ANALYSES OF THE DOSE RATES DUE TO ACTIVATED MATERIALS IN THE COLLIMATOR SECTION OF THE SNS ACCUMULATOR RING

I. Popova
Spallation Neutron Source Project
Oak Ridge National Laboratory
701 Scarboro Road, RM-369
Oak Ridge, TN 37830
(865) 241 5281
irt@ornl.gov

SUMMARY
The highest controlled losses along the proton beam line in the Spallation Neutron Source appear in the collimator straight section of the accumulation ring tunnel. The structural materials are activated by these protons and by secondary particles, which appear due to spallation reactions caused by the proton losses, and produce the residual radiation after shut down in the tunnel environment. The dose rates at 30-cm distance from the beam line components due to residual radiation from the structural materials of those components and from the tunnel concrete walls were analyzed in the collimator section of the accumulator ring tunnel. The analyses show that the collimator straight tunnel is an area with high dose levels with up to 14-rem/h after 30 years of operation and 1 hour following shut down.

I. INTRODUCTION

The Spallation Neutron Source[1] (SNS) accumulator ring is a 248-meter circumference ring into which a 1-GeV and 2-mA proton beam is injected, accumulated through nominally a thousand turns, and then extracted to the Hg target station.[2] The accumulator ring consists of four straight sections: the injection section, the collimator section with a series of collimators, the extraction section and the bunching section. These are connected with 90-degree curved sections. The collimator section is designed to strip the halo from the beam, which therefore generates a high radiation area (the controlled losses in this section are the highest in the accelerator tunnel system). Photons, neutrons and other secondary particles appear due to the spallation reactions initiated by the proton beam halo interacting with the components along the proton beam line. During operations those particles are activating the structural materials and the tunnel walls. After shut down the activated materials become the source of radiation. The purpose of the present analyses is to estimate the dose rates at 30-cm distance from components in the collimator section due to the residual radiation from the structural materials and from the concrete walls of the tunnel.

Four operational scenarios (cases) have been considered for residual dose analyses:

1. 137 hours of continuous operation, then shut down for maintenance;
2. 9 weeks of continuous operation, then shut down for the target change,
3. 21 week of continuous operation, then shut down for a long break twice per year;
4. 30 years of continuous operation, (the facility lifetime).

Each case includes analyses for different decay times after shut down: 1 hour, 4 hours, 1 day, 1 week, and for the last case – 1 month.

The dose rates during the operation were calculated as well.

II. CALCULATION MODEL

The geometry model for the accumulation ring in the MCNPX[3] input language was developed for earlier studies,[4,5] where the beam line structures were described rigorously, and was adapted for the present analyses. The same geometry used for the prompt radiation calculations was used for residual dose calculations. The model consists of the 30-meter-long collimator section and both adjacent curved sections, which are 32 meters long each (Fig. 1). The model includes the 70-cm-thick tunnel walls surrounded by the soil. The ring tunnel is 5.5 m high and 5.2 m wide. The center of the proton beam line is located 177 cm from the inner sidewalls and 127 cm from the floor. The beam passes through the steel vacuum tube with inside radius 9 cm and thickness 1 cm through the whole configuration.

The straight collimator section houses a scraper/collimator, first doublet, second collimator, second doublet and third collimator (Fig. 1). Each doublet consists of two quadrupoles and a corrector magnet. All components in the straight collimator section are modeled explicitly and consecutively along the proton beam line.

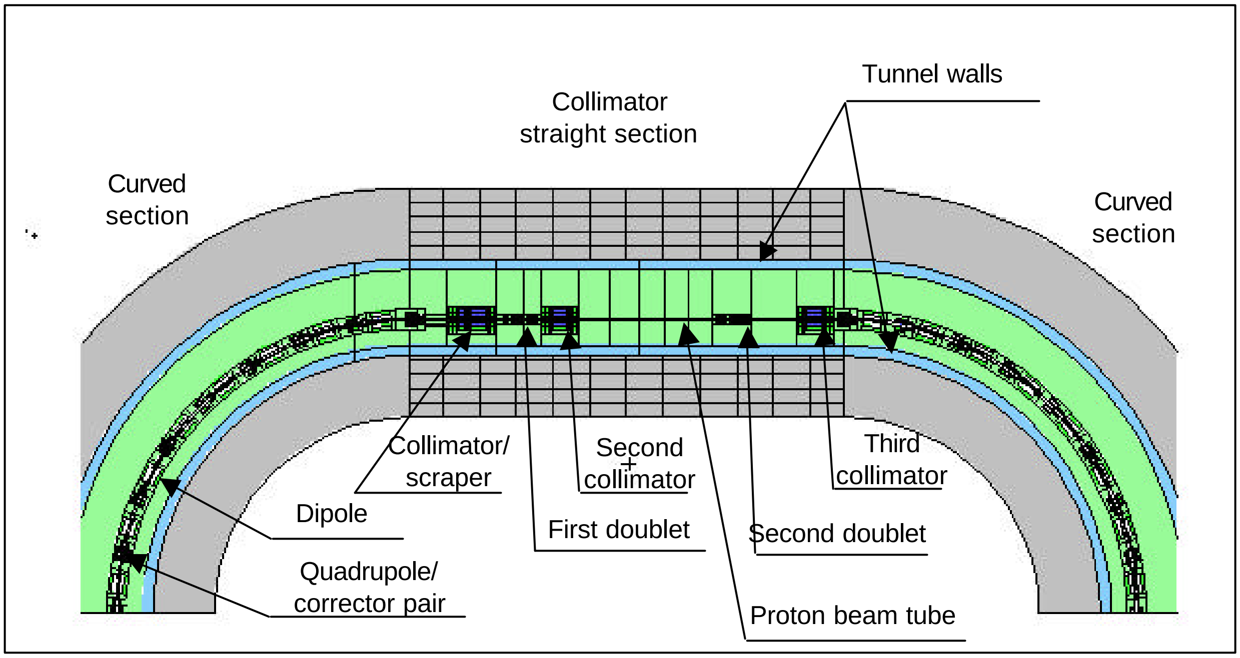


Fig. 1. MCNPX model of collimator straight section with two curved sections.

There are 8 dipoles and 9 quadrupole/corrector pairs lined up in each curved section of the beam tunnel (Fig. 1). This equipment has been modeled using the MCNPX repeated structure capability, which allows us to describe each component in detail only once, and then to rotate and shift the component multiple times to the correct geometry locations.

III. METHODS

The prompt dose rates in the collimator section of the accumulator ring were calculated entirely with the MCNPX Monte Carlo multi-particle transport code. The proton beam loss characteristics are defined by the SNS beam loss document[6] and are shown in Fig. 2. Blue bars describe losses in the collimators; red bars describe losses in the doublets and in the beam tube. The uncontrolled losses of 1 watt/meter were assumed to appear in both curved sections. All the losses were modeled with the standard MCNPX input cards. The proton beam losses were described as a continuous set of cylindrical surface sources with 9.1-cm radius located inside the beam tube, with uniformly distributed 1 GeV 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. The source intensity in each cylindrical surface source corresponds to the integral beam losses in the specified component.

Volume flux tallies, combined with the flux-to-dose energy-depended conversion coefficients from the HILO library[7] with 83-neutron groups, have been applied to obtain neutron and gamma doses. Each volume detector is modeled as a 1-cm thick cylinder, located around each piece of equipment, at a distance of 30-cm. There are 2 detectors in the area around first doublet, five detectors around the beam tube between the second collimator and second doublet, and one detector around each of the remaining elements comprising the collimator straight section (Fig. 3).

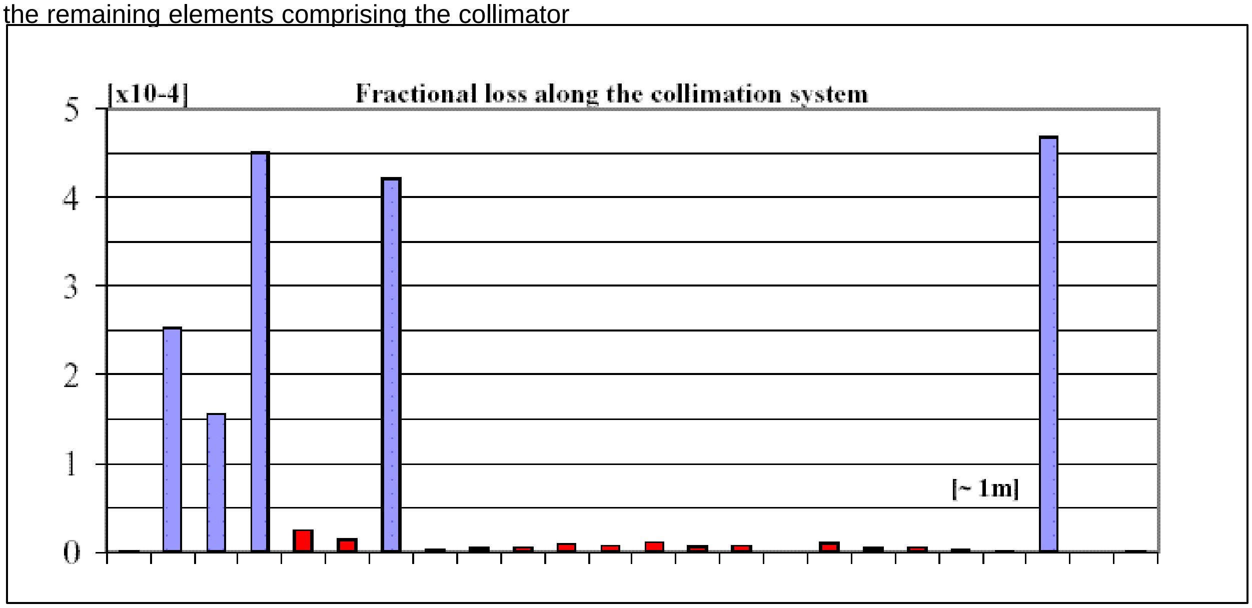


Fig. 2. Loss distribution along the collimator straight section. The data are fractional loss assuming a total loss $1.9 \cdot 10^{-3}$ from the full beam.

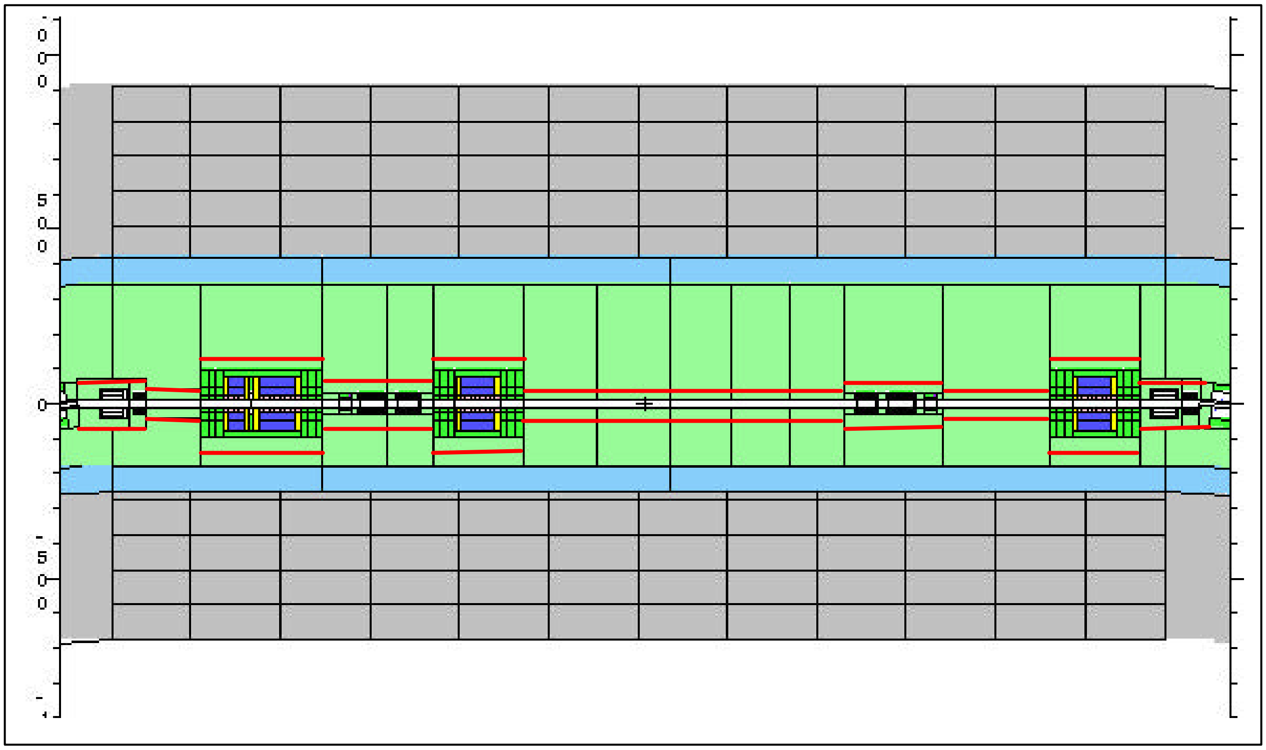


Fig. 3. Position of detectors for tallying of the dose rates (red lines) in the collimator straight air tunnel.

The residual dose calculation requires the knowledge of the decay gamma sources in the activated materials after specified hours following shut down. The sources are obtained by performing buildup and decay calculations on the basis of isotope production rates during operation. The MCNPX code is used to perform the particle transport and to obtain this information.

Solving this complex task involves using different codes and data libraries. The analyses of dose rate due to residual activation of materials in the collimator section of accumulator ring have been performed in three steps. In the first step, the fluxes below 20 MeV and reaction rates above 20 MeV in each cell of the section components were calculated using the Monte Carlo code MCNPX. The same geometry model used for the prompt radiation calculations has been used here except that some thick cells such as the front and end collimator shields and the concrete walls were subdivided into a few thinner cells to obtain a more detailed activation profile.

For the second step, the Activation Analyses System[8] (AAS), which includes the ORIHET95[9] isotope production and depletion module, has been used. This system reads neutron fluxes below 20 MeV from MCNPX calculation and folds them with the FENDL-based neutron production-rate cross sections for each nuclide in each material. Then the low-energy nuclide production rates are combined with the high-energy production rates from the MCNPX calculation to obtain the total production rates for a large number of resulting nuclides in each cell. These total production rates are then fed into the ORIHET code. The ORIHET code uses these total production rates, as well as internal decay constants, for the final ORIHET buildup/decay calculations. This code produces isotope concentration tables and other data tables including gamma spectra and gamma power in the multi-group structure of the DABL69 and HILO libraries.

In the third step the gamma production spectra in the multi-group structure of the DABL69 library and gamma power were extracted from the ORIHET outputs for each cell and formatted into source descriptions in the MCNPX input language. Due to the geometry complexity and some restrictions in the MCNPX source language (the MCNPX general source card allows 999 distribution functions to be used) the calculation for each case and for each decay time has been divided into seven independent calculations with the following components as decay gamma sources:

1. Collimator/scraper;
2. First doublet;
3. Second collimator;
4. Second doublet;
5. Beam tube between second and third collimator;
6. Third collimator;
7. Concrete walls.

Nevertheless, performing the residual dose calculation due to each component separately gives the added benefit of determining the influence of the different structures on the final residual dose.

IV. RESULTS

The prompt radiation in the collimator straight section is shown in the Fig. 4. The red line describes the neutron doses; the blue line describes the gamma doses. The collimator locations are marked by the gray shaded area.

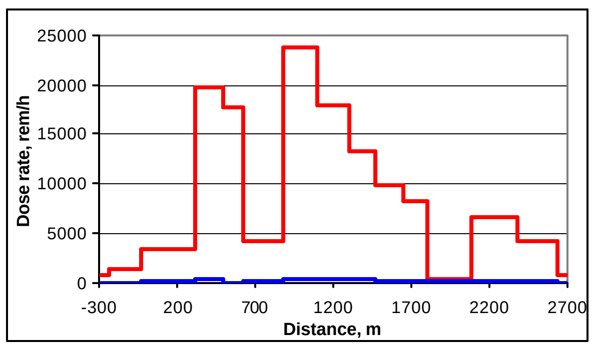
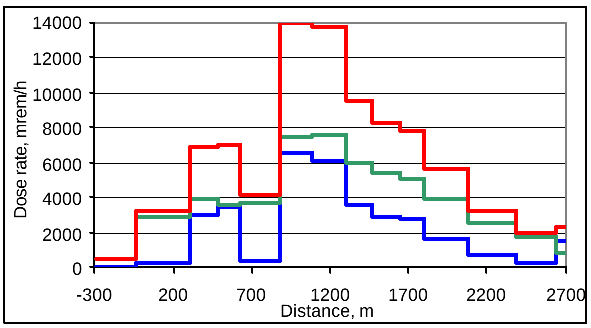


Fig. 4. Operational dose rates in the collimator straight section.

Although the highest proton losses are located in the collimators, the highest dose rates show up in the areas downstream of the collimators. The collimators are heavily shielded but more effectively in the radial direction than in the axial direction. Hence, there is a high probability of protons and secondary particles leaking out through the beam tube opening since the particle distributions are forward directed. The losses in the beam tube after the second collimator are smaller than in the collimators but the beam tube does not provide any shielding.

The residual dose distribution along the beam line at 30-cm distance from the equipment shows a profile similar to the operational dose rate profile in the sense that there is an increase of the dose levels directly after the collimators. Figure 5 shows the residual dose distribution 1-hour after shut down from both the concrete wall and the equipment for the worst case - after 30-years of operation. The area with the highest dose is located around the beam tube after the second collimator.

The residual dose rate from the activated concrete walls is a significant part of the total dose.



equipment; concrete walls; both

Fig. 5. Residual dose distribution after 30 years operation and 1 hour decay at 30-cm distance from the beam line structures.

Additionally, the concrete walls are the largest sources of decay gammas, even relative to the decay gammas from the beam line structures, for the case of 30 years operation. However, the dose rates from the concrete walls drop more rapidly than that from beam line components (Fig. 6) after shut down.

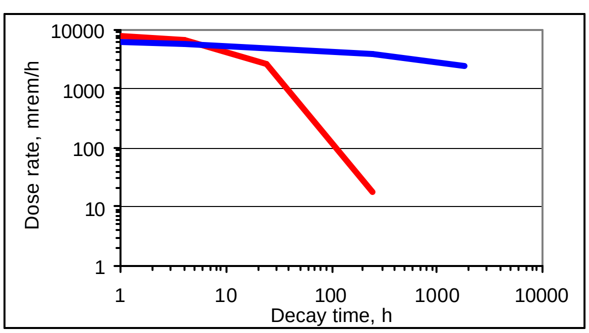
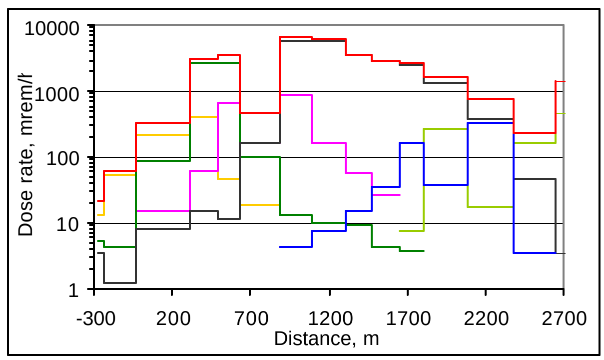


Fig. 6. Dose rate from concrete ( ) and from equipment ( ) during decay time downstream of the second collimator.

Mostly Na^{24}, AL^{28}, K^{42}, Ca^{49}, N^{13} and some N^{16} cause the concrete residual activation. Those isotopes have relatively short half-lives, which explains the rapid decrease of residual dose rates from the concrete walls. The activation analyses show that the concrete isotopes reach equilibrium after about 150 hours of operation. Therefore, only one case, which is 9 weeks continuos operation, was analyzed.

The materials comprising the doublets and collimators are generally steel and copper. These materials produce significant amounts of long living isotopes such as Mn^{54}, V^{48}, Co^{56} and etc., during the activation, which explains the slow decrease of the residual dose rates.

The analyses of the dose rates from the components shows that the biggest dose rates come from the beam tube between the first and second collimator (Fig.7).



Collimator/scraper; First doublet;
Second collimator; Second doublet;
Beam tube between second and third collimator;
Third collimator; Total dose from components

Fig. 7. Influence of activated components to the residual dose rates from all components at 30-cm distance from the beam line structures.

The dose rates due to equipment residual material are increasing with operational time (Fig. 8).

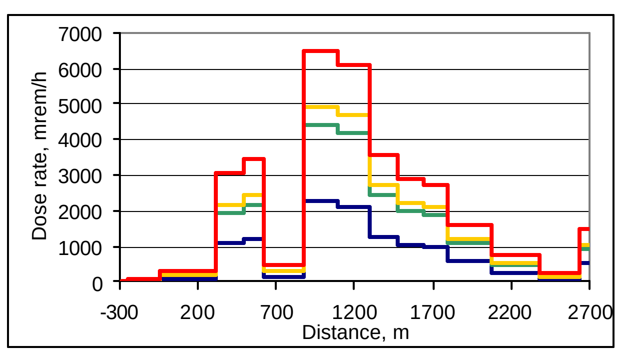


Fig. 8. Residual dose rates from beam line components for different scenarios and 1 hour following decay at 30-cm distance from the beam line structures.

The blue line is for 1-week operation, the green line is for nine-week operation, the yellow line is for 1-year operation and the red line is for 30 years operation.

V. CONCLUSIONS

The operational and residual dose rates were calculated at 30-cm distance from the beam line components in the collimator section of the SNS accumulator ring tunnel. Residual dose calculations were performed in three steps using the Monte Carlo code MCNPX for the fluxes, reaction rates above 20 MeV and dose rate calculations, and the AAS for activation analyses to obtain decay gamma sources from the activated materials.

The analyses show that the collimator straight tunnel is an area with high dose levels even after shut down. The hottest spot in the tunnel is down stream of the second collimator – first four meters of the beam tube – with radiation level up to 9.5 rem/h, 11.5 rem/h, 12.5 rem/h and 14.0 rem/h corresponding to 137 hours, 9 week, 21 weeks and 30 years of operation, and 1 hour following shut down. In the first 7 - 10 hours after shut down the dose rate from the concrete walls is a significant part of the total dose. Later, the main contributors are the activated beam line components.

According to obtained results for operational and residual dose rates, the collimator straight section of the accumulator ring is a hazard area from the radiation-protection point of view. This area will be declared as an area with restricted access and accordingly closed off. In case of emergency, the access for maintenance personnel, which are radiation worker trained, will be allowed only after 100 hours following shut down.

ACKNOWLEDGMENTS

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