SHIELDING ANALYSES AND PROCEEDURES FOR THE SNS *

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Abstract

In order to provide radiologically safe Spallation Neutron Source operation, shielding analyses are performed according to Oak Ridge National Laboratory internal regulations and to comply with the Code of Federal Regulations. An overview of on-going shielding work for the accelerator facility and neutrons beam lines, and associated procedures and regulations are presented.

INTRODUCTION

The Spallation Neutron Source (SNS)[1] in Oak Ridge, Tennessee, is an accelerator driven neutron scattering facility for materials research. SNS operates at 1 megawatt (MW) proton beam power incident on a mercury target with a proton beam energy of 1 GeV and 60 Hz repetition rate. The facility is still ramping up the power to reach the planned 2MW on target.

All stages of the SNS development require significant research and development in the field of radiological shielding design to assure safety from a radiation-protection point of view and to optimize accelerator, target system, and scattering instrument performance.

At present, most of the shielding work is focused on the instrument beam lines and their enclosures in order to commission and provide save operation in the future. This effort is performed according to the guidelines for the SNS neutron beam line shielding calculations[2], which sets standards for the analyses and helps to prepare for the Instrument Readiness Review (IRR). The IRR ascertains that the instrument has been designed, constructed, and installed to allow safe operation and maintenance. There is still support for the accelerator facility to redesign parts of the accelerator structures, to design storage containers for removed components and test stands for accelerator structures, and for radiation protection analyses for evaluations of accelerator and target safety systems.

The SNS accelerator is powered by an H- beam produced in the front-end ion source and systems. The beam is accelerated in the linear accelerator (LINAC), then goes through the high-energy-beam-transfer line (HEBT) into the accumulator ring. In the ring H- ions are stripped by a 2-µm-thick carbon foil to protons, which, after one thousand turns, are extracted through the ring-to-target-beam-transfer line (RTBT) and delivered to mercury target station. The high energy neutrons resulting from the proton initiated spallation reactions with the mercury target are converted to thermal and cold neutrons by one ambient water and three supercritical hydrogen moderators placed on top and bottom of the target. The thermalized neutrons are directed to the neutron scattering instruments through neutron beam lines. There are 18 beam lines, 6 of which serve two instruments, so the facility is able to accommodate 24 instruments.

OVERVIEW ON PROCEEDURES, REGULATIONS AND FACILITY STAGES

Shielding analyses for SNS facilities, both accelerator and target with scattering beam lines, are performed to meet the requirements of SNS-OPM 2.H-5 "SNS Radiation Safety Policy" and Section 7.8 of the "Spallation Neutron Source Final Safety Assessment Document for Neutron Facilities," and to comply with 10 CFR 865 regulations.

According to the regulations, the design dose rate in generally occupied area will be below 0.25mrem/h at 30 cm from the shielding surface and further away. Historically there were multiple stages of shielding design:

- Before and during the accelerator and target facility construction, the initial design;
- Support of the accelerator and later the target commissioning;
- Shielding support during the power ramp up and operation, which is on-going.

Initial Design

The SNS operates a high current and high power accelerator. The accelerator systems are designed to be maintained hands on. This sets the acceptable beam losses to the level of around 1 Watt per meter limiting the activation level in the accelerator and proton beam line tunnels. This also determines the bulk shielding requirement for the accelerator tunnels, which results in about five meters of soil on top of the tunnels to ensure doses below 0.25 mrem/hr.

The target monolith housing the target station has the task to provide shielding to a dose rate of 0.25 mrem/hr, both for personnel protection and neutron background reasons. Low neutron background is desired by the neutron scattering instruments. The SNS design includes 18 main shutters, which can be used to close neutron beam lines while SNS is operating, allowing access to the instrument cave. Another important shielding piece is the target cart, a 5 meter long plug providing downstream shielding with the target mounted in the front.

Commissioning

Commissioning of the accelerator system is a critical step in the transition from the fabrication and installation phase to the operation. Predictions for radiation fields induced inside and outside of the accelerator tunnel were calculated for all commissioning steps, which took place according to the SNS Commissioning Program Plan[3].

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The beam power deposited locally in the accelerator tunnel during the commissioning phases greatly exceeded typical operational line losses that are on the order of 1W/meter, with the consequence of very high radiation fields. On the basis of neutronics analyses proper temporary shielding was installed in local areas near beam termination points (beam stops and beam collectors) and some critical locations, such as penetrations, in order to minimize dose rates in normally occupied areas.

Each commissioning step was preceded by an Accelerator Readiness Review (ARR). The ARR process verifies the machine readiness for each commissioning step. ARRs are conducted in accordance with the requirements established in DOE Order 5480.25, "Safety of Accelerator Facilities."

Power Ramp Up and Operation

During power ramp up, shielding analyses are mainly concentrated on neutron scattering beam lines and instrument enclosure shielding design. There is still a need for shielding analyses for the accelerator facility.

CURRENT SHIELDING ANALYSES

Now that the facility is successfully operating, there is still demand for neutronics analyses for radiation-protection support. This need arises from bulk shielding design for the neutron beam lines, redesigning some parts of the accelerator facility, facility upgrades, designing additional structures, designing test stands for accelerator structures, and verification and code validation analyses on the basis of the measured data. Presently shielding work is mostly concentrated on the neutron beam line shielding. Neutron beam lines require bulk shielding because of a large high-energy component in the neutron beam streaming though the guide to the instruments.

Beam Line Shielding

Beam line shielding analyses are carried out according to the guidelines for shielding calculations for SNS neutron beam lines. This document is intended to guide shielding analyses for instruments and beam lines and to help prepare for the Instrument Readiness Review (IRR), and for other safety reviews. Before beam lines start to operate, and the primary shutter opens; the beam line team goes through the IRR, which ascertains that the beam line and corresponding instrument have been designed, constructed and installed to allow safe operation and maintenance for both staff and general users. The IRR is conducted by the SNS Instrument Safety Committee (ISSC) and is expanded as necessary at the direction of the ISSC chairman. The IRR committee gives recommendations to operation manager for authorization of the operation of instruments. The ISSC performs an independent evaluation of instruments as they are constructed, commissioned, operated, and modified. Beam line shielding analyses are logically divided into two sets:

- Analysis of the incident beam line
- Analysis of the instrument cave or enclosure, including the neutron beam stop

Neutron beam lines at the SNS can be straight (allowing passage of fast and high-energy neutrons) or curved (relying on neutron optics to transport slow neutrons). All beam lines have primary shutters within the shielding monolith. Many beam lines also have secondary shutters, either to allow multiple instruments to use a single primary shutter or to permit more rapid personnel access to the instrument sample area. The prime goal is to design bulk shielding around the beam line and, if applicable, a secondary shutter. For beam line shielding analyses any beam obstruction expected to affect the shielding is taken into consideration.

Fig.1 shows an example of the dose rates along the beam line for beam line 17, the SEQOUIA instrument. Black lines represent the beam line geometry. Dotted lines represent cavities for the choppers. The beam line model starts at 100 cm from the moderator and extends to 1709 cm from moderator. Lines after 1709 cm from the moderator represent the front portion of the instrument enclosure shielding.

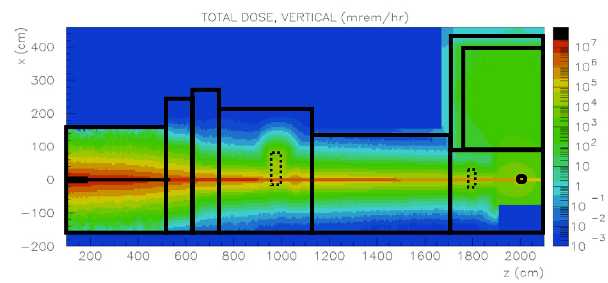

Figure 1: Elevation view of the dose rate map for beam line 17.

The instrument enclosure shielding analysis generally includes two separate analyses: the beam stop shielding design and the instrument enclosure shielding design. The beam stop is designed assuming unobstructed beam going to the beam stop.

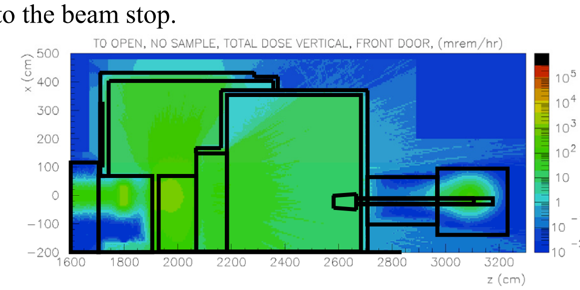

Figure 2: Elevation view of the dose rate map for the beam line 17 sample enclosure and beam stop.

Figure 2 gives an example of the dose rates around and inside the beam stop for beam line 17. Black lines represent the beam line 17 instrument enclosure from 1708 cm from the moderator to 2710 cm from the moderator. The beam stop is located outside of the enclosure and starts at 2710 cm from the moderator.

Instrument enclosure shielding usually is designed for so called "normal beam line operation," not for the accident scenario. Normal beam line operation considers the beam coming to the enclosure and hitting a standard sample without intercepting any other objects from the moderator to the sample.

Figure 3 shows a dose rate map for the beam line 16b shielding enclosure, which is the VISION instrument. The black lines are the beam line 16b instrument enclosure. The beam line 16b beam stop is located inside the instrument enclosure.

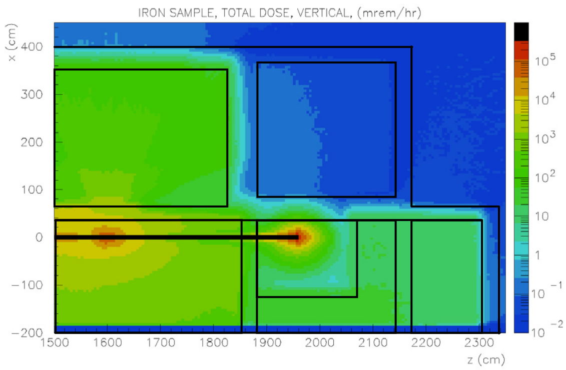

Figure 3: Elevation view of the dose rate map for the beam line 16b sample enclosure and beam stop.

Shielding Analyses for the Accelerator Facility

There is always demand for neutronics work from the various sections of the accelerator facility. Examples of recent work are shown below.

According to the accelerator operation plan the existing HEBT momentum dump will be replaced with a new passively cooled momentum dump. The existing momentum dump should be safely removed, placed in a container for storage, and removed from the accelerator building. The container was developed with the criteria that the dose rate outside the container after a one year cool down will not exceed 5 mrem/h at 30 cm from the container surface.

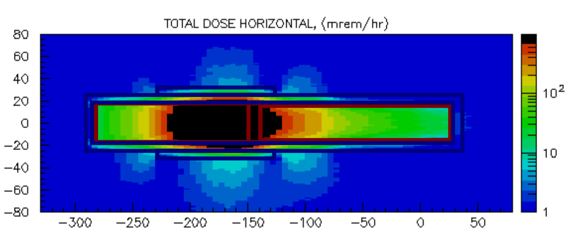

Figure 4: Dose rates map inside and outside beam dump container.

Figure 4 shows the dose rate map for the beam dump container. The blue lines represent the container, which is cylindrical in shape and surrounds the beam stop. The container profile changes thickness along its length to match the beam dump residual activation.

Extensive work has been completed to summarize the response of the area radiation monitors ("chipmunks") to the maximum possible accidental beam spill around the accelerator facility and to evaluate whether any beam-spill accidents would be detected by at least two chipmunks. Analyses for the dose rates at the chipmunks were performed based on the maximum possible accident for each considered accelerator section. The location of the accident was considered to be in the closest possible position to the chipmunk. As an example, Fig. 5 shows chipmunk readings in case of a possible maximum beam spill in the ring section of accelerator. The colored dot shows the location of the beam spill at a thick target or the center of the beam spill on the beam pipe assuming a Gaussian distribution. The coloured numbers near each chipmunk shows the dose rate at them. The color of the number refers to the dose rate measured by the chipmunk when the spill appears in the place marked with the same color. Chipmunk locations are marked in Fig. 5 by the letter R. Analyses show that the existing chipmunk locations are satisfactory to measure any elevated dose rate from accident conditions in the accelerator.

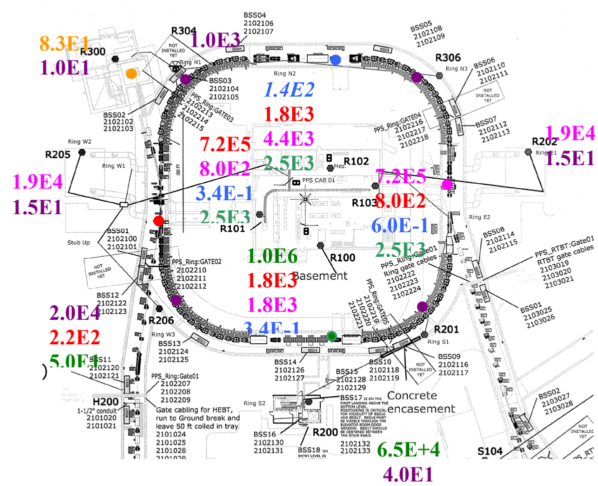

Figure 5: Dose rates at chipmunks in the storage ring.

CONCLUSIONS

Neutronic work is in full progress for the accelerator facility of SNS, meeting demands on redesigning parts of the facility, facility upgrades, designing additional structures, designing test stands for accelerator structures, and understanding of measured residual dose rates inside the accelerator tunnel. However most of the shielding efforts are concentrated on neutron beam line shielding design in order to bring instruments online. There are established procedures that guide neutron beam line shielding design.

REFERENCES

[1] National Spallation Neutron Source Conceptual Design Report, Oak Ridge National Laboratory, NSNS/CDR-2/VI, 1997.

[2] I. Popova, Guidelines for Shielding Calculations for SNS Neutron Beam Lines, Oak Ridge National Laboratory, SNS 106100200- WI0001-R00

[3] "Spallation Neutron Source Commissioning Program Plan" Oak Ridge National Laboratory, SNS 100000000P-PN0004-R00, July 2002.A. Name and D. Person, Phys. Rev. Lett. 25 (1997) 5.