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NEUTRONIC ANALYSES TO SUPPORT WASTE MANAGEMENT FOR SNS*

I.I.Popova, F.X.Gallmeier, S.Trotter, M.Dayton, ORNL, Oak Ridge, TN 37831-6466, USA

Abstract

According to the Spallation Neutron Source (SNS) operations plan facility components are replaced when they reach their end-of-life. These components must be safely removed, placed in a container for storage, and transported from the site. In order to classify components and suggest an appropriate shipping container an accurate estimate of the radionuclide inventory is performed. After the choice for the container is made, it is modelled with the facility component placed inside in order to perform transport calculations to ensure that the container is compliant with waste management regulations.

INTRODUCTION

The Spallation Neutron Source (SNS) in Oak Ridge, Tennessee, is an accelerator driven neutron scattering facility for materials research, operating at 1.3 megawatt (MW) proton beam power incident on a mercury target with a proton beam energy of 1 GeV and 60 Hz repetition rate. The SNS consists of an accelerator facility, target facility, and a world-class suite of neutron scattering instruments supporting material, life-science and fundamental physics research.

SNS components are replaced when they reach their end-of-life due to radiation induced material damage or burn-up, or because of mechanical failure, or design improvements. During operation these components, especially those in proximity to the target, are exposed to a radiation environment and build up significant activity during their service lifetime. All these components must be safely removed, placed in a container/package for storage, and ultimately transported offsite for disposal.

In order to classify a spent component, an accurate estimate of the radionuclide inventory is performed, assuming realistic irradiation history and decay time. On the basis of a calculated radionuclide inventory, the spent component is classified, and an appropriate cask/package for transport and storage is suggested. After the choice for the container is made, transport calculations are performed for the facility component placed inside the container, to ensure that the container is compliant with the waste management regulations. When necessary, additional shielding is added. Before a spent component leaves the SNS site, supporting documentation with radionuclide inventory prediction and dose rate analyses is produced. Dose rate analyses for the exposure prediction of personnel during components change out are performed as well. Most of the effort is concentrated on the target facility components such as target vessel, proton beam window (PBW) and core vessel insert (CVI) plugs because of severe radiation conditions. Some work is performed as well for the accelerator facility components.

METHODS

Full three-dimensional radiation transport calculations with the state-of-the-art code MCNPX version 2.6.0 [1] and the latest as-built target station model and accelerator components models are performed to simulate the radiation environment due to the proton beam impact in the mercury target. Isotope production rates due to spallation reactions and the below-20-MeV neutron fluxes binned in the 63 energy groups are calculated for areas of interest in preparation of the activation analyses.

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 radionuclide inventory distributions, the component is subdivided into smaller cells for each of which activation calculations are performed based on cell specific isotope production rates and neutron fluxes.

Decay gamma sources for a defined history of build-up and decay are extracted for all component cells, and are formatted into source descriptions for MCNPX transport analyses by running the GAMMA_SOURCE_SCRIPT [4]. The decay gamma source term is utilized in photon transport calculations of the component with liner (if liner is present) and of the component inside the transport container. For the analyses of the residual dose rates, next-event point and ring detectors were applied as well as dose rate mesh tallies. Effective dose rates are obtained by folding gamma fluxes with flux-to-dose conversion coefficients, which are taken from standardized SNS neutron and gamma ray flux-to-dose rate conversion factors libraries [5]. If dose rate requirements outside of the container are not compliant with the waste management regulations, additional analyses are performed to design proper shielding.

TARGET SYSTEM FACILITY

Target vessel, proton beam window (PBW) and core vessel insert (CVI) plugs are routinely scheduled to be replaced in maintenance periods following the facility operation periods about twice per year. Target and proton beam window are replaced to avoid material embrittlement. The peak damage limit for steel and inconel structures is 10 dpa. CVI plugs are temporary components and are replaced when actual optic components are received.

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Target Vessel

The most time consuming analyses are required for the target vessel disposal. The SNS target vessel contains the liquid mercury target in the in-beam area of the target station. The target vessel is routinely replaced as it approaches its estimated life-time, or if it prematurely fails. Based on the estimated radionuclide inventory for full beam power (2MW) over 5000 h operation, as well as the size and weight of the target vessel, it was decided to use the TN-RAM cask or equivalent for off-site transport to a waste disposal facility. Fig. 1 shows the MCNPX model of target station for target vessel for transport calculations.

The radionuclide inventory for the target vessel includes three components: the target vessel, 200g of activated mercury dispersed in the target, and 10% of the mercury radionuclide inventory (other than mercury, gold and noble gas isotopes) deposited on mercury exposed steel piping. In order to simplify analyses and avoid errors arising from manual preparation of calculations, the Perl script TARGET_DISPOSAL was created to run these analyses. This script uses reaction rates in the target vessel and in the mercury calculated by MCNPX, and stored in the output and runs ACTIVATION_SCRIPT, for transmutation analyses to produce the radionuclide inventory and gamma source terms. Then, the script prepares the decay gamma source definition for MCNPX photon transport calculations for the target vessel inside a liner and also for the target vessel inside liner inside the transport cask. For analyses of residual dose rates, next-event point and ring detectors are applied, as well as dose rate mesh tallies, to allow for dose rate contours in and around liner and cask geometries. After completion of the transport analyses, the script automatically generates a final report. Fig. 2 shows typical configuration for spent target inserted in liner and TN-RAM cask modelled in MCNPX geometry language and dose rate contours in and around the TN-RAM cask loaded with the liner and the SNS spent target #8 after 202 days decay, as an example. Target #8 module had a service lifetime of approximately 0.97 years in which it accumulated slightly more than 3744 MWh proton beam energy at 1GeV proton energy.

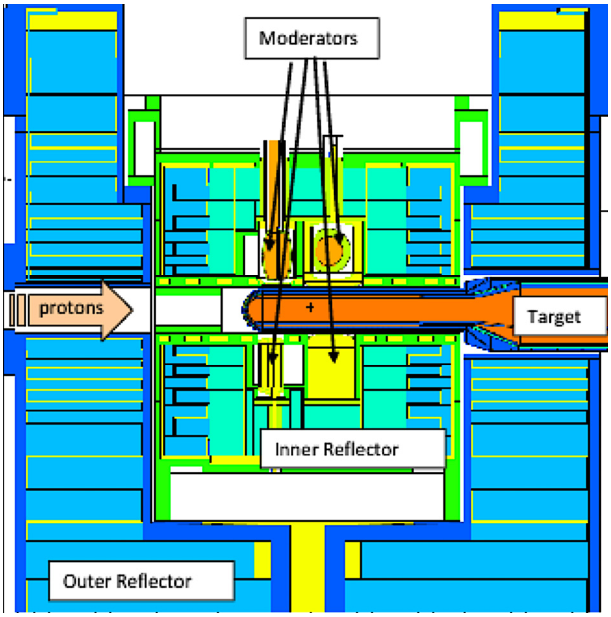

Figure 1: MCNPX model for target vessel and proton beam window transport calculations.

Proton Beam Window

The SNS PBW module is mounted in the target monolith, approximately 2.3 meters upstream from the target, and establishes the boundary between the accelerator environment and the target environment. In essence, it serves as the gateway for the proton beam en route to the target.

After completing transport and activation analyses, the PBW module is extracted from the target monolith model and placed into a steel liner and TN-RAM cask model. For the waste management purposes, report similar to the

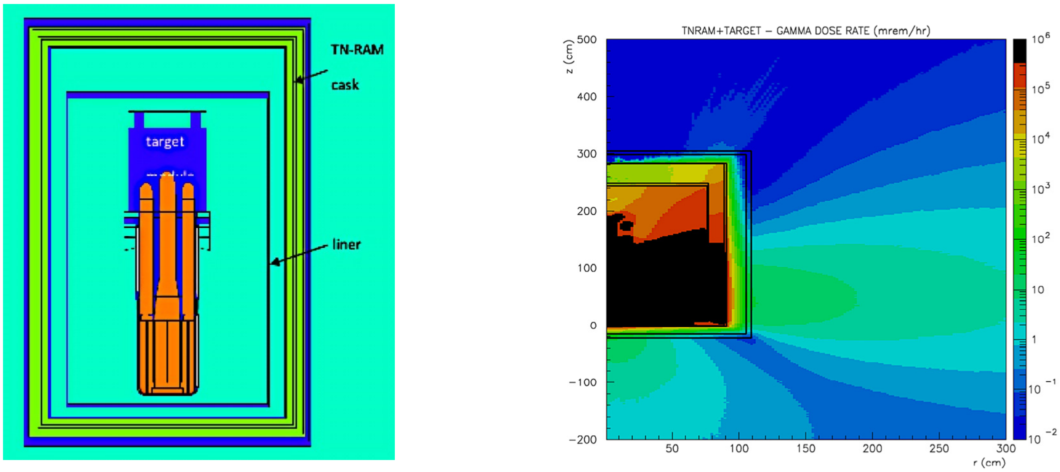

Figure 2: MCNPX model for typical configuration of spent target inserted in liner inside TN-RAM cask (left) and dose rates map around this configuration (right), mrem/h.

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spent target report is generated for spent PBWs. Also, as the result activity-based packaging determinations, the TN-RAM cask or equivalent is used for off-site transport of PBWs to a waste disposal facility.

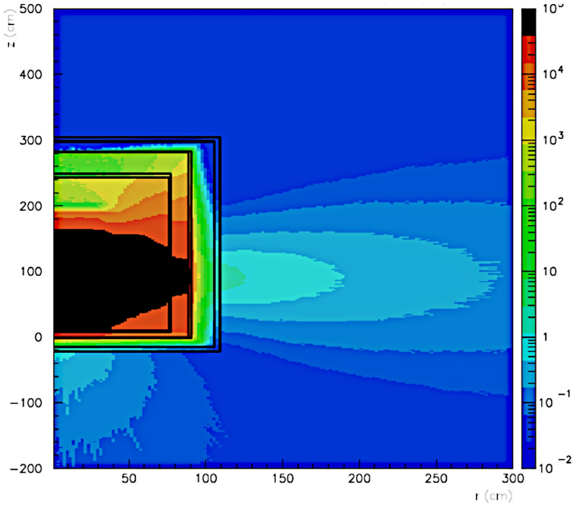

Figure 3: Dose rate contours in and around the TN-RAM cask loaded with the liner and the third PBW module.

Fig. 3 shows dose rate contours in and around the TN-RAM cask loaded with the liner and the SNS spent PBW #3 after 286 days decay, as an example. PBW module had a service lifetime of approximately 1.5 years in which it accumulated slightly less than 6300 MWh (9.54 dpa) proton beam energy at 1GeV proton energy.

ACCELERATOR SYSTEM FACILITY

Temporary storage casks for accelerator spent structures are designed under the criterion that the dose rate outside the container will not exceed 5 mrem/h at 30 cm distance from the container surface and are already designed for the HEBT momentum beam stop, the RTBT harp and the ring injection dump (RID).

Ring Injection Dump

According to the accelerator operations plan, the beam stop core and window assemblies of the existing RID will be removed when they have reached their end-of-life. Both parts are expected to be highly activated, because the RID receives the highest losses in the accelerator facility, 5% of the accelerator beam power (100kW). Shielding above these two assemblies has to be removed to allow access, and will be placed into temporary storage containers while the beam stop core and window assemblies are removed and reinstalled. Two container configurations for each assembly were suggested. The first configuration assumes use of a lead container whereas the second configuration assumes use of a steel container, but reinforced with lead. Fig. 4 shows dose rate distribution for beam stop assembly lead container as an example. The container has variable thickness around the RID assembly.

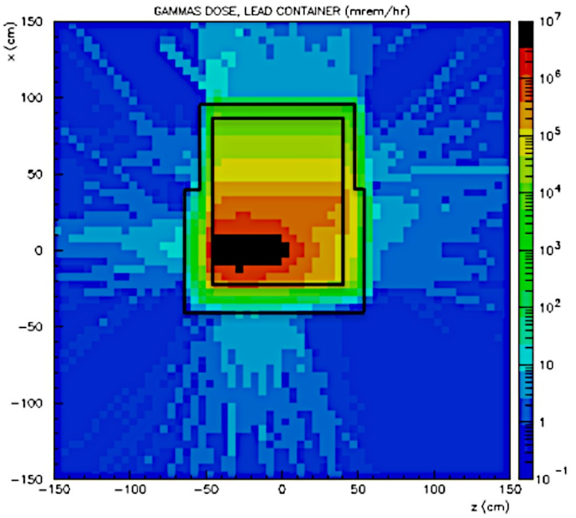

Figure 4: Dose rates map inside and outside the beam stop assembly lead container.

HEBT Momentum Beam Stop

Container dimensions for HEBT momentum dump were calculated on the basis that the beam dump was cooling down for one year and then placed into steel container. Source terms for the analyses was 850 MeV proton beam at 1 kW intercepting beam stop at 7 cm from the beam centre line and having Gaussian distribution in vertical and horizontal direction. On the base of the analyses a stainless steel cylindrical container was suggested. The container profile changes thickness along its length from 7cm to 13cm to match the momentum dump residual activation profile.

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