SNS Beamline Shielding Design Challenges: Neutron Beamline 1 Example

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INTRODUCTION

While considerable experience has been amassed on the shielding of neutron beamlines and experimental areas at neutron scattering facilities, the required radiation transport calculations often remain challenging. In this paper we will discuss the shielding design analyses for a dual beamline under construction at the Spallation Neutron Source (SNS) at Oak Ridge National Laboratory. Our objective is to highlight the practical difficulties encountered in beamline shielding design and the needs for future developments in modeling, variance reduction, and processing of the results.

The SNS construction project was completed in May 2006 at a total cost of ~$1.4B. SNS is the world's most powerful accelerator-driven short-pulse neutron scattering facility. On September 18, 2009, SNS achieved a new world record when 1 MW of beam power was delivered to the target [1]. The proton beam power is gradually being ramped up toward the design power of 1.4 MW.

At the SNS target station, 1 GeV protons interact with mercury in the target and free neutrons predominantly through spallation reactions. Neutrons are slowed in moderators placed adjacent to the target. Three of the moderators are supercritical hydrogen moderators, and one is an ambient-temperature water moderator. The thermal and subthermal neutrons emerging from the moderators are delivered via beamlines to the experimental stations.

The SNS target hall will eventually contain 24 instruments on 18 beamlines. Currently seven instruments are conducting experiments, three are approaching operation and are accepting proposals, and nine are under construction.

BEAMLINE SHIELDING DESIGN CHALLENGES: EXAMPLE OF BEAMLINE 1

The example analysis presented in this paper deals with beamline 1, which will deliver neutrons to two instruments: the Time-of-Flight Ultra-Small-Angle Neutron Scattering Instrument (USANS) through beamline 1A and the Nanoscale-Ordered Materials Diffractometer (NOMAD) through beamline 1B [2].

The generic methodology applied to the SNS beamline shielding design is well described in a paper by Gallmeier et al. [3]. The calculations are performed with the MCNPX code. The neutron source is defined at the beginning of the neutron guide as a planar source (over 100 × 120 mm area) ~1 m from the moderator. The source emits neutrons in an angular cone with 2 degrees opening with respect to the beamline direction and has an energy distribution characteristic of the moderator type and beamline direction relative to the proton beam. The source spectrum extends well into the 100 MeV region, (up to ~ 300 MeV for beamline 1), and while the intensity at the high energies is greatly reduced, the high-energy neutrons still dictate shielding requirements.

Geometry models

The first step in the preparation of the analysis is the generation of the models for the MCNPX. An example of a model can be seen in Fig. 1. In practice this presumably trivial step requires a substantial amount of an analyst's time because of the complex design. In every case several iterations are typically required, sometimes based on results of previous analyses and sometimes due to unrelated design changes.

As an example, the original USANS design called for a straight diverging beam guide up to the pre-monochromator. However, simulations revealed that the dose rates in the NOMAD sample room would exceed 10 mrem/h due to the USANS operation, and it would therefore be impossible to change the USANS sample without closing the primary shutter. This led to the consideration of installing a T-0 chopper in the USANS beamline. Adding the T-0 chopper (and its cavity) proved to be an adequate solution to the dose rate problem, but it required modification of the shielding around it and complete manual reworking of the MCNPX shielding model.

While at present the modeling is still largely manual, automated conversion processing from CAD- to MCNP-style geometry is becoming available [4], and promising work is under way on direct usage of CAD or PRO-E designs by MCNP [5].

Variance Reduction

Computing realistic dose rates in a reasonable time for regions outside thick shields requires efficient variance reduction methods. For the SNS beamline simulations, the variance reduction workhorse is still geometry splitting and Russian roulette because more

sophisticated approaches, such as mesh-based weight windows have typically not produced satisfactory results. Geometry splitting, however, requires additional segmentation of the computational models. This further increases both modeling difficulties and computational run times.

The modeling effort required for effective variance reduction in the analysis of beamline 1 is reflected in the fine zone splitting of the thick shield components shown in Fig. 1. For this beamline two distinct models were required to achieve adequate variance reduction: one for the neutron beam through the USANS guide and one for the neutron beam through the NOMAD guide.

Efforts to improve variance reduction are under way [6-7] and may soon be available for routine applications.

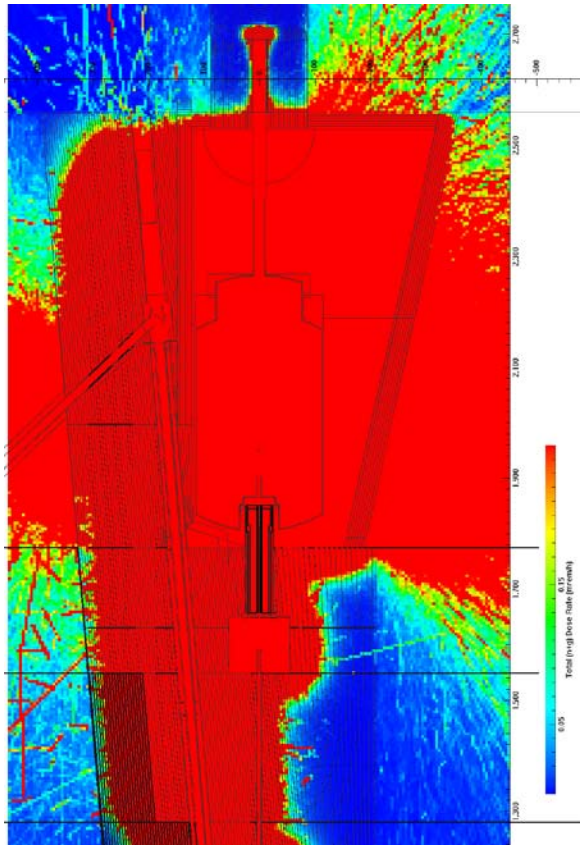

Fig. 1. Total (neutron + gamma) dose-rate distribution in the horizontal plane through beamline 1 at the beam elevation. Only part of the model is shown.

Results Analysis

Fig. 1 shows an example of the total (neutron and gamma) dose-rate distribution superimposed on the geometry model in a horizontal section through the USANS and NOMAD beamline at the beam elevation. The data were generated with the MCNPX mesh tally feature. Mesh tallies from two separate MCNPX runs were merged with an external utility program, which also combined neutron and gamma dose rates. The data were then plotted with the MORITZ code [8].

Generating 1-D plots, for example dose rate versus distance perpendicular to the beam, from the 2-D data, such as that shown in Fig. 1, is another feature useful for detailed analyses.

Such plots are essential for understanding and presenting results. Unfortunately, in most instances generating these visually informative results is not straightforward and requires manual manipulation of the models and data. Automation of these features into an MCNPX plotter, MORITZ, and other software available to general users would significantly improve the efficiency of beamline shielding analyses and facilitate the communication of the analyses to the instrument design teams.

CONCLUSION

Some of the challenges and inefficiencies of neutron beamline shielding design analyses have been described with the intention of encouraging future methods and software development.

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