PRELIMINARY ESTIMATES OF DOSE AND RESIDUAL ACTIVATION OF SELECTED COMPONENTS IN RING COLLIMATION STRAIGHT OF THE SNS*

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Abstract

The highest doses to components in the SNS ring are expected to be to those located in the collimation straight section. In this paper we present estimated doses to magnets and cable located between collimators. In addition the buildup of relatively long half-life radioactive isotopes is estimated, following machine operation and shutdown. Finally, the potential dose to operators approaching the machine following operation and shutdown for four hours is made. The results indicate that selected components might require replacement after several years of full power operation. In addition, the reflection of gamma-rays from the tunnel walls contribute a non-negligible amount to the dose of an operator in the tunnel following machine shutdown.

1 INTRODUCTION

In this paper an estimate of the dose to magnet windings and cables located in the collimation straight of the ring will be made. In addition, the residual activation of the tunnel and collimator cooling water immediately following machine shutdown will be made. The estimate of activation will be made primarily to determine the concentration of tritium. Finally, an estimate of the residual dose in the vicinity of the first doublet, following machine shutdown for a period of 4 hours following machine shutdown will be made.

In all the above estimates the machine is assumed to operate at an average power of 2 MW, with a proton energy of 1 GeV, and a loss of 0.001. In the case of the dose estimates it was assumed that the loss occurs at all three collimator locations i.e. 0.001 at the first, 0.001 at the second, and finally 0.001 at the third. If the loss profile is different the dose components due to losses at the various collimators can be added in different proportions. In the case of the residual activation estimates the loss was simulated only at the first collimator. In these estimates the entire collimation straight will be simulated, including the primary scraper/collimator, the other two collimators, two doublets, two quadru-poles at either end, and one corrector magnet positioned in the most vulnerable position (between the first doublet and the scraper/collimator). Four cable trays are positioned along the inner wall at a variety of elevations above the vacuum chamber. Two tunnel cooling water lines are considered, one along the inside wall of the tunnel, and the second along the outside wall below the crane.

2 METHODS AND MODELING

The above estimates of dose and residual activation are both based on the MCNP family of codes. In the case of the dose estimate the MCNPX [1] code was used. This code uses the combinatorial representation of geometry, in the same way all previous MCNP based codes have used it, and the geometry descriptions are inter-changeable among all codes. However, MCNPX has a high energy transport section available, which allows the same physical phenomena as the LAHET code [2]. The primary proton (1 GeV), and all the resulting secondary particles can be followed, edited and tallied in any desirable manner over the entire energy range of interest.

Due to the need to link to other codes the residual activation estimate was made using the LAHET codes for particles above 20 MeV; and MCNP [3] for particles below 20 MeV. In addition, a suitably modified version of the ORIGEN [4] code was used to estimate the buildup of spallation products during machine operation, and their decay following shutdown. In addition to the variation of radioactivity with time during operation and following shutdown, the ORIGEN code determines the variation with time of the gamma-ray spectrum of the decaying nuclides. These gamma-ray spectra are used as input to a second MCNP calculation, which only considers photons in the source description, and transports these photons through the various ring components. The result of this calculation will be used to determine doses at various positions in the tunnel due to the decay gamma-ray source.

3 DOSE TO MAGNETS DURING MACHINE OPERATION

Dose estimates were carried out for the section of the magnet windings protruding from the magnet frame. Thus there are four cells on each side of a quadru-pole magnet.

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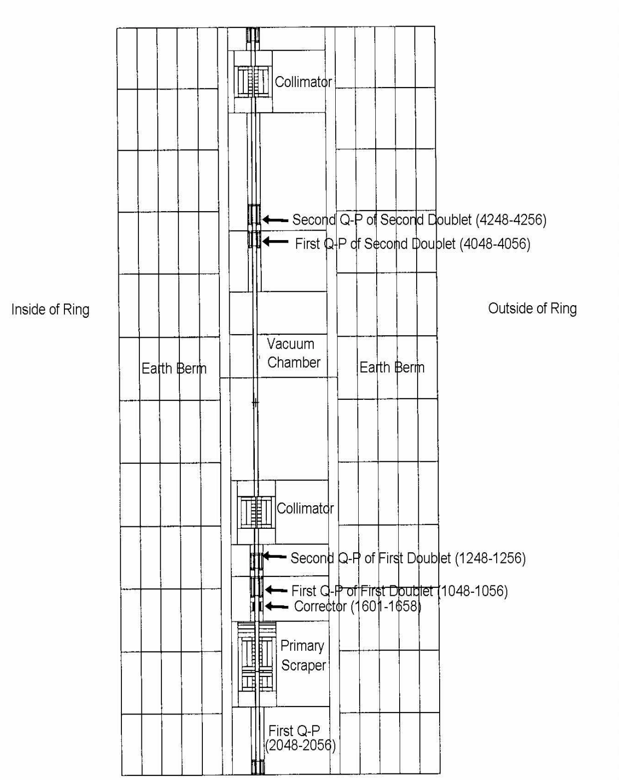
The MCNP model illustrated in the figure below shows the three collimators, two doublets, two quadru-poles and one corrector. The estimated doses for selected magnets is shown on the following table for the loss pattern described above:



Longtitunal Section Along Collimation Straight of Ring at Level of Vacuum Chamber
(Number in parenthesis correspond to magnet cell number used in tables)

Magnet Dose

Cell Number (Figure 1)	Dose (rad/hr)	Remark
2053 - 2056	54	Front** of first quadru-pole
1248 - 1251	5132	Back of second quadru-pole of first doublet
4048 - 4051	240	Back of first quadru-pole of second doublet
1148 - 1151	597	Back of last quadru-pole

* Back refers to direction opposite to beam direction
** Front refers to direction in beam direction

The first quadru-pole experiences a comparatively low dose, approximately 3 rad/hr on the side opposite the collimator, and approximately 50 rad/hr on the side facing the collimator. The corrector magnet volumes experience doses varying from 2000 rad/hr - 4000 rad/hr depending on location, and the attached doublet experience doses between 4000 rad/hr - 5000 rad/hr. This combination experiences the highest dose, since it is comparatively close to the primary scraper/collimator. Cells in the second doublet have doses which are between 150 rad/hr - 250 rad/hr, and finally cells in the last quadru-pole experience doses between 515 rad/hr - 620 rad/hr.

The life expectance of kapton (proposed insulation for the magnet windings) in a radiation field is between $5x10^8$ rad - 10^9 rad, thus at the highest dose rate the magnet insulation should last approximately 10^5 hrs - $2x10^5$ hrs. If it assumed that the machine will operate for three quarters of a year it should be expected that the first doublet will have to be changed at least once in the machine lifetime - assuming a thirty year life.

4 DOSE TO CABLE DURING MACHINE OPERATION

The cable tray is assumed to be located along the inside wall of the ring, at an elevation just above the height of the collimator diameter (1 m above the vacuum chamber centerline). The results show that the dose varies axially along the tunnel, with the highest dose occurring just downstream of the primary scraper/collimator. It was found that the dose varies between 125 rad/hr - 1525 rad/hr. Although this dose is lower than that experienced by the magnet windings, the insulation on cables is generally not as resistant to radiation damage as the insulation on magnet windings. If the insulation can withstand between 10^8 rad - $5x10^8$ rad the cables should last approximately $7x10^4$ hrs - $4x10^5$ hrs. This lifetime estimate would suggest that at least a section of the cable might have to be replaced during the lifetime of the machine.

5 RESIDUAL ACTIVITY FOLLOWING MACHINE SHUTDOWN

An estimate was made of the residual activity immediately following machine shutdown in the collimator and tunnel cooling water. In addition, doses around the first doublet, between the primary scraper/collimator and the secondary collimator were made four hours following machine shutdown. These estimates were made assuming that the losses are confined to the primary scraper/collimator, additional activity due to other losses have not been estimated at this time. However, based on the above results, losses at this location are responsible for a significant fraction of the dose. In all cases it is assumed that the machine operates at full power (2 MW) for 180 days, and then the residual activation is determined immediately following shutdown, 4 hrs later, and at a selection of times beyond that period.

6 COLLIMATOR COOLING WATER

Activation of the cooling water in the four major volumes in the primary collimator was estimated for the operating cycle summarized above. Two of these volumes are situated on either side of the scraper, and thus experience the scattered primary proton and secondary proton and neutron fluxes. The other two volumes are situated at either end of the collimator structure and thus are exposed primarily to neutron fluxes, the protons being stopped by the collimator.

The results show that the cells closest to the scraper have the highest residual activity, which dies off quite rapidly as the shorter lived isotopes decay. Immediately following shutdown the activity is dominated by ^{15}O, ^{16}N, ^{11}C, and ^{12}B, all of which have a short half-life. Following 4 hrs. the dominant nuclides are ^{7}Be, and ^{14}C, in selected cases ^{3}H and ^{10}Be also play a role. ^{3}H is generated in all cells.

7 TUNNEL COOLING WATER

The location of the tunnel cooling water line has not been fixed yet. Thus two locations were investigated for this estimate. In the first case it is assumed that the cooling pipe runs along the inside tunnel wall, at essentially floor level, and in the second case it is assumed the cooling pipe runs along the outside tunnel wall and is suspended approximately 1.5 m below the ceiling. Several cells on either side of the scraper/collimator were used to estimate the activity. The activation products have the same distribution as those of the collimator cooling water. The cooling water line located along the inside wall has an activity significantly higher than the line located along the ceiling.

8 DOSE ESTIMATES FOLLOWING MACHINE SHUTDOWN

An estimate of the dose due to the decay gamma-ray source was made, with and without the moveable shield in place. The shield was orientated parallel to the direction of the beam. Thus, any dose experienced behind the shield must be due to reflection (walls, tunnel air etc.) or off the collimator shield faces.

The results indicate that there is a substantial dose along the vacuum chamber (~200 rem/hr). Introduction of the moveable shields reduces the dose by approximately an order of magnitude closest to the faces of the collimators, and close to a factor of 50 at intermediate locations. It should be noted that the dose closest to the collimator faces is due to the residual activity of the front and back shields surrounding the collimators. However, the dose at significant distances from the collimators is due to reflection off the walls, floor, and ceiling. It is thus essentially impossible to reduce the dose to vanishingly small values, since the accelerator components will always be irradiated, and the resulting gamma-ray source will be reflected from the concrete structures.

9 CONCLUSIONS

The following conclusions can be drawn from this study:

1) The dose received by the magnets comprising the first doublet and associated corrector, and the cable at that location suggest that they will need replacement before the end of the facilities operating life,
2) Cooling water activity is primarily due to ^{7}Be, the production of tritium is several orders of magnitude lower,
3) The dose level in the tunnel following machine shutdown can be reduced by the use of moveable shielding, but refection off the walls determines the lower level of the dose operators will be exposed to, and
4) The results reported in this study are a strong function of the loss profile and may have to be repeated for a more prototypic profile.

REFERENCES

[1] *MCNPX Users Manual - Version 2.1.5,* L.S. Waters, ed., Los Alamos National Laboratory, Los Alamos, NM, TPO-E83-G-UG-X-00001 (1999).

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