RESIDUAL DOSE RATE ANALYSES FOR THE SNS ACCELERATOR FACILITY

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Abstract

The Spallation Neutron Source accelerator is a neutron scattering facility for materials research that recently started operations and presently is in the process of power ramp-up to reach mega-watt power level within a year in cycles of operations and maintenance and tuning periods. The structural materials inside the accelerator tunnel are activated by protons beam losses and by secondary particles. Secondary particles appear due to spallation reactions caused by the proton losses, and produce the residual radiation after shut down in the tunnel environment. 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 to calculate expected residual dose rates after shut down. Calculation analyses are performed using the transport code MCNPX followed by the activation calculation script, which uses the nuclear inventory code CINDER'90, then converting gammas production spectra and gamma power to the dose rates. Calculated results for various locations are compared with measured data.

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.

In order to limit the activation level in the accelerator and proton beam tunnel, the SNS accelerator 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.

In order to plan maintenance work after each operations 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 and then used as a source to calculate expected residual dose rates after shut down. Analyses were performed using the transport code MCNPX [2] and the newly developed activation calculation script in combination with CINDER'90 [3]. Calculation results were compared with measured data for three locations in superconducting LINAC (SCL) and in the ring section near stripping foil, where the highest residual dose rates are measured.

METHODS

Analyses for residual dose calculations were performed in 3 steps. On the first step, reaction rates in the accelerator structures were calculated applying MCNPX, which simulates the generation of secondary radiation fields due to the impact of proton beams with accelerator beam line structures.

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

The material activation is caused by proton losses in the beam pipe, which were considered to be the sources for the analyses. The proton 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. The source definition methodology was the same as in previous studies [4, 5] for the dose rate analyses in accelerator structures vicinity.

On the second step, for decay gamma sources in the activated material calculations, the activation script as

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interface between MCNPX and CINDER'90 reads the isotope production rates and neutron fluxes, which were resulting from the MCNPX calculations. This script also executes the CINDER'90 code to obtain the time dependence of the isotope buildup and decay including decay gamma spectra for given locations according to the provided operational scenario. The operational scenario is provided from BLM readings taken during operation cycle.

On the third step 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.

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 modeling 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

Calculations were scaled to the measurements and plotted for each location. There were 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 maintenance period. Calculation analyses 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 I to III 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 behavior in time, it just gives better visual reading.

The curves slop for measurements and calculations are overall in a good agreement, taking into account all the uncertainties. Measurements show 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..

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 especially taking into account a large number of uncertainties.

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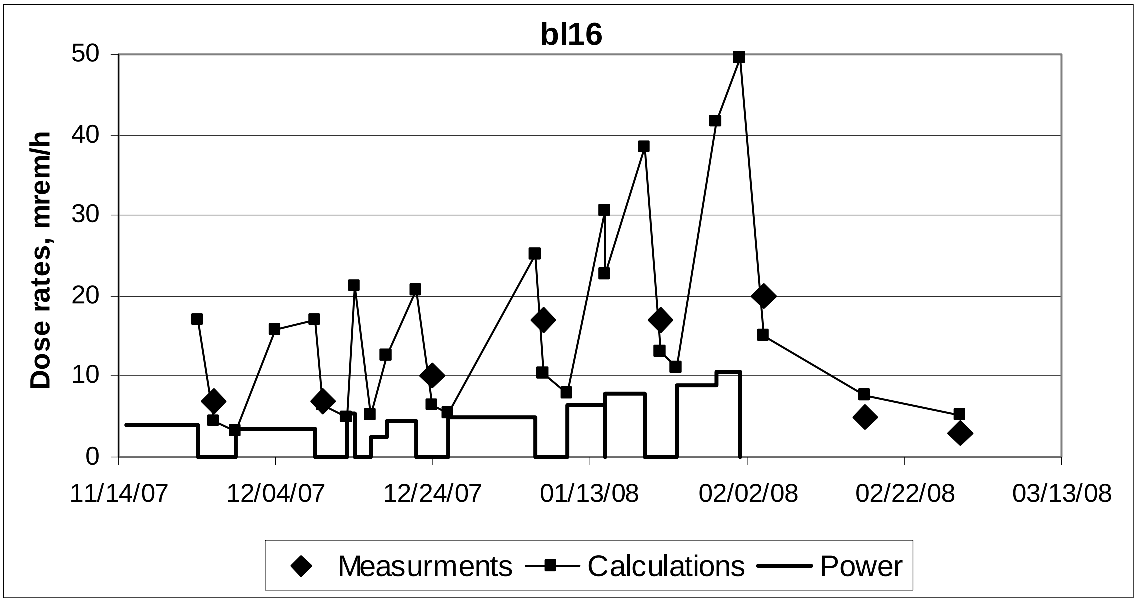

Figure 1: Measured dose rates vs. calculated for blm16 location in SCL section.

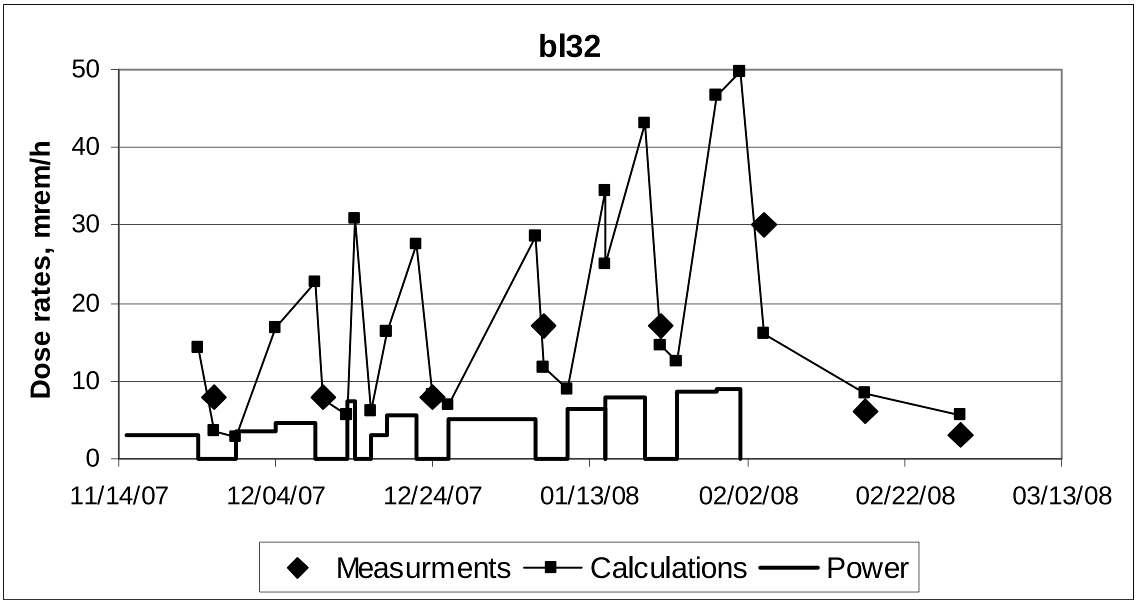

Figure 2:. Measured dose rates vs. calculated for blm32 location in SCL section.

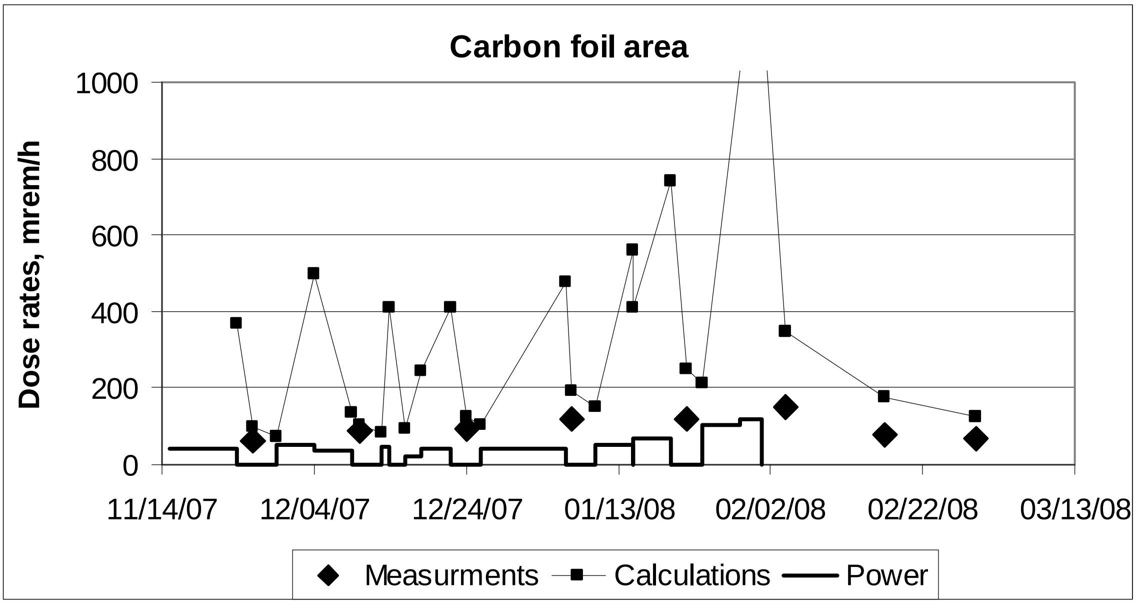

Figure 3: Measured dose rates vs. calculated for blm A11 location in HEBT injection section near carbon foil.

Table 1: Beam Energies for Various Locations

Location	After cryomodule 2	After cryomodule 16	After cryomodule 32	After stripping foil
Beam lost monitor	scl02c	scl16b	scl32b	ring_A11c
Beam energy	210	660	945	945