

Calculations vs. Measurements for Remnant Dose Rates from SNS Spent Structures

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INTRODUCTION

The Spallation Neutron Source (SNS) in Oak Ridge, Tennessee, is an accelerator driven neutron scattering facility for materials research. Presently SNS is capable to operate at 1.4 MW proton beam power incident on a mercury target with a proton beam energy of 1 GeV and 60 Hz repetition rate.

SNS target system components are periodically replaced because they reach their end-of-life due to radiation induced material damage. Target vessel, which houses mercury target, is exchanged about two-three times per year and the proton beam window (PBW) is exchanged every two – three years.

Each spent structure that leaves the SNS site requires supporting documentation with radionuclide inventory and dose rate prediction for the time of the transportation. Neutronics analyses are performed, assuming realistic irradiation history and decay case to ensure that the container/package, housing the structure, is compliant with the waste management regulations. Analyses are complex due to geometry, multi-code usage and following data treatment.

To validate analyses, measurements of dose rates from the spent target vessel # 13 and PBW module #5 were performed. Neutronics analyses were performed to calculate residual dose rates from both structures for the time of measurements.

SPENT COMPONENTS WASTE MANEGEMENT

All these components must be safely removed, placed in a container for temporary on-site storage, and ultimately transported off-site to a nuclear waste disposal site.

In order to characterize and classify spent components, accurate estimates of radionuclide inventory are performed. A bounding case considering the maximum possible radionuclide inventory, based on a scenario with maximum possible irradiation exposure during life-time, is established for the respective component. Using these data, the spent component is characterized and classified, and an appropriate container for temporary storage on-site and subsequent transport off-site is suggested. Once the

container has been selected, radiation transport calculations for the Department of Transportation (DOT) package are performed to ensure that the transport package is compliant with transportation and waste management regulations. Analyses for the spent component radionuclide inventory and dose rates are performed for each off-site shipment with realistic irradiation history and for the time of the shipment. Because these analyses are occurring on regular basis the automated script system for both target vessel and PBW was developed

METHODS FOR NEUTRONIC ANALYSES

Full three-dimensional radiation transport calculations with the state-of-the-art code MCNPX Version 2.7.0 [1] and the latest as-built target station model, including PBW model, are performed to simulate the radiation environment. Specifically isotope production rates due to spallation reactions and the below-20-MeV neutron fluxes in the 63 group CINDER90 group structure are calculated for target facility areas of interest. Isotope reaction rates and neutron fluxes are extracted from the transport calculation output and are fed into the CINDER90 transmutation code [2] using the standardized ACTIVATION_SCRIPT [3] to calculate the radionuclide inventory of the component. In order to obtain local distributions of radionuclide inventory and subsequent decay source terms, the component is subdivided into small pieces (cells). Decay gamma sources for a defined history of build-up and decay are extracted from each cell and compiled to a source term in MCNPX language by running the GAMMA_SOURCE_SCRIPT [4]. The decay gamma source is prepared for the time, when measurements of the dose rates are occurred.

The decay gamma source term is utilized in photon transport calculations of the bare component, which was extracted from as-built model. To simulate measurements, box-type volumes of $2 \times 2 \times 2 \text{ cm}^3$ at the detector positions were defined around the components at the locations of the measurements. For the residual dose rate scoring in the detector volume, a F4 flux tally, was applied. Dose rates are obtained by folding fluxes with SNS specific flux to dose conversion coefficients [6]. The standard deviation for most of the dose rate values is less than 3%.

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MEASUREMENTS

A specialized high-range radiation detection instrumentation Ludlum Model 9-7 with 9-7-BH Detector (Figure 4) was used for measurements of the residual dose rates. According to specification, the detector range is 0.01 – 19.99 kR/hr with a resolution of 0.01 kR/h and 10% linearity. The detector calibration was performed at ORNL with Cs-137 source. A certificate of calibration was issued.

Measurements were performed placing the detector at 30 cm distance from the spent components surface at numerous locations. The detector placement around target vessel #13 and PBW module #5 is shown in Figure 1 and Figure 2 correspondingly.

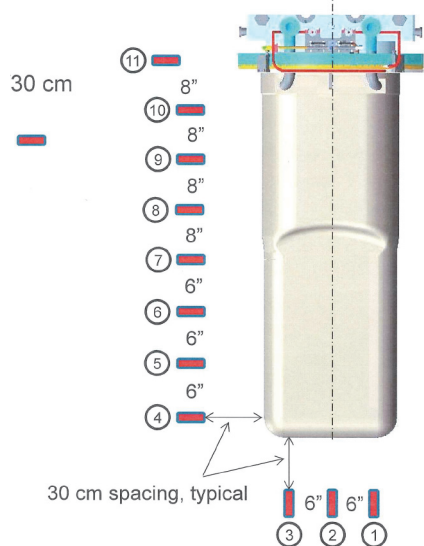


Fig. 1. Detectors positioning around the target vessel #13.

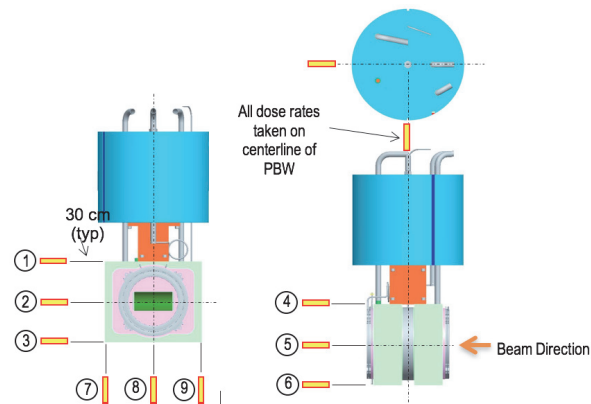


Fig. 2 Detectors positioning around the PBW module #5.

RESULTS

Analyses for residual dose rates were performed for the time of measurements, which is 106 day for the target #13 and 80 days for the PBW module #5 after beam termination on target.

Target

Different code versions and physics settings were used for the radiation transport analyses:

- MCNPX version 2.5 with Bertini model for high-energy particles interactions;
- MCNPX version 2.7 with Bertini model for high-energy particles interactions;
- MCNPX version 2.7 with CEM model for high-energy particles interactions.

Mercury, which is left over after the drainage from the target vessel, 200g, was modeled in two ways – dispersed inside the target vessel, and as a paddle at of the target nose. Results are presented in Table I and Table II.

Table I. Calculated dose rates vs measured dose rates for target vessel #13 with dispersed mercury. Dose rates are in mrem/h.

Detec tor#	Measure ments	MCNPX	C/M	MCNPX	C/M	MCNPX	C/M
		2.5.0 Bertini		2.7.0 Bertini		2.7.0 CEM	
1	2.04E+6	3.35E+6	1.64	2.94E+6	1.44	3.00E+6	1.47
2	2.42E+6	3.80E+6	1.57	3.28E+6	1.36	3.36E+6	1.39
3	1.96E+6	3.34E+6	1.70	2.95E+6	1.51	3.02E+6	1.54
4	1.40E+6	1.92E+6	1.37	1.71E+6	1.22	1.65E+6	1.18
5	1.60E+6	2.31E+6	1.44	2.05E+6	1.28	1.99E+6	1.24
6	1.45E+6	2.25E+6	1.55	2.00E+6	1.38	1.93E+6	1.33
7	1.09E+6	1.85E+6	1.70	1.63E+6	1.50	1.58E+6	1.45
8	6.60E+5	1.08E+6	1.64	9.89E+5	1.50	9.69E+5	1.47
9	3.70E+5	5.50E+5	1.49	5.12E+5	1.38	4.92E+5	1.33
10	2.20E+5	2.45E+5	1.12	2.69E+5	1.22	2.41E+5	1.10
11	1.60E+5	1.45E+5	0.91	1.57E+5	0.98	1.34E+5	0.84

Table II. Calculated dose rates vs measured dose rates for target vessel #13, with mercury modeled as a puddle. Dose rates are in mrem/h.

Detector #	Measure ments	MCNPX	C/M	MCNPX	C/M
		2.5.0 Bertini		2.7.0 Bertini	
1	2.04E+06	2.83E+06	1.39	3.00E+06	1.47
2	2.42E+06	3.19E+06	1.32	3.38E+06	1.40
3	1.96E+06	2.86E+06	1.46	3.03E+06	1.54
4	1.40E+06	1.66E+06	1.19	1.76E+06	1.26
5	1.60E+06	2.00E+06	1.25	2.12E+06	1.32
6	1.45E+06	1.95E+06	1.34	2.06E+06	1.42
7	1.09E+06	1.59E+06	1.46	1.68E+06	1.54
8	6.60E+05	9.95E+05	1.51	1.05E+06	1.59
9	3.70E+05	5.15E+05	1.39	5.45E+05	1.47
10	2.20E+05	2.67E+05	1.21	2.83E+05	1.29
11	1.60E+05	1.60E+05	1.00	1.69E+05	1.05

Overall the calculated dose rates are in good agreement with measured dose rates, overestimating by as much as 50%. Using CEM model vs. Bertini model for high-energy particles physics does not show significant impact on calculations. Using reaction rates and fluxes generated by MCNPX version 2.7.0 compared by MCNPX version 2.5.0 with dispersed mercury brings calculated dose rates closer to measured dose rates. Modeling of mercury as a puddle vs. distributed mercury at lower density does not impact the dose rates significantly.

PBW

The respective analyses for the PBW module were performed using MCNPX version 2.7 with Bertini model for high-energy particles interactions. Results are presented in Table III.

Table III. Calculated dose rates vs measured dose rates for PBW module #5. Dose rates are in mrem/h.

Detector #	Measurements	Calculations	C/M
1	0.16	0.22	1.38
2	0.22	0.24	1.09
3	0.17	0.2	1.18
4	0.38	0.4	1.05
5	1.15	1.03	0.90
6	0.52	0.38	0.73
7	0.22	0.23	1.05
8	0.26	0.31	1.19
9	0.21	0.24	1.14

Most of the calculated results are quite consistent with measured data, within 20% and generally higher than measured data. There are two locations where the dose rates are differing by as much as 40%. This difference could be driven by uncertainty in the detector position during the measurements. All-in-all, the C/M values obtained for the PBW confirm the findings of the target.

ACKNOWLEDGMENTS

ORNL is managed by UT-Battelle, LLC, under contract DE-AC05-00OR22725 for the Energy. This research was supported by the DOE Office of Science, Basic Energy Science, Scientific User Facilities.

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