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SNS SECOND TARGET STATION PROTON ACCELERATOR SHIELDING DESIGN AND ACCIDENT SCENARIO EVALUATION*

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Abstract

Design of the Second Target Station (STS) for Oak Ridge National Laboratory's (ORNL) world-class Spallation Neutron Source (SNS) Facility is underway. The STS will provide an optimized high-brightness cold neutron source for up to 18 new beamlines, both expanding and complementing the current neutron science capabilities at ORNL. The Ring-to-Second-Target beam Transport (RTST) will deliver a 700 kW beam of 1.3 GeV protons at 15 Hz to a rotating target composed of individual water-cooled tungsten wedge segments. Spanning roughly 220 m, the RTST will consist of 56 quadrupole focusing magnets and 15 dipole bending magnets. Installation and maintenance of large beamline components will be facilitated via a truck access tunnel. While the proton accelerator is in operation, the truck access tunnel entrance is shielded by an arrangement of stacked steel shielding blocks. This shielding design must account for both normal operating conditions as well as design-basis accident scenarios. Provided in this work is an analysis of the accelerator truck access tunnel shielding design for a worst-case full beam loss accident scenario.

INTRODUCTION

The STS is a planned upgrade to the SNS at ORNL that will provide a high-brightness cold neutron source for up to 18 new beamlines. A 1.3 GeV, 700 kW proton beam will be delivered from the SNS accumulator ring via the 220 m RTST line, which incorporates focusing and bending magnets as well as extensive shielding. A dedicated truck access tunnel allows installation and removal of large components; during operations its entrance is shielded by stacked steel blocks, concrete bookends, and an overhead lintel to limit radiation streaming.

The most severe design-basis accident considered is a dipole magnet failure near the tunnel opening, directing the full proton beam into the RTST tunnel wall. Although the credited Personnel Protection System (PPS) will terminate the beam within 2 s [1], the shielding must ensure that potential radiation exposures in accessible areas remain below the 11 mrem design criterion.

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This work presents a radiation transport analysis of the truck access tunnel shielding for the RTST under the worst-case full-beam-loss accident scenario. The analysis evaluates the labyrinth geometry, stacked steel shielding, and concrete structures using Monte Carlo transport methods to predict effective dose rates in the surrounding accessible areas. The results are intended to verify compliance with the STS radiation safety design goals and to inform any necessary design refinements prior to construction.

SHIELDING DESIGN CRITERIA

The RTST truck access tunnel, labyrinth, and stacked steel shield block design is being evaluated for a full beam loss accident. The design objective is that the ensemble of shielding design components mitigates human radiation exposures in generally accessible areas to less than 11 mrem over a period of 2 s [1, 2].

METHODOLOGY

In this analysis, a geometry representative of the RTST truck access tunnel was constructed. Radiation transport calculations were then performed to propagate a loss-of-beam source term throughout this geometry. Variance reduction methods were employed to converge the expected radiation exposure quantities in the vicinity of the RTST truck access tunnel labyrinth and the stacked configuration of steel shielding blocks.

Geometry

The geometry for this work is built using constructive solid geometry (CSG) format. The major components included in this geometry are the RTST tunnel, truck access tunnel, the labyrinth, the stacked steel shielding blocks (see Fig. 1).

The RTST tunnel contains the beamline and magnet components. The truck access tunnel branches from the RTST tunnel and opens to the exterior of the main shielding berm structure. A labyrinth between the end of the truck access tunnel and the exterior of the primary berm shielding structure facilitates personnel access to the RTST.

Directly outside of the truck access tunnel sits a collection of large, stacked steel blocks that shield the exterior environment from the radiation produced within the RTST tunnel. The steel shielding blocks are accompanied by two poured-in-place concrete bookends as well as a lintel overhead (see Fig. 2). The bookends and lintel mitigate radiation streaming from the gap between the stacked shielding and the exterior face of the truck access tunnel. The steel shielding blocks are in place during beam operations and is removable to bring equipment into the RTST tunnel.

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Figure 1: Geometry plan view of the RTST truck access tunnel at the beamline elevation. The whitespace represents air.

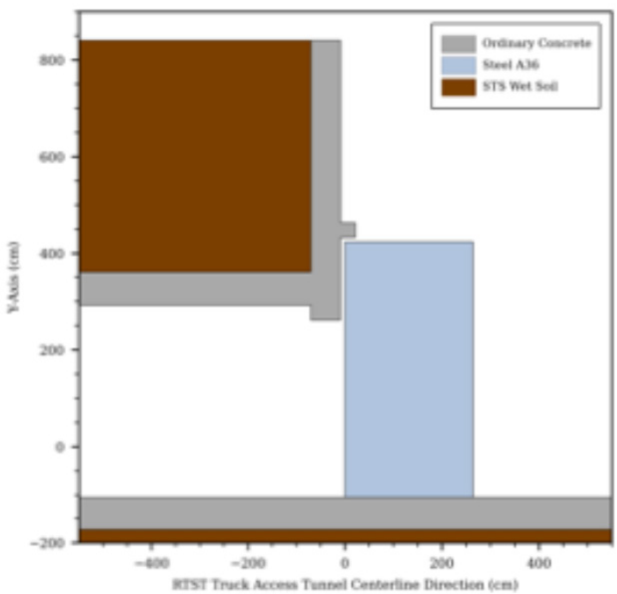

Figure 2: Geometry elevation view slice through the centerline of the stacked steel shielding. The whitespace represents air.

Radiation Transport

The MCNP6.2 general purpose Monte Carlo radiation transport code was used to perform the transport calculations [3, 4]. The nuclear cross section data selected for the Monte Carlo calculations is the ENDF/B-VII.1 library [5]. Weight windows generated using the ADVANTG code [6] were utilized in the Monte Carlo transport calculations to aid in statistical convergence of the quantities of interest.

Radiation Source

The radiation source evaluated for this analysis is a dipole magnet failure accident condition. It is assumed that dipole magnet DH39 (see Fig. 1) instantaneously experiences a complete loss of power. In this scenario, the 700kW proton beam fails to bend to the right and instead continues straight ahead through the steel bulk of the dipole magnet and eventually into the wall of the RTST near the opening for the Truck access tunnel. This condition is assumed to last for a maximum duration of 2 s.

The source term used in the radiation transport calculation is a monoenergetic, monodirectional disk of 1.3 GeV protons. The disk is located within the primary beam tube at the center of the horizontal-focusing quadrupole magnet QH39 and directed along the beam direction.

Tallied Quantities

A 3-dimensional mesh tally is used to independently track flux and dose contributions from protons, neutrons, and photons throughout the geometry. Human effective dose tally contributions are scored by interpolating from species and energy dependent flux-to-dose conversion factors [7-10]. The results are then summed in post-processing to produce a map of expected total dose.

RESULTS

The calculated total effective dose rates for the 2 s full beam-loss accident are shown in Figs. 3 and 4. Figure 3 presents a plan view of the RTST truck access tunnel region at the beamline elevation, and Fig. 4 shows an elevation view through the tunnel centerline and stacked steel shielding. Air regions, previously depicted as whitespace in Figs. 1 and 2, are now filled with a colormap of expected dose. Contours are overlaid on all materials, with the bold contour indicating 11 mrem.

The generally accessible regions of interest (originally shown in Fig. 1) lie outside the 11 mrem contour, indicating that the shielding meets the design goal. The single exception to this observation is a roughly 1 m volume above the stacked shielding blocks.

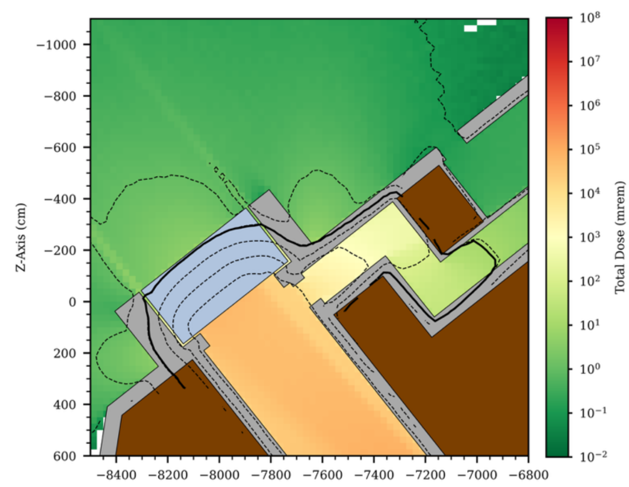

Figure 3: Plan view at the beamline elevation showing total effective dose for a 2 s accident. The solid contour denotes 11 mrem; dotted lines mark order-of-magnitude graduations on the color scale.

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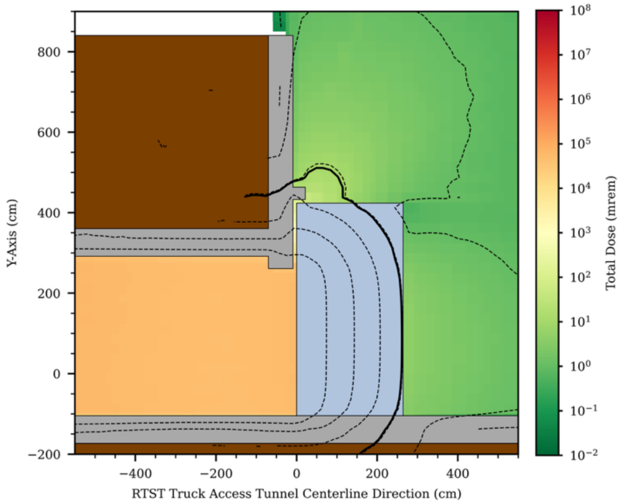

Figure 4: Elevation view through the stacked steel shielding centerline showing total effective dose for a 2 s accident. The solid contour denotes 11 mrem; dotted lines mark order-of-magnitude graduations on the color scale.

CONCLUSION

Radiation transport analysis of the RTST truck access tunnel shielding under the worst-case full-beam-loss accident scenario demonstrates that the current labyrinth, stacked steel blocks, and concrete bookend configuration is effective in meeting the STS design goal of keeping exposures in accessible areas below 11 mrem over a 2 s event. All primary regions of interest lie outside the 11 mrem contour, with the only exceedance limited to a small volume above the stacked shielding blocks. These results confirm the adequacy of the shielding concept and provide a quantitative basis for any final design refinements prior to construction.

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