

# **Shielding and Activation Analyses in Support of The Spallation Neutron Source (SNS) ES&H Requirements**

**Naoteru Odano, Jeffrey O. Johnson and R. Mike Harrington, and Joe R. DeVore**

## **Abstract**

Shielding and activation analyses play an important part in determining how to meet the Environmental, Safety and Health (ES&H) requirements of an intense high-energy accelerator facility like the proposed Spallation Neutron Source (SNS). The shielding and activation analyses described in this paper were performed primarily using the CALOR code system coupled with MCNP for radiation transport, the ORIHET95 isotope generation and depletion code for activation analysis, and the DOORS multi-dimensional discrete ordinates transport code system for shielding analyses. Additionally, a portion of the shielding calculations were performed with the semi-empirical code - CASL. This paper gives an overview of relevant ES&H policies and requirements, and provides detailed discussions of the shielding and activation analyses completed in support of those policies and requirements.

## **1. INTRODUCTION**

In 1996, the United States Department of Energy (DOE) initiated a conceptual design study for the Spallation Neutron Source (SNS)<sup>1</sup> accelerator facility with the Oak Ridge National Laboratory (ORNL) as the reference site. The DOE Office of Energy Research has subsequently issued a formal determination to prepare an Environmental Impact Statement (EIS) for the SNS project to evaluate the potential environmental consequences for the proposed ORNL site, as well as three additional possible sites at other national laboratories. The conceptual design of the SNS consists of an accelerator system capable of delivering a 1 GeV proton beam with 1 MW of beam power into a single target station. The present intention is to upgrade the SNS facility in stages until ultimately the SNS will be a 4 MW facility with two target stations (a 60 Hz station and a 10 Hz station).

## **2. EIS PREPARATION AND ENVIRONMENTAL, SAFETY AND HEALTH (ES&H) POLICY**

The SNS EIS will evaluate and document a comprehensive range of potential environmental impacts of the construction and operation of the SNS on four candidate sites in the United States: Oak Ridge National Laboratory, Argonne National Laboratory, Los Alamos National Laboratory, and Brookhaven National Laboratory. Release of radioactive materials into the environment is one of the many topics being addressed by the EIS.

Section 3 of this paper discusses initial radionuclide activation calculations completed for EIS input: the activation of soil utilized in earth berm shielding, and the activation of air inside the accelerator tunnels. The soil activation calculations help define the potential for groundwater contamination and the tunnel air activation calculations help define the normal airborne contamination released by tunnel ventilation. Neither activation calculation in itself is sufficient to define the impact. For example, the airborne radionuclide releases depend on the tunnel ventilation rate and configuration. The soil activation impact on groundwater contamination depends on the presence (or exclusion of) groundwater from the soil under consideration.

Section 4 presents the results of calculations of the necessary shielding thickness for both normal and accident conditions. The minimum requirements for radiological protection of personnel at a DOE site under normal and anticipated conditions are listed in Title 10 of the U. S. Code of Federal Regulations in 10 CFR 835, "Occupational Radiation Protection". For accident conditions, the DOE has published Order 5480.25, "Safety of Accelerator Facilities" (currently under revision), which provides guidance on shielding needs for design basis faults in the control of high-energy particle beams.

The SNS shielding design policy provides project-level shielding design criteria that are more stringent than the minimum DOE requirements. This is necessary and desirable because margin is needed for calculation and design uncertainties, and because, per 10 CFR 835, it will be necessary during detailed design to be able to show that the SNS personnel exposures will be as low as reasonably achievable (ALARA).

Part of the guidance provided by DOE directive 5480.25 is to mitigate worst case design basis beam control

faults. These faults should be demonstrated not to cause a radiation dose exceeding 25 rem to any individual worker, or a dose exceeding 1 rem to any member of the public, without taking credit for automatic beam cutoff systems (even though such systems are provided on all DOE accelerators). The philosophy behind this approach is that the prevention of radiation injury should be insured by passive, highly reliable means -- such as specified thicknesses of massive shielding material. The 5480.25 guideline dose limits (i.e., 25 rem and 1 rem) for design basis beam control accidents do not imply an acceptance of rem-level doses. The SNS conceptual design, consistent with other DOE accelerators, includes very rapidly-acting and highly-reliable automatic systems that cut off the beam when it is not in its desired path (or if personnel access to the tunnel is attempted during operation of the beam). The automatic beam cutoff would function to limit worker exposures to a small number of millirem even for worst-case beam-control accidents.

### **3. ASSESSMENT OF ACTIVATION FOR INPUT TO THE EIS: SOIL AND AIR**

#### **3.1 METHODOLOGY AND MODELS FOR THE ANALYSIS**

As mentioned in Section 2, the assessment of soil and air activation is a first step in determining potential environmental impacts. Neutron activation of soil in earth berm shielding could lead to contamination of groundwater if a mechanism exists for migration of radioactive nuclides to occur. Similarly, activation of air in the linac tunnel can certainly affect airborne environmental releases. In this section, the methodology and modeling for the activation analyses are presented.

For the neutron transport calculation, the CALOR<sup>2</sup> code system coupled with MCNP<sup>3</sup> was used along with the ORIHET95<sup>4</sup> isotope generation and depletion code for activation analyses. Details of the activation analysis methodology used in the SNS conceptual design is presented in an accompanying paper<sup>5</sup>. The total length of the proton linac will be ~550 m and protons will be accelerated to 1 GeV over the length of the linac. Although additional proton energy dependent analysis will be required in the future, the preliminary analyses were performed for proton energies of 333 MeV, 667 MeV, and 1 GeV for simplification of the problem. In the computational model, a Cu cylinder (0.15 m diameter \_ 1 m length) was placed in the beam centerline and assumed as a target of beam loss. The conceptual design of the linac tunnel consists of a concrete wall (2.3 m inside-diameter by 0.46 m thickness) surrounded by a 9.14-m-thick earth berm shield. In the analysis, a 20 meter segment of the tunnel was modeled. The analysis used the assumption that the accelerator operates continuously for 20 years without shutdown. This is equivalent to the planned facility life. The proton beam losses, that drive the soil activation, are assumed to be at the design value of 1 nA/m which is considered as a design goal for average beam loss. Radionuclide concentrations were calculated using the ORIHET95 analysis results as follows; (1) integrating the activities over the total volume of earth berm shielding, (2) using a simplifying conservative assumption that all the activation takes place in the first meter of soil immediately adjacent to the outer concrete wall of the linac tunnel.

#### **3.2 SOIL ACTIVATION ANALYSIS FOR ASSESSMENT OF GROUNDWATER CONTAMINATION**

Assessment of the environmental impacts of the contamination of groundwater requires detailed modeling of the groundwater movement in the area. Distribution coefficients between the soil-bound nuclides and groundwater must be used to assess leaching of the radionuclides from the soil, and then the groundwater model is used to calculate an off-site groundwater concentration to be used to assess the off-site dose to potential individuals. This type of modeling will be conducted for the EIS. The conservative approach utilizes a direct comparison of radioactive nuclide concentrations in soil at the high-energy end of the linac tunnel with the 10CFR20 limits for release of water to an unrestricted area as shown in Table 1. This table shows the long-lived nuclides, which are of the greatest interest, since groundwater transport times are generally much longer than the half-lives of the short-lived nuclides. Column 2 shows the activation averaged out over the volume of the entire earth berm shield at the high-energy end of the linac. However, it is known that there is a distribution of radionuclides in the berm, and that 85% of the activation is contained within the first meter of soil surrounding the tunnel concrete wall. Column 3 shows these latter concentrations.

The results in Table 1 indicate that tritium, <sup>10</sup>Be, and <sup>53</sup>Mn are unlikely to present any off-site dose problem or to require any special mitigation. The concentrations of the other nuclides are high enough to be of potential concern. Present design considerations include isolating the first four meters of soil from groundwater with the use of a

capillary break and waterproof membrane, in addition to an impervious clay cap over the berm for surface-water diversion. Furthermore, the capillary break and the foundations of buildings that incorporate the earth shielding are provided with a system of gravel-embedded drain lines designed to route any water there for collection in a system of sumps. Water entering the sumps would be monitored before it is pumped into a waste collection system for treatment. These measures function to ensure that the soil that is in contact with the outermost concrete shielding does not become a source for leaching of radioactive nuclides into the groundwater. Thus groundwater control during facility operation and some degree of access control for some nominal period after shutdown will allow the short-lived nuclides to decay to negligible levels before uncontrolled groundwater conditions are allowed at the site.

**Table 1. Radionuclide concentrations in the soil at the high-energy end of the linac.**

Radionuclide (half life)	Total berm calculated concentration ( $\mu$ Ci/ml)	First meter calculated concentration ( $\mu$ Ci/ml)	10CFR20 water release limit ( $\mu$ Ci/ml)
H-3 (12.33 y)	$6.03 \times 10^{-8}$	$9.82 \times 10^{-7}$	$1.00 \times 10^{-3}$
Be-10 ( $1.51 \times 10^6$ y)	$5.23 \times 10^{-10}$	$8.52 \times 10^{-9}$	$3.00 \times 10^{-5}$
C-14 ( $5.73 \times 10^3$ y)	$4.09 \times 10^{-4}$	$6.66 \times 10^{-3}$	$3.00 \times 10^{-5}$
Na-22 (2.6019 y)	$8.68 \times 10^{-4}$	$1.42 \times 10^{-2}$	$6.00 \times 10^{-6}$
Al-26 ( $7.4 \times 10^5$ y)	$5.82 \times 10^{-7}$	$9.49 \times 10^{-6}$	$6.00 \times 10^{-6}$
Cl-36 ( $3.01 \times 10^5$ y)	$2.27 \times 10^{-7}$	$3.70 \times 10^{-6}$	$2.00 \times 10^{-5}$
K-40 ( $1.28 \times 10^9$ y)	$7.10 \times 10^{-9}$	$1.16 \times 10^{-7}$	$4.00 \times 10^{-6}$
Ca-41 ( $1.03 \times 10^5$ y)	$2.23 \times 10^{-6}$	$3.64 \times 10^{-5}$	$6.00 \times 10^{-5}$
Mn-53 ( $3.74 \times 10^6$ y)	$4.34 \times 10^{-9}$	$7.07 \times 10^{-8}$	$7.00 \times 10^{-4}$
Mn-54 (312.12 d)	$2.07 \times 10^{-3}$	$3.38 \times 10^{-2}$	$3.00 \times 10^{-5}$
Fe-55 (2.73 y)	$5.83 \times 10^{-2}$	$9.50 \times 10^{-1}$	$1.00 \times 10^{-4}$

### 3.3 LINAC TUNNEL AIR ACTIVATION ANALYSIS

Assessment of the environmental effects of the release of radionuclides during normal operations requires knowledge of the operating parameters of the facility. Air emissions fall under 40CFR61, National Emission Standards for Emissions of Radionuclides Other Than Radon from Department of Energy Facilities. These regulations require, among other things, that site emissions (from all sources) be below 10 mrem/y. In doing these calculations, care must be given in using the ORIHET95 results not to utilize equilibrium quantities as production rates since the half lives of some of the isotopes are so short that equilibrium is established within the first calculation time step. Using the equilibrium value will underestimate the release for short-lived isotopes. Very short time steps (10 s) were used in these ORIHET95 calculations for activated air to estimate the production rate. The tunnels are intended to be continuously vented, and therefore activated air discharges decay in the ventilation system. An average decay time of 28.5 s was calculated, based on the tunnel ventilation flow rates and the average of the distance from the closest and farthest points from the linac to the stack. The doses, which were calculated using a U. S. Environmental Protection Agency (EPA)-approved computer code, CAP-88<sup>6</sup>, are a small percentage of the present site annual dose from air emissions.

Table 2 shows calculated radionuclide production and release from the linac, ring and transition tunnels after decay in the ventilation system. The continuous venting reduces the concentration of long-lived radionuclides such as tritium and C-14 to essentially zero. The off-site dose calculated totals  $5.59 \times 10^{-3}$  mrem/y, which is a trivial fraction of the site limit.

**Table 2. Radionuclide release in the linac tunnel at the high-energy end of the linac.**

Nuclide (half life)	Annual production (Ci/y)	Annual release (Ci/y)	Annual off-site dose (mrem/y)
He-6 (0.81 s)	9.24_ 10 <sup>2</sup>	0	0
Li-8 (0.84 s)	2.83_ 10 <sup>2</sup>	0	0
Be-8 (6.7×10 <sup>-17</sup> s)	6.02_ 10 <sup>2</sup>	0	0
B-12 (0.0202 s)	3.61_ 10 <sup>3</sup>	0	0
B-13 (0.0174 s)	1.60_ 10 <sup>2</sup>	0	0
C-10 (19.26 s)	1.13_ 10 <sup>2</sup>	4.04_ 10 <sup>1</sup>	0
C-11 (20.3 min)	6.14_ 10 <sup>2</sup>	6.04_ 10 <sup>1</sup>	1.04_ 10 <sup>-3</sup>
N-12 (0.044 s)	1.44_ 10 <sup>3</sup>	0	0
N-13 (9.97 min)	4.99_ 10 <sup>2</sup>	4.83_ 10 <sup>2</sup>	4.41_ 10 <sup>-3</sup>
N-16 (7.13 s)	1.81_ 10 <sup>2</sup>	1.13_ 10 <sup>1</sup>	0
O-14 (70.6 s)	1.76_ 10 <sup>2</sup>	1.33_ 10 <sup>2</sup>	1.24_ 10 <sup>-5</sup>
O-15 (122.2 s)	6.10_ 10 <sup>2</sup>	5.19_ 10 <sup>2</sup>	1.29_ 10 <sup>-4</sup>

## 4. PERSONNEL PROTECTION AGAINST EXTERNAL EXPOSURE

### 4.1 METHODOLOGY AND MODELS FOR THE ANALYSIS

The DOORS multi-dimensional discrete ordinates transport calculation code system was one of the code systems used for the shielding analyses. Radiation sources for the analyses were generated by the HETC code that calculated angular dependent neutron energy spectra. The CASL code, which is based on semi-empirical formula, was also used to demonstrate the shielding requirements. The details of the calculational model for each analysis are presented in the corresponding subsections.

### 4.2 DESIGN CRITERION FOR DETERMINING SHIELD THICKNESS.

The SNS conceptual design shielding policy established a goal stipulating that accessible outer surfaces of shields should not exceed a dose rate of 0.125 mrem/h with the facility operating at its maximum design level. This goal is considerably below regulatory requirements, which is desirable to provide for potential uncertainties and future ALARA considerations to be assessed in detail at a later stage of the project.

#### 4.2.1 Linac Tunnel Earth Berm Shielding

Table 3 shows results for the preliminary earth berm shielding analyses. The analyses were performed for three incident proton energies, 333 MeV, 667 MeV, and 1 GeV, and assumed a 10 nA/m continuous proton beam loss as the intensity of the radiation source calculated by HETC. The 10 nA/m continuous proton beam loss assumption was taken as 10 times the design goal for average beam loss to account for higher beam losses occurring at localized points. The CASL code and coupled HETC-ANISN sequence were used for the analysis. For the ANISN calculations, a one-dimensional spherical model (isotropic model) and a one-dimensional cylindrical model (anisotropic model) were used. The required earth berm shield was determined to give dose rates less than approximately half the value of the 0.125 mrem/h design goal limit, considering the accuracy of the models and assumptions used. The CASL results indicate a need for more earth berm than the ANISN calculations for all incident energies. The principal reason for this difference is the elemental composition of the earth material in CASL and ANISN. The ANISN model earth contained some water to simulate ground moisture, whereas the CASL earth material was completely dry. Consequently, the CASL results will represent a conservative estimate of required earth berm for the linac tunnel.

**Table 3. Earth berm shielding requirements for the linac.**

Calculational methodology	Earth shielding (m)	Dose rate (mrem/h)
<b>333 MeV protons</b>		
CASL	6.40	0.060
HETC-ANISN (aniso.)	4.39	0.063
HETC-ANISN (iso.)	4.21	0.062
<b>667 MeV protons</b>		
CASL	7.47	0.056
HETC-ANISN (aniso.)	5.85	0.061
HETC-ANISN (iso.)	5.51	0.064
<b>1.00 GeV protons</b>		
CASL	7.92	0.077
HETC-ANISN (aniso.)	6.34	0.065
HETC-ANISN (iso.)	6.72	0.064

#### 4.2.2 Maintenance Cells Concrete Shielding

The target service cell and general maintenance cell will be located behind the target station for remote maintenance of the highly activated target components, reflector, and shield plug. Radiation levels outside the remote handling cells must be reduced to less than 0.125 mrem/h per the SNS design goal for accessible shield surfaces. Table 4 shows the results of the shielding analyses of the target service cell and general maintenance cell. The analyses were performed using the ANISN one-dimensional spherical model and incorporating source terms obtained from the HETC/MCNP/ORIHET95 sequence of calculations. The analysis indicates that ordinary concrete, which was originally considered as the shielding material of the remote handling cells, does not come close to satisfying the shielding requirements. The use of heavy concrete, with approximately 0.20 m of additional thickness added to the 1-m-thick general maintenance cell walls, does provide adequate shielding and satisfy the shielding requirements.

**Table 4. Shielding analysis of the target service cell and general maintenance cell.**

Activation source	Shielding material	Dose rate (mrem/h)
<b>Target service cell</b>		
Target SS-316 jacket	Ordinary concrete (1.00m)	$1.19 \cdot 10^1$
Target SS-316 jacket	Heavy concrete (1.00m)	$7.90 \cdot 10^{-2}$
<b>General maintenance cell</b>		
Be/D <sub>2</sub> O reflector	Ordinary concrete (1.00m)	$3.29 \cdot 10^1$
Be/D <sub>2</sub> O reflector	Heavy concrete (1.00m)	$6.04 \cdot 10^{-1}$
Be/D <sub>2</sub> O reflector	Heavy concrete (1.20m)	$8.00 \cdot 10^{-2}$
Nickel inner plug	Ordinary concrete (1.00m)	$2.08 \cdot 10^1$
Nickel inner plug	Heavy concrete (1.00m)	$2.01 \cdot 10^{-1}$
Nickel inner plug	Heavy concrete (1.08m)	$7.00 \cdot 10^{-2}$

#### 4.2.3 Beam Stop Shielding

The SNS accelerator system will require three beam stop systems; the linac tune stop, the ring tune stop, and the ring injection stop, for normal operation of the facility. The linac tune stop will be located at the end of the linac tunnel beyond the junction with the high-energy beam transport (HEBT) tunnel, and will be required to operate at

100 kW incident proton beam power. The ring tune stop will be required to operate at up to 50 kW incident proton beam power, and the ring injection stop will be capable of 200 kW of power operation. All three stops are to be of similar design. The basic design of the stops employs an 80% copper - 20% water cylindrical target region approximately 0.60 m in diameter and 0.75 m in length. The central target is encased by a water-cooled inner steel shielding assembly, and further shielded by bulk steel shielding. The entire monolith is encased in 0.46 m of concrete and surrounded by an earth berm. In the analysis, the steel shielding required to obtain a dose rate of 0.125 mrem/h on the outside of the concrete encasement was determined. This dose rate constraint was established to ensure the beam stops would not contribute significant activation of the earth outside the shield. Table 5 shows steel shielding requirements and associated dose rates at the outside surface of the concrete for the linac tune stop. The results indicate excellent agreement between the CASL and HETC-ANISN calculations. The stop requires approximately 8.5 m of steel per side to obtain dose rates of approximately 0.125 mrem/h on the external surface of the concrete. This low dose rate ensures insignificant activation in the soil due to beam stop operation.

**Table 5. Steel shielding requirements and associated dose rates at the outside surface of the concrete for the linac tune stop.**

Calculational methodology	Shield direction	Required steel shielding (m)	Dose rate (mrem/h)
CASL	Front	4.89	$1.22 \times 10^{-1}$
HETC-ANISN	Front	4.59	$1.08 \times 10^{-1}$
CASL	Back	3.47	$1.21 \times 10^{-1}$
HETC-ANISN	Back	3.35	$1.20 \times 10^{-1}$
CASL	Top	4.17	$1.23 \times 10^{-1}$
HETC-ANISN	Top	4.24	$1.15 \times 10^{-1}$
CASL	Side	4.09	$1.18 \times 10^{-1}$
HETC-ANISN	Side	4.24	$1.15 \times 10^{-1}$

#### 4.3 RADIATION LEVELS IN RADIOLOGICAL AREAS REQUIRING ROUTINE OR FREQUENT ENTRY FOR EXPERIMENTS AND MAINTENANCE

In an area that is occupied less than 500 hours per year, the SNS Shielding Policy requires that shielding reduce the radiation dose rate to less than 0.5 mrem/h at 0.30 m from any accessible shielding wall or accessible surface through which radiation penetrates. Current plans call for the utility vault area in the target station, where the cooling-water pipe chase (through which flows highly activated cooling water) will be installed, to be accessible during normal operation of the facility. The pipe chase will be required to have a steel shield to reduce the dose rate to an acceptable level. The analysis to determine the required additional shielding was performed using the ANISN one-dimensional spherical model. The radiation source was calculated by the HETC-MCNP-ORIHET95 calculational sequence. The analysis indicates that 0.62 m of steel will be required to reduce the dose rate to 0.5 mrem/h at 0.30 m from the surface of the pipe chase shielding. The radiation source calculated for one minute after shutdown was also used to determine the required steel thickness. Using the one-minute delay source will significantly reduce the required steel shield thickness to 0.42 m because the activated cooling water contains the short-lived nuclide,  $^{16}\text{N}$ , which decays out rapidly.

#### 4.4 RADIATION LEVELS FOR ACCIDENT CONDITIONS

Under the guidance of DOE Order 5480.25, shielding and other passive features will limit the radiation dose to a member of the public and to any worker to 1 rem and to 25 rem, respectively, resulting from a worst-case design-basis accelerator accident at a low-hazard accelerator facility. For this purpose, a member of the public is assumed to have access to any uncontrolled area, and a worker is assumed to have access to any areas not designated as an “exclusion area” or “very high radiation areas”. In this section, the linac beam loss accident and target liquid mercury spill accident are discussed to confirm the radiation safety of the facility in the case of these postulated catastrophic accidents.

#### 4.4.1 Beam Loss Accident (Linac Tunnel)

For the SNS conceptual design, the following beam loss accident is postulated: loss of beam directional control occurs, allowing the proton beam, with 4 MW of beam power, to hit the proton beam tube and/or other structural materials continuously for one hour. This is a very conservatively-framed accident because the highly-reliable and rapid-acting beam cutoff system would detect the beam loss and shut off the beam within a few pulses. Failing that, the beam would cause failure of the proton beam tube and subsequent loss of vacuum well before an hour had elapsed. The required earth berm shielding was determined in a manner similar to that in Section 4.2.1. The dose-rate constraint for this hypothetical accident is 25 rem/h at the top surface of the earth berm. The analysis results are shown in Table 6. Comparing the results to those in Table 3 for the analysis for the continuous beam loss, the results indicate that the required shield thicknesses are less than those for the continuous beam loss. These results indicate that the current design shield thickness of the earth beam, 9.14 m, will meet the shielding requirements for both the hypothetical accident-related point beam loss and the continuous beam loss. A rough estimation, using the radiation relaxation length of soil (approximately 0.6 m) and the source at the high-energy end of the linac, derives a dose rate less than 1 rem/h at the top of the 9.14-m-thick earth berm. This indicates that the design shielding thickness of 9.14 m of soil would be adequate to meet the DOE Order 5480.25 accident criterion for public dose even if the controlled area boundary is placed at the base of the berm.

**Table 6. Earth berm shielding requirements for the beam loss accident of the linac.**

Calculational methodology	Earth shielding (m)	Dose rate (rem/h)
<b>333 MeV protons</b>		
CASL	5.99	12.29
HETC-ANISN	4.46	12.00
<b>667 MeV protons</b>		
CASL	6.93	12.18
HETC-ANISN	5.89	12.12
<b>1.00 GeV protons</b>		
CASL	7.49	12.00
HETC-ANISN	6.44	12.09

#### 4.4.2 Mercury Spill in the Target Service Cell

Outside the surface of the shielding wall of the target service cell, the dose rate is required to be reduced to less than 0.125 mrem/h, even for an accident, since that area is considered to be a place of frequent access by radiological workers and escorted non-radiological workers. The accident scenario assumed that the highly-activated target liquid mercury would spill and uniformly cover the floor of the target service cell. In the analysis, the DORT two-dimensional cylindrical model was adopted, and the radiation source was calculated by the HETC-MCNP-ORIHET95 sequence for 4 MW beam power operation. The analysis indicated that 1.20 m of heavy concrete (0.20 m above that detailed in the conceptual design) would be needed to reduce the dose rate to approximately 0.08 mrem/h outside the concrete wall for the postulated mercury spill accident.

The postulated accident scenario taken in the present analysis is the worst case accident without consideration of the existence of the engineered spill confinement features such as the drainage paths/pipes that would channel any spilled mercury into a drain tank in a shielded vault at a lower floor level. Taking into account the current target service cell design in the postulated mercury spill analysis would probably eliminate any additional shielding above that already in the SNS conceptual design for the requirements of the shield thickness.

## 5. CONCLUSIONS

The preliminary shielding and activation analyses to determine ES&H requirements for the proposed SNS have been completed and the results compared with the relevant requirements. The assessment of the activation analyses for the soil determined potential environmental impacts due to groundwater contamination. The results showed that the groundwater control during the facility operation and some degree of access control would eliminate any potential groundwater contamination problem. The activation analysis for air in the linac tunnel showed that total off-site dose due to the release of activated air to the environment was a trivial fraction of the site limit. The preliminary shielding analysis results were also used to discuss the personnel protection against external exposure and indicated that the shielding design of the SNS facility meets the shielding policy which was determined from the DOE Order 5480.25 and associated guidance. Additional shielding analyses, considering both normal operation and more realistic accident scenarios, will be necessary to support the detailed design of the SNS facility shielding.

## REFERENCES

- 1. Oak Ridge National Laboratory, "The Spallation Neutron Source (SNS), Conceptual Design Report Documentation," Oak Ridge National Laboratory, SNS/CDR-5 (1997).
- 2. T. A. Gabriel, et al., "CALOR: A Monte Carlo Program Package for the Design and Analysis of Calorimeter Systems," Oak Ridge National Laboratory, ORNL/TM-5619 (1977).
- 3. J. F. Briesmeister, Ed. "MCNP - A General Purpose Monte Carlo Code for Neutron and Photon Transport," LANL Report LA-7396-M, Rev. 2 (1986).
- 4. P. Cloth, et al., "HERMES, A Monte Carlo Program Systems for Beam Material Interaction Studies," KFA Jülich, Report Jul-2203 (1988).
- 5. N. Odano, et al., "Development of the Activation Analysis Calculational Methodology for the Spallation Neutron Source (SNS)," To be published in these proceedings.
- 6. D. Beres, Editor, "The Clean Air Act Assessment Package - 1988 (CAP88) A Dose and Risk Assessment Methodology for Radionuclide Emissions to Air," Volume 1, User's Manual, and extracted from Vol. 3 Appendix L: Available Star Data Sets, U. S. EPA (1990).

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Naoteru Odano\*, Jeffrey O. Johnson  
Oak Ridge National Laboratory<sup>†</sup>  
Computational Physics and Engineering Division  
P.O. Box 2008  
Oak Ridge, Tennessee 37831-6363

R. Mike Harrington and Joe R. DeVore  
Engineering, Lockheed Martin Energy Systems, Inc.  
P. O. Box 2008  
Oak Ridge, Tennessee 37830

To be presented at the  
1998 ANS Radiation Protection and Shielding Division Topical Meeting  
Nashville, Tennessee  
April 19-23, 1998

\*Present address: Ship Research Institute, Ministry of Transport, Tokai-mura, Ibaraki-ken, 319-11 Japan

<sup>†</sup>Managed by Lockheed Martin Energy Research Corp. for the U.S. Department of Energy under Contract No. DE-AC05-96OR22464.