members to meet project research objectives, securing additional funding for participants, and scheduling additional meetings. It should be emphasized that Advisory 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 two UNLV graduate students, one undergraduate student, and summer salary for the Project Coordinator to support project activities.

Objective 2: Develop a prioritized list of radionuclides produced during the spallation process that will be considered as part of the study.

Due to the magnitude of the project, the Technical Advisory Group will work collectively to develop an exhaustive list of radionuclides that could potentially be created during the spallation process. It is proposed that the list be divided into two major categories: radionuclides with half-lives greater than ten minutes and those with half-lives less than ten minutes. This is based upon the fact that ICRP models used to describe the behavior of radionuclides in the body are not valid for the intake of short-lived radionuclides ($T_{1/2} < 10$ min). Subsequently, both internal and external DCCs will be calculated for radionuclides with $T_{1/2} > 10$ min, while only external DCCs will be determined for the shorter half-life species. Further ranking of radionuclides within each grouping with respect to the rate of biological elimination, organ of uptake, and other pertinent biological and metabolic data will be performed by the Technical Advisory Group at a later date. Radiological hazards associated with each nuclide cannot be used as initial sorting criteria due to the complicated decay scheme of the majority of the radionuclides.

Objective 3: Develop a reproducible methodology to determine internal and external DCC.

The metabolic models and data from ICRP Publication 30, "Limits for Intakes of Radionuclides by Workers" will be applied in order to maintain consistency with current standards. ICRP Publication 30 defines 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 DCCs involves determining U_s and $SEE(T \leftarrow S)$ values. For consistency with Federal Guidance Report No. 11, dose conversion 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 first step in calculating the DCCs is to calculate the number of transformations per Bq in the source over 50 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. For the gastrointestinal tract and lung system, transformations are calculated for up to two progeny. In order to calculate the U_s , the number of transformations in both the respiratory and gastrointestinal models must be calculated, as well as the activity transferred to the transfer compartment (i.e. blood). In addition, the number of transformations over 50 years in each body tissue or organ to which activity is transferred must

also be calculated. A Microsoft Excel spreadsheet will be developed to perform these calculations.

The second step in determining DCCs is to calculate the $SEE(T \leftarrow S)$ values. Computer codes have been developed at Oak Ridge National Laboratory's Radiation Safety Information Computational Center to determine these values. The primary code of interest is CCC-620: SEECAL 2.0, which evaluates the $SEE(T \leftarrow S)$ in target tissues or organs per unit activity residing in the source regions. The type, energy, and frequency of the nuclide radiations, as well as progeny information, used in SEECAL are accessed from the DLC-172: NUCDECAY code. Within this code are two radionuclide databases, one that consists of the data on the radiations emitted by the 825 radionuclides reported in ICRP Publication 38, and one that consists of the 242 radionuclides published in a MIRD monograph. However, a majority of the radionuclides that will be produced by the AAA program's potential spallation neutron sources are not included in either database. Therefore, it is proposed that a third radionuclide database be developed, which contains decay data for nuclides of interest that are not included in the other two databases. The nuclear decay data tabulated in this project would be available to ICRP Task Group on Dose Calculations for the planned revision of ICRP Publication 38.

Two different approaches can be used to develop the aforementioned database. The most straightforward approach would be to manually enter the decay data for each radionuclide obtained from the Evaluated Nuclear Structure Data File, maintained by Brookhaven National Laboratory. The second method would be to use the PSR-191: EDISTR code developed at ORNL in order to calculate the mean energies and absolute intensities of all principal radiations associated with the radioactive decay of each nuclide. In either case, the database will be referenced by the NUCDECAY and SEECAL programs in order to obtain the necessary $SEE(T \leftarrow S)$ values. Note that ORNL has a collaborative effort underway under the auspices of the U.S. EPA, with the Japan Atomic Energy Research Institute (JAERI) for the processing of nuclear decay data through the EDISTR code. It is expected that the present proposed work will tie in closely with that effort.

Once both U_s and $SEE(T \leftarrow S)$ values are calculated, the committed dose equivalent in a target organ, T , can be calculated 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.

Some preliminary work on developing a methodology to complete this work has already been initiated by individuals at Georgia Institute of Technology. Nolan Hertel from this institution will be invited to share this methodology at early meetings of the technical working group. Group members will further develop the methodology so it can be used by all individuals/organizations working on the project. It is expected that several members of the technical working group will provide valuable insight during the development and potential

modification of the methodology. For example, Keith Eckerman of ORNL is a member of the ICRP's Task Group on Dose Calculation and is leading the development of the DCAL code used to calculate internal and external DCCs.

Objective 4: Generate DCC values for selected radionuclides.

The Technical Advisory Group will divide the list of radionuclides among the participating universities. Faculty and students at these institutions will employ the methodology to determine DCCs for each of their assigned radionuclides. A limited number of DCC values are expected to be generated the first fiscal year. The remainder of the radionuclides will be completed in Years 2 and 3.

Proposed Schedule

<u>Year 1 Activities</u>	<u>Completion Date</u>
Establish research consortium participation	September 2001
Preliminary meeting of the Technical Advisory Group (Subsequent meetings held bi-annually at a minimum)	October 2001
Complete prioritized list of radionuclides	December 2001
Complete DCC methodology	March 2002
Determine preliminary set of DCCs	September 2002
Generate Annual Report	September 2002
<u>Year 2 Activities</u>	<u>Completion Date</u>
Determine second set of DCCs	September 2003
Generate Annual Report	September 2003
<u>Year 3 Activities</u>	<u>Completion Date</u>
Determine third set of DCCs	September 2004
Generate Annual Report	September 2004

Deliverables

The following deliverables will be completed during Year 1 of the project:

DCC Methodology Report (April 30, 2002): The principal investigator will generate a report describing the methodology developed by the Technical Advisory Group to calculate internal and external DCCs for radionuclides produced from spallation neutron sources. The report will also include the prioritized list of radionuclides that will be considered in the study.

Annual Report (September 30, 2002): The principal investigator will generate an annual report that outlines project activities performed during FY 02. The report will include preliminary DCC data generated for a number of radionuclides.

Professional Meeting Presentations/Publications (September 30, 2002): 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 AAA/UNLV program for review.

Annual Reports and any professional meeting presentations, technical publications, or student theses will also be developed and delivered to the AAA/UNLV program at the end of the FY 03 and FY 04.

Los Alamos National Laboratory

*Advanced Accelerator Applications
Technology Project Office*

P.O. Box 1663, Mail Stop H816
Los Alamos, NM 87545
(505) 665-4595/ FAX: (505) 667-7443

Date: August 3, 2001
Refer to: AAA-TPO-01-052

Anthony Hechanova
Director, UNLV
AAA University Participation Program
Harry Reid Center for Environmental Studies
University of Nevada, Las Vegas
4505 Maryland Parkway, Box 454009
Las Vegas, NV 89154-4009

Subject: Support for Proposed Research Project

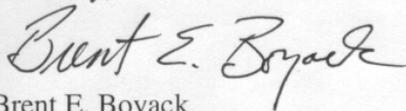
Dear Mr. Hechanova:

Having reviewed the research proposal titled "Development of Dose Conversion Coefficients for Radionuclides Produced in Spallation Neutron Sources" and having reviewed the subject proposal with my colleagues, I wish to offer my support for this activity.

Internal and external dose conversion coefficients for radionuclides produced in spallation neutron sources are needed to support the siting and licensing of accelerator-driven nuclear initiatives within the U.S. Department of Energy complex.

I support this proposal and wish the investigators success in this important research endeavor.

Sincerely,



Brent E. Boyack
ES&H Project Leader

Cy:
AAA-TPO file