

**Annual Report for U.S. DOE Office of Environmental Management:** Year 2000-2001

**Project Title:** Improved Radiation Dosimetry/Risk Estimates to Facilitate Environmental Management of Plutonium Contaminated Sites

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## Research Objective

The main objective of this project is to improve capabilities for evaluating health risks to humans associated with inhaling plutonium (Pu). Two key DOE issues are being addressed: (1) the need to improve capabilities for evaluating plutonium dioxide (PuO<sub>2</sub>)-associated health risks for DOE workers involved in decommissioning/decontamination (D&D) activities; and (2) the need to improve capabilities for evaluating health risks for public exposures arising from residual PuO<sub>2</sub> in soil at remediated (cleaned-up) DOE sites. The scientific goal of this project is to improve capabilities for assessing health risk distributions for DOE workers and the public associated with inhaling Pu. The focus of our work has been on DOE worker and public exposure scenarios related to the Rocky Flats Environmental Technology Site near Denver, Colorado, commonly called Rocky Flats.

## Research Progress and Implications

This report summarizes work after 1 year of a renewed 3-year project. The project has focused on applying basic and applied science methodology to improve the following: (1) characterization of Pu/amerium (Am) intake by inhalation; (2) subsequent organ radiation doses; and (3) the associated health risks. To achieve these improvements, more appropriate distributions relating to uncertainty/variability have replaced traditional but inappropriate point estimates.

The at-risk populations considered are members of the public who could inhale low-specific-activity, PuO<sub>2</sub>-contaminated soil arising from Department of Energy (DOE) sites during or after remediation and DOE workers who could inhale pure, highly radioactive PuO<sub>2</sub>, e.g., related to D&D accidents or other Pu-related incidents. Our main interest is in the Rocky Flats Environmental Technology Site where cleanup of Pu-contaminated soil and D&D of Pu-contaminated facilities pose risks to DOE workers and where remediation activities and residual radionuclides in soil after remediation could pose risks to the public.

We have focused on the following radionuclides: <sup>238</sup>Pu, <sup>239</sup>Pu, <sup>240</sup>Pu, <sup>241</sup>Pu, <sup>242</sup>Pu, and the hazardous Pu daughter radionuclide <sup>241</sup>Am. For worker exposures during D&D accidents involving PuO<sub>2</sub>, very small numbers of highly radioactive PuO<sub>2</sub> particles could be presented to a worker for inhalation. As was demonstrated in a glovebox-related PuO<sub>2</sub> incident that occurred in March 2000 at Los Alamos National Laboratory, intake of radioactivity is stochastic rather than deterministic when relatively small numbers of PuO<sub>2</sub> particles are airborne. Exposure scenarios involving relatively small numbers of airborne PuO<sub>2</sub> particles represent what we call the stochastic-intake (StI) paradigm.

For the StI paradigm, some workers may take in (via inhalation) a relatively large amount of radioactivity, while others may take in little or no radioactivity. Our research has indicated that when very few highly radioactive PuO<sub>2</sub> particles are airborne, continuous air monitors may not alarm, while an unlucky worker may take in via inhalation one or two or so highly radioactive particles. In such cases, workers could have Pu isotopes detected in their urine, but with no knowledge of how they got there. Our research results related to characterizing the stochastic intake of radioactive particles indicate that it would be wise to routinely monitor Pu workers at Rocky Flats and elsewhere for possibly unknown Pu intakes.

We also recommend improvements in controlling worker intakes for the StI paradigm, based on a probabilistic approach. In the past, the annual limit on intake (ALI) has been used to control worker intake by inhalation of radionuclides using a deterministic approach in which point estimates of intake based on inhaling many particles are required not to exceed the ALI. Our research shows how a probabilistic approach can be used to control worker intake of radionuclides for StI scenarios. With our recommended approach, the probability of exceeding the ALI is required not to exceed a criterion value (e.g., 5%). This 5% value would correspond to a 95% probability of not exceeding the ALI.

When considering possible public exposure to Pu residual radioactivity in soil after remediating a DOE site, one uses radionuclide soil action levels (RSALs) to provide protection. Associated with exposure scenario-dependent RSALs are cancer risks for the public. These risks are evaluated based on the linear, no-threshold (LNT) model. Based on this model, any amount of radiation (including background radiation) could increase the risk of cancer. Because of the LNT model, stringent and very costly criteria can be associated with remediation of radionuclide-contaminated sites.

We are conducting both modeling and epidemiological research related to evaluating the validity of the LNT model for radiation-induced stochastic effects. The cited modeling research relates to neoplastic transformation induced *in vitro* by low radiation doses. Neoplastic transformation is considered an early stage related to cancer induction. Demonstrating a curvilinear dose-response curve for neoplastic transformation would suggest a curvilinear dose-response relationship for cancer induction. Our research has revealed several plausible biological events that would cause the radiation dose-response curve for neoplastic transformation to be nonlinear at low radiation doses. These events are as follows: (1) no repair errors below a damage threshold; (2) activation of enhanced repair above a threshold dose; and (3) very efficient killing (via apoptosis) of cells with radiation-induced, persistent, problematic genomic instability. Biological events 1 and 3 can lead to a radiation dose threshold for neoplastic transformation (and possibly for cancer induction).

We are conducting a joint Russian Federation/U. S. case-control epidemiological study of lung cancer induction in Russian nuclear workers by inhaled  $^{239}\text{Pu}/^{241}\text{Am}$  in combination with cigarette smoke and gamma radiation. Our preliminary results indicate that cigarette-smoking effects may obscure the presence of a radiation dose threshold for lung cancer induction.

Some of our research has focused on evaluating risks for workers at Rocky Flats for deterministic effects of inhaled weapons-grade Pu. Present results indicate that mg quantities of Pu need to be inhaled in order to cause serious deterministic effects such as radiation pneumonitis and impaired lung function.

### **Planned Activities**

Our future research activities will include the following: (1) using clinical data in developing a biological dosimetry system for evaluating Pu intake by inhalation by Mayak Plutonium Production Facility workers; (2) conducting experimental studies that relate to penetration by  $\text{PuO}_2$  of respirators (and associated filters) used at DOE facilities; (3) preparing a stochastic version of the ICRP respiratory tract deposition model for inhaled radioactive aerosols; and (4) characterizing variability/uncertainty in lung, bone, and liver cancer and leukemia risks for inhaled Pu aerosols.

### **Information Access**

*Web resources arising from full or partial support from this project follow:*

Improving Radionuclide Soil Action Levels for Rocky Flats (poster): <http://www.radiation-scott.org/rocky>

Issues Related to Radionuclide Soil Action Levels for Rocky Flats (poster): <http://www.radiation-scott.org/rockyflats/index.htm>

Plutonium Resources (at our Institute): <http://www.radiation-scott.org/>

Plutonium-Related Cases (via hyperlinks): <http://www.radiation-scott.org/Cases.htm>

Plutonium-Induced Health Effects (based on publications on Mayak workers): <http://www.radiation-scott.org/health.htm>

Other Plutonium-Related Web Sites: <http://www.radiation-scott.org/other.htm>

Deposition of Radioactive Substances in the Respiratory Tract: <http://www.radiation-scott.org/deposition>

Radiation Glossary for Students: <http://www.lrri.org/radiation/rad.htm>

Electronic Borders' Dictionary of Health Physics: <http://www.hpinfo.org>

NEOTRANS1 Model for Radiation-Induced Neoplastic Transformation (analytical solutions): <http://www.radiation-scott.org/neotrans1.pdf>

Bayesian Approach to Applying the NEOTRANS1 Model: <http://www.radiation-scott.org/bayesian.pdf>

Modeling the Influence of Dose Rate on the ED50 and LD50 (in English): <http://www.radiation-scott.org/model-english.pdf>

Modeling the Influence of Dose Rate on the ED50 and LD50 (in Russian): <http://www.radiation-scott.org/model-russian.pdf>

*Year 2000-2001 publications fully or partially supported by this project follow:*

Schöllnberger, H., Scott, B. R., Stafford, M., and Osovets, S. "A closed form solution of a mechanistic model for radiation-induced neoplastic transformation." Submitted to the Bulletin of Mathematical Biology for presentation on their web site.

Schöllnberger, H., Scott, B. R., and Hanson, T. E. "Application of Bayesian inference to characterize risks associated with low doses of low-LET radiation." Bulletin of Mathematical Biology (in press).

Scott, B. R. and Schöllnberger, H. "Introducing biological microdosimetry for ionizing radiation," Radiation Protection Dosimetry 91, 377-384 (2000).

Scott, B. R. "An approach to evaluating intake distributions for inhaled plutonium dioxide for the stochastic intake paradigm" (submitted for publication).

Tokarskaya, Z. B., Khokhryakov, V. F., Zhuntova, G. V., Okladnikova, N. D., Belyaeva, Z. D., Drozhko, E. G., Scott, B. R., and Schöllnberger, H. "Interaction of radiation and smoking in lung cancer induction among workers at the Mayak Nuclear Enterprise" (in revision).

Osovets, S. A., and Scott B. R. "Modeling the dependence of the median effective dose on dose rate," (Abstract, submitted).

*Year 2000-2001 presentations fully or partially supported by this project follow:*

Schöllnberger, H., Scott, B. R., and Hanson, T. E. "Application of Bayesian inference to characterize risks associated with low doses of low-LET radiation." Presentation given at the American Nuclear Society Trinity and Rio Grande Chapter Technical and Dinner Meeting, Crown Plaza Pyramid Hotel, Albuquerque, NM; October 27, 2000.

Scott, B. R., "Radiological problems in the Chelyabinsk region of Russia." Special seminar presented at Beckman Institute, University of Illinois, Urbana, Illinois. Sponsored by Russian and East European Center; Arms Control, Disarmament, and International Security Program; Department of Nuclear Plasma, and Radiological Engineering; Department of Molecular & Integrative Physiology; Center for Biophysics and Computational Biology; Radiation Biophysics and Bioengineering in Oncology Training Program; October 24, 2000.

Scott, B. R., "Mechanistic models for radiation-induced neoplastic transformation: Bayesian approach to model characterization." Seminar presented at Beckman Institute, University of Illinois, Urbana, Illinois. Sponsored by the Radiation Biophysics and Bioengineering in Oncology Training Program; October 25, 2000.

**Optional Additional Information:** None

**Optional Proprietary Information:** None