RESIDUAL DOSE RATE ANALYSES FOR THE SNS ACCELERATOR FACILITY*

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Abstract

The Spallation Neutron Source (SNS) accelerator is a neutron scattering facility for materials research that recently started operations. The facility started up at low power and is presently in the process of power ramp-up. In order to plan maintenance work after each operations period, residual dose measurements are taking at 30 cm distance from the accelerator structures and on contact. During normal operation, beam losses and beam scenario are recorded and used as a source in build-up/decay analyses. Preliminary analyses of residual dose rates due to accelerator component activation are performed in order to predict and to understand nature of the radiation field behavior inside the accelerator tunnel.

INTRODUCTION

The Spallation Neutron Source (SNS) in Oak Ridge, Tennessee is an accelerator driven neutron scattering facility for materials research that recently started operations. After commissioning, the facility was operated at low power to gain experience with this prototypic facility and is presently in the process of a power ramp to reach the designed power level during cycles of operations, maintenance, and tuning. The design time average current of 1.4 mA will produce power of 1.4 MW at the target at a 60 Hz rate repetition rate. With this very high beam power it essential that losses be kept extremely low to allow normal accelerator maintenance at moderately low decay gamma radiation fields, because the whole accelerator systems are designed to be maintained, repaired, and upgraded manually between cycles of operations.

The SNS accelerator is powered by H- beam produced in the front-end ion source and systems. The beam accelerates in the linear accelerator (LINAC), then goes through high-energy-beam-transfer line (HEBT) into accumulator ring section. In the ring section H- are stripped by 2-μm-thick carbon foil and become the proton beam, which after thousand turns through the ring-to-target-beam-transfer line (RTBT) the beam is delivered in to target station.

The SNS accelerator, as all high power machines, is operated as loss limited machine, with maximal acceptable beam losses at around 1 Watt per meter. Ion chambers [1] used as beam loss monitors (BLM), are located along the beam line and measure prompt radiation induced during accelerator operation and inhibiting the beam when excessive losses occur.

To plan maintenance work after each operations period, residual dose measurements are taken at 30 cm distance from the accelerator structures and on contact.

In order to be able to predict induced radiation after shut down and understand its nature, residual dose rates analyses for two last running cycles fall 2007 and spring 2008 have been performed. During accelerator operation, beam losses and beam scenario are recorded and used as a source to calculate expected residual dose rates after shut down. Calculation analyses are performed using the transport code MCNPX [2] followed by the newly developed activation calculation script, which uses the nuclear inventory code CINDER'90 [3], then converting gammas production spectra and gamma power to the dose rates. Calculated results for both cycles for various locations are compared with measured data.

METHODS

Analyses for residual dose calculations were performed in 3 steps. On the first step reaction rates in the accelerator structures were calculated applying the MCNPX Monte Carlo multi-particle transport code, which simulates the generation of secondary radiation fields due to the impact of proton beams on the beam guide and transports primary secondary and secondary particles. The portion of the proton beam intercepting beam tube or any accelerator structure is considered to be the source for transport calculations. The sources for SCL section 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 (Table 1). The proton source for HEBT section near stripping foil was defined as a proton pencil beam intercepting a carbon foil located inside beam pipe.

Table 1. Beam energies for various locations

Location	**After cryo-module 16**	**After cryo-module 32**	**After stripping foil**
Beam lost monitor	scl16b	scl32b	ring_A11c
Beam energy	660	945	945

According to the residual dose measurements, the highest source of residual operation from all the accelerator structures is the steel beam tube. In order to simplify calculations analyses were performed for very

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simple model of beam pipe without adjacent beam structures. In later studies accelerator tunnel walls were added in the analyses

On the second step, for decay gamma sources in the activated material calculations, the isotope production rates, which were resulting from the MCNPX calculations, were fed into 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. Operational scenario is the reading from beam line monitors during operation cycle depending on time.

On the third step for simple model, which includes only beam pipe, gammas production spectra in the multi-group structure and gamma power for each time step, according to the operational scenario, were converted to the dose rates by dividing by the area corresponding to the distance from the beam pipe and folding with flux to dose conversion factors. For model with beam tube and tunnel walls dose rates are calculated by feeding back to MCNPX decay gamma spectra and gamma power for each time step.

INSTRUMENTS AND UNCERTAINTIES

Both calculations and measurements involve uncertainties.

Measurement uncertainties include instrument precision, location and timing. There are two types of instruments used for the measurements. Beam losses are measured by ionization chambers – BLM. The BLM precision is about 20%. They are located about 10 cm from the beam line in SCL and 60 cm from the beam line in HEBT. Locations could give, especially for the SCL section about 40% of uncertainty in the instrument reading.

The residual dose rates are measured by hand-held ionization chambers. Their precision is about 15%. Standard measurements are carried out by hand on 30 cm distance from the beam tube. This introduces at least 20% of geometry uncertainty in radial direction. Location for each measurement is not precise in axial direction (along the beam pipe) as well and could vary relatively corresponding BLM location up to 1 m. This introduces one more source of uncertainty, which is difficult to quantify and could be …., because the dose measurement performed near beam tube in BLM vicinity, however only the highest reading is recorded, which could be located up to about 1 m from the BLM position. In other words the measured residual dose rates could not exactly correspond to the loss recorded by BLM. In future studies this problem will be fixed by marking locations for the measurements.

Calculation uncertainties are:

- Geometry representation in calculations. According to the measurements the highest activation in induced in the beam tube. So, in the modelling for each location just beam pipe in represented and influence of adjacent beam equipment is not taking into account
- Uncertainties in material composition
- Assumptions in source representations
- Accuracy in physics model and cross sections data
- Statistical errors in the code

Calculation accuracy for these analyses could be about 30%.

RESULTS

Residual dose rates analyses were performed for two last running cycles: fall 2007 and spring 2008. Calculation performed for fall 2007 operation cycle with five running periods. Eight measurement campaigns were total during operational cycle, about one or two days after the beam termination for each running period, and two additional measurements to monitor cooling down during maintenance person.

For spring 2008 operational cycle only decay calculations after the cycle were compared to the measurements. BLM monitors were set to measure decay gamma radiation in small time increments in the end of the cycle. Due to some inconsistency in the decay rates in the analyses for fall 2007 cycle a set of sensitivity analyses were performed to estimate influence of:

- Different types of steel: S304 vs. S316
- Energy of beam intercepting the pipe: 200MeV, 400MeV, 600MeV, 800MeV, 1000MeV
- Influence of surrounding concrete walls

Analyses for both cycles 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. Calculations were scaled to the measurements and plotted for each location.

Fall 2007

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

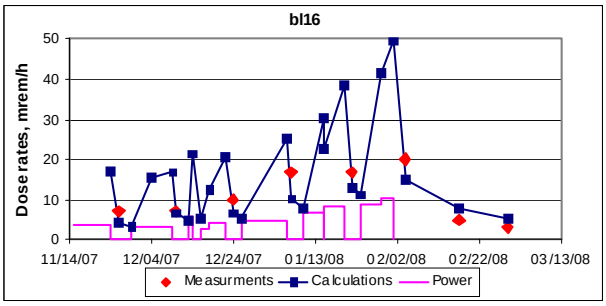

Figure 1. Measured dose rates vs. calculated for blm16 location in SCL section.

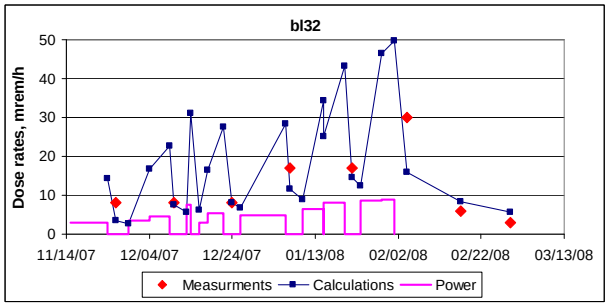

Figure 2. Measured dose rates vs. calculated for blm32 location in SCL section.

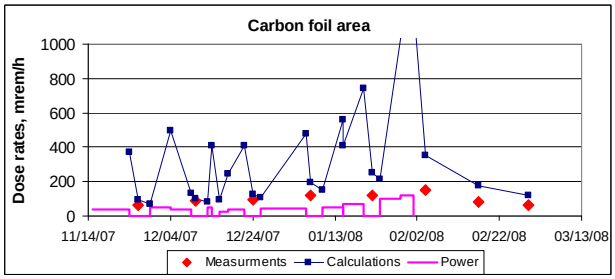

Figure 3. Measured dose rates vs. calculated for blm A11 location in HEBT injection section near carbon foil.

Analyses of the results show that measurements have slightly faster decay in the SCL section, which could be due to surrounding structures and material uncertainties in calculation model and time delay between taking measurements and recording them.

Fall 2007

Figures 4 to 6 show results from the residual dose analyses vs. measurements after the end of the spring 2008 running cycle. Only decay measurements are compared to calculations and only for one location – cryomodule 32.

Comparisons show that for about two first days after beam termination measured decay is faster, than calculated decay.

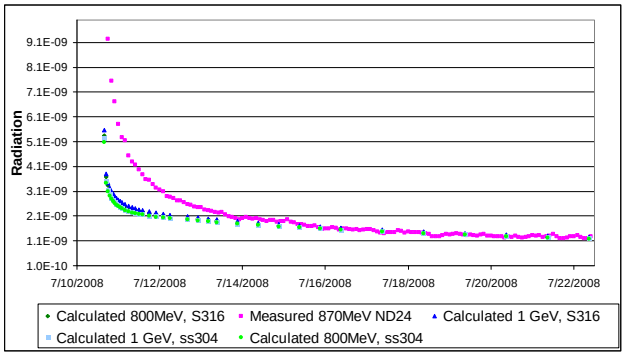

Figure 4. Measured dose rates vs. calculated for beam pipe from ss304 and ss315 for 800MeV and 1GeV beam.

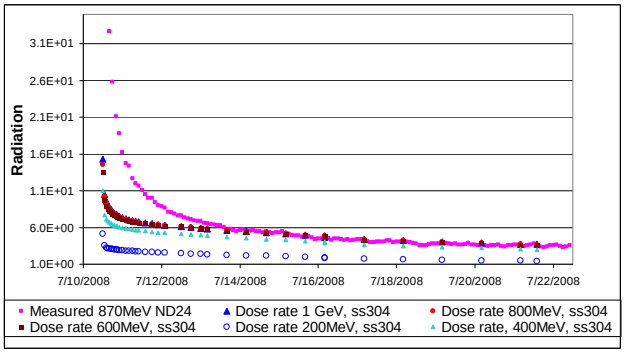

Figure 5.Comparison of the dose rates due to beam with vary energy.

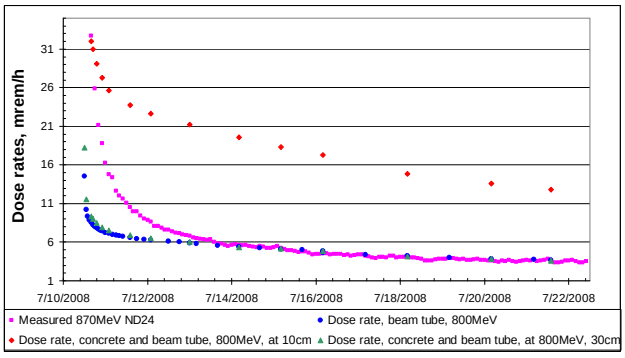

Figure 6. Measured dose rates vs. calculated for geometry with concrete wall and without concrete walls due to beam with 800MeV.

Range of analyses was performed to understand nature of this disagreement. Calculations show that decay rate almost no sensitive to beam tube steel change from ss316 to ss304. Difference is about couple percents. For beam energy from 600MeV to beam energy 1GeV, residual dose rate are very slightly sensitive. The biggest influence has taking into account accelerator tunnel concrete wall. However this influence is noticeable only in first 5 hours after beam termination.

CONCLUSIONS

MCNPX followed by newly developed activation calculation script with CINDER'90 was used to calculate residual dose rates for two locations in SCL and one location in HEBT. Obtained simulations data was compared to the performed measurements and appeared to be generally in a good agreement about two days after the end of the running cycle, especially taking into account a large number of uncertainties. Upcoming efforts will be made to understand the nature of faster decay in the measurements vs. calculations in the first two days.

REFERENCES

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[3] 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 Environmment 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.