NEUTRONICS CALCULATIONS TO SUPPORT THE SNS ACCELERATOR FACILITY*

I. Popova[#], P. Ferguson, J. Galambos, G. Dodson, F. Gallmeier
ORNL/SNS PO Box 2008, MS6475, Oak Ridge, TN 37831-6471

Abstract

The Spallation Neutron Source (SNS) is an accelerator driven neutron scattering facility for materials research that recently started operations. After commissioning, the facility started at low power and is presently in the process of a power ramp to reach the Megawatt power level within two years of operations, maintenance, and tuning cycles.

Extensive neutronics work for shielding development and dose rate predictions was completed during design and construction for various operational and shut down scenarios. Now that the facility is successfully operating, there is still demand for neutronics analyses for radiation-protection support. This need arises from redesigning some parts of the 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.

INTRODUCTION

The Spallation Neutron Source (SNS)[1] is an accelerator driven neutron scattering facility consisting of accelerator system, target system, and a world-class suite of neutron scattering instruments to benefit several areas of science. During all phases of SNS development, which are design, construction, commissioning and operation, extensive neutronics work was performed for both the accelerator system and the target system in order to provide adequate shielding and optimise performance of the target system and the instruments. Although the accelerator construction is finished and it is presently in operation mode there is still demand for shielding and activation analyses to support redesign of some parts of the facility, facility upgrades, designing additional structures, designing test stands for accelerator structures, and analyses and understanding of measured residual doses inside the accelerator tunnel.

The SNS accelerator is powered by an H^- beam produced in the front-end ion source and systems. The beam accelerates 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 and become the proton beam, which, after one thousand turns, are extracted through the ring-to-target-beam-transfer line (RTBT) and delivered to mercury target station.

METHODS

Shielding design analyses, which are transport analyses, are performed mainly with Monte Carlo code MCNPX[2] version 2.5.0 with full three-dimensional detailed modelling of the accelerator and additional structures. The MCNPX code simulates the particle transport of hadrons, continuous energy loss of charged particles in matter, elastic and nonelastic hadron interactions, secondary particle generation (here mainly gammas and neutrons) and their transport. Dose equivalent rates were obtained by folding neutron and gamma fluxes with flux-to-dose conversion coefficients, which were taken from the HILO2K neutron/gamma multi cross section library[3]. Geometry splitting was applied to force particles towards the outside of the shielding for deep penetration calculations.

Analyses for residual dose calculations inside the accelerator tunnel were performed in three steps. In the first step reaction rates in the accelerator structures were calculated using MCNPX.

According to residual dose measurements, the highest source of residual activation from all the accelerator structures is the steel beam tube. In order to simplify calculations, analyses were performed for a very simple model of the beam pipe without adjacent beam structures.

The material activation is caused by proton losses in the beam pipe, which are considered to be the sources for the analyses. The proton losses for the LINAC were defined as a continuous set of cylindrical surface sources located inside the beam tube, with uniformly distributed protons along each cylindrical surface. The direction of the protons, as the direction of axis of each cylinder, is parallel to the direction of the nominal proton beam. Calculations were performed for each location with corresponding proton beam energy. The proton source for the HEBT section near the stripping foil was defined as a proton pencil beam intercepting a carbon foil located inside the beam pipe.

In the second step, decay gamma sources are created by calculating isotope production rates using the activation script. This script provides the interface between MCNPX and the transmuation codes CINDER'90, ORIHET3 and SP-FISPACT. CINDER'90 was applied to obtain the time dependence of the isotope buildup and decay for given locations according to the provided operational scenario, and gamma decay spectra were extracted. The operational scenario used the time dependent reading from beam line monitors during the operation cycle.

In the third step photon spectra were transported and converted to dose rates by dividing by the area

---

[*] Work supported by the Division of Materials Science, U.S. Department of Energy, under contract number DE-AC05-96OR22464 with UT-Battelle Corporation for ORNL.

[#] popovai@ornl.gov.

corresponding to the distance from the beam pipe and folding with flux to dose conversion factors.

For the materials activation analyses the same method as above was used except that the third step was skipped.

SCOPE OF WORK

There is always demand of neutronics work for the various sections of the accelerator facility. Some of the most significant performed work is shown below.

There is also a smaller (by volume) set of neutronic work for the facility, such as optimizing calculations to choose materials for lower residual radiation after beam shut down, designing beam stops for various locations and so on.

Residual Dose Analyses

After commissioning, the facility started to operate at low power and is presently in the process of a power ramp to reach the designed power level during cycles of operation, maintenance, and tuning. The design average current of 1.4 mA will produce a beam power of 1.4 MW at the target at 60 Hz. This high average beam power makes it crucial that losses be kept extremely low to allow normal accelerator maintenance without high background radiation, because the whole accelerator systems are designed to be repaired, exchanged and upgraded manually during the maintenance periods.

In order to plan maintenance work after each operation period, residual dose measurements are taken at 30 cm distance from the accelerator structures and on contact. During the operation cycle, the time line of beam losses and beam scenarios are recorded by beam line monitors (BLM), placed along the accelerator, and then used as a source to calculate expected residual dose rates after shut down. Analyses were performed for three locations in the superconducting LINAC (SCL) and in the ring near the stripper foil, where the highest residual dose rates are measured. The calculated results were scaled to the beam power for the measurements and plotted for each location. There were in total eight measurement campaigns, six of them were performed after each running period in the operational cycle, about one or two days after the beam termination, and two additional measurements to monitor cooling down during the maintenance period. Calculations for residual radiation were performed according to the operational scenario with different beam power on and beam off for the time points corresponding to the beginning and end of each running period and to the time of measurements.

Figures 1 to 3 show results from the residual dose analyses vs. measurements and beam power scenario, which is recorded by BLMs. Calculated points are connected by straight lines on the plots, which do not represent real dose rate behaviour in time; it just gives better visual reading.

The slope for the measurements and calculations are overall in a good agreement, taking into account all the measurement and calculation uncertainties such as locations of the instruments, energy of the spilled beam, geometry simplification and so on. The measurements show slightly faster decay in the SCL section, which could be due to surrounding structures and material uncertainties in the calculation model and the time delay between taking measurements and recording them.

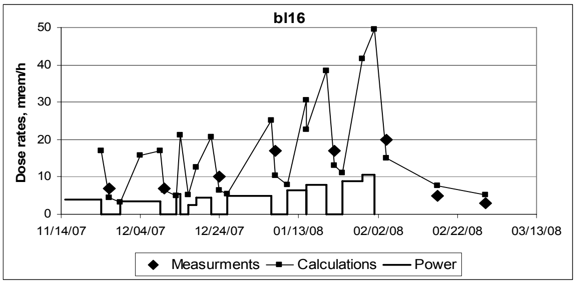

Figure 1: Measured dose rates vs. calculated for BLM16 location in SCL section.

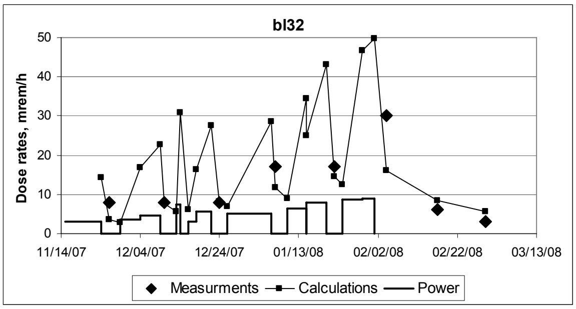

Figure 2: Measured dose rates vs. calculated for BLM32 location in SCL section.

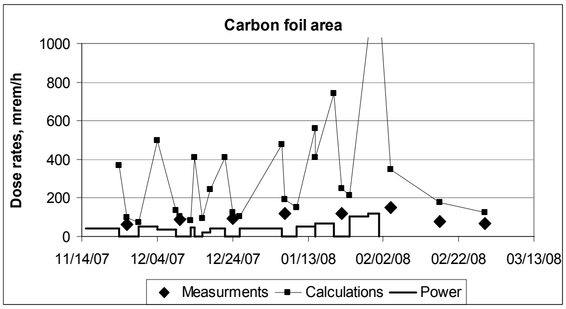

Figure 3: Measured dose rates vs. calculated for BLMA11 location in ring injection section near carbon foil.

Shielding for the Test Facility

A test facility was built as containment with 150 cm thick walls to test medium and high beta cryo-modules. Out of necessity there are a number of penetrations in the shielding wall for wave guides and for the helium supply lines. The containment itself has a large opening in the wall for taking in and out cryo-modules and an access opening maze with three legs. In order to protect people working near this containment a proper shielding wall for the opening and shielding for both penetrations should be developed and placed during cryo-module turn on.

The radiation source for these analyses is super conducting modules emission of x-rays with energies up to 800 keV. For safety reasons fast interlocked photon detectors will limit radiation inside the cave below 10 R/h 30 cm away from the cryo-module surface. As a conservative assumption, the shielding was designed using 800 keV photons as the source term, starting from the cryo-module surface isotropoically (1.41e+12gammas/s) and creating 10 R/h everywhere at 30 cm from the cryo-module surfaces.

On the basis of the provided source, proper shielding was calculated (Fig.4) and later on implemented as

- 60 cm of concrete for the door to close the opening for moving cryo-module in and out
- 20 cm thick and 150 cm high concrete shielding around the wave guide penetration
- 35 cm of concrete with 30 cm overlap to close the helium supply lines penetration
- Maze initially planned to be two legs transformed into three legs with an additional wall

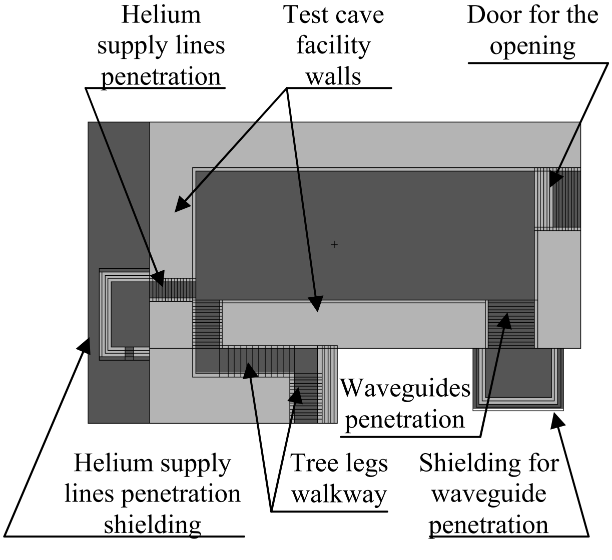

Figure 4: Layout of shielding.

Front End Door

The beginning of the accelerator tunnel starts in the front end building. In the front wall of the accelerator tunnel there is an opening for taking in and out LINAC equipment and supplies. This opening stays closed by the so-called plug door, which is composed of 90cm thick concrete, the same as the surrounding tunnel walls. The plug door is very heavy and difficult to handle. In order to make the door more manageable it was a desired to design a door with lighter weight.

A full scale model of the front end of the accelerator and first accelerating sections was used for these simulations. First source terms near the front end inside the tunnel were calculated based on measured beam losses during normal operations. Then scaling calculations were performed to figure out the proper amount of materials for the door, which were calculated to be 35cm of 5% borated polyethylene followed by 2.5 cm of steel.

CONCLUSIONS

Neutronics work is in full progress for the accelerator facility for SNS meeting demands on redesigning some parts of the facility, facility upgrades, designing additional structures, designing test stands for accelerator structures and analyses and understanding of measured residual doses inside the accelerator tunnel.

REFERENCES

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

[2] L.S. Waters, ed., MCNPX User's Manual – Version 2.1.5, Los Alamos National Laboratory, NM, TPO-E83-G-UG-X-00001, Nov. 1999.

[3] R. A. Lillie, F. X. Gallmeier, J.O. Johnson, "*HILO2K: Transport Cross Sections for Neutron Energies to 2 GeV*", Proc. 12th Bi-annual RPSD Topical Meeting, Santa Fe, New Mexico, USA, April 14-18, 2002.

[4] F.X Gallmeier, W.L Wilson, M. Wohlmuther, B. Michlich, E.B. Iverson, E. Pitcher, W. Lu, H.R. Trellue, Ch. Kelsey, G. Muhrer, I.I. Popova, P.D. Ferguson, "An Environment Using Environment Nuclear Inventory Codes in Combination with the Radiation Transport Code MCNPX for Accelerator Activation Problems", Proc. Eight International Topical Meeting on Nuclear Applications and Utilization of Accelerators, American Nuclear Society, Pocatello, Idaho, July 29 – August 2, 2007, pp. 207-208.