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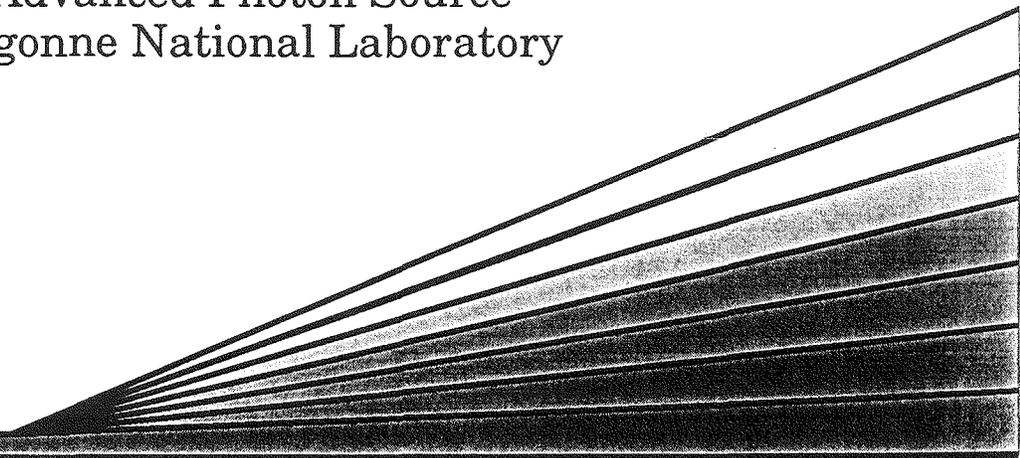
LS-243

Dose Rate Estimates in the First Optical Enclosure due to Particle Beam Loss in the Insertion Device Transition Region during Injection

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May 9, 1995

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Introduction

The particle beam, during injection into the storage ring, can be partly lost in one of the transition regions between the storage-ring vacuum chamber and the insertion-device (ID) straight section [1]. The transition region is a copper interface between a standard aluminum vacuum chamber and an insertion-device vacuum chamber. This can be a problem, at least in the first few insertion devices where the injected beam is still unstable (sectors 1 to 3)[2]. It may create higher photon and neutron dose rates in the first optical enclosures of the upstream ID beamlines adjacent to this region. This report presents the results of the dose rate estimates for such an event and some recommendations for mitigation.

Calculation Method

The photon dose rates due to the particle beam loss in the transition region has been calculated using the EGS4 electron-photon Monte Carlo transport code [3]. The electron-photon cross sections used in the EGS4 program are generated by a pre-processor program called PEGS4. The geometry used for the calculation is shown in figure 1. In this geometry, the copper cone of the transition region is 4 cm thick followed by a region of air of 140 cm. The concrete wall of the storage ring is taken as 80 cm of low-density concrete (density = 2.5 gm/cm^3), which is equivalent to 56 cm of high-density concrete (3.7 gm/cm^3) of the ratchet wall. (This is due to the availability of data for the low-density concrete cross sections). Outside the concrete wall, 30 cm of ICRU tissue [4] is placed with an energy scoring bin size of 1 cm each. The particle

beam is incident on the copper cone at a glancing angle of 7° . The number of particles incident is 1.8×10^{14} /hour, which corresponds to 20% of the beam loss at the transition region during injection at the safety envelope (7.7 GeV, 330 mA). The dose rates calculated in materials do not include the neutron dose because this implementation of EGS4 does not incorporate hadron production in the electromagnetic showers. The results are the average of 10,000 particle histories.

Results and Discussion

Figure 2 gives the dose rate estimates calculated by the EGS4 program in various materials in the configuration. The dose rate is plotted as a function of cell number. A cell is a bin width into which the material thickness is divided for the energy scoring. The number of cells in copper, air, concrete, and tissue are two, six, eight, and fifteen, respectively. This calculation is not able to score energy in the tissue outside the concrete wall. It can be mentioned that the expected dose in tissue is still an order of magnitude smaller than the scale minimum. This problem can be solved in different ways, each with their own disadvantages. Increasing the number of events is one way. A minimum of a few million particle events may partially solve the problem with considerable strain on the computing resources. The method of forward biasing the particles will decrease the reliability of the results. Lowering the AP (the lower cutoff energy for photons to be created) and PCUT (the energy below which the photon history is terminated) values for photons in EGS4 [5] may cause incorrect PEGS4 cross section parameterization below certain energies.

Nevertheless, the photon dose rate estimates can be extrapolated to obtain the dose rates in the FOE. Figure 2 shows that the photon dose rate at the inside face of the ratchet wall is 0.70 Gy/h (70R/h) before passing through the concrete. Taking the attenuation in 56 cm of high-density concrete of attenuation

length 50 g/cm^2 , and correcting for the drop off with increased distance, the photon dose rate in the FOE is calculated as 575 mrem/h, and the corresponding dose/injection for 42 seconds [6] of filling time ($8.3 \times 10^{12} / 0.8 \times 2.5 \times 10^{11}$) is 6.7 mrem.

The neutron dose rates are calculated from the beam power loss in the copper transition region and the neutron production from a thick copper target [7, 8] at 90° to the beam loss. This assumption gives a very conservative estimate of the neutron production. The neutron dose rate in the FOE is calculated taking into account the distance and the attenuation of the neutrons in the 56 cm of concrete ratchet wall for the three different neutron energy intervals (0-25, 25-100, 100-400 MeV). The neutron dose rate in the FOE, corresponding to a 20% loss of injected beam at the safety envelope, is calculated as 676 mrem/h or 7.9 mrem per injection with 42 seconds of filling time.

Table 1 is a summary of the results. The dose rates are given in mrem/h. The numbers corresponding to shielding labelled 'none' are the dose rates in the upstream ID beamline FOE, outside the 56 cm of the concrete ratchet wall due to 20% loss of the injected beam in the transition region during injection. In this case, the duration of injection is 42 seconds, and the dose per injection will be the fraction of the dose rate for the injection time. With no additional shielding, the total dose rate in the FOE is 1251 mrem/h and the dose per injection is 14.6 mrem.

Shielding Optimization

The dose created by a mixed radiation environment, as in this case, requires a multi-shield optimization study. Most high-Z materials can shield gamma radiation effectively, whereas they have little effect on neutrons. The low-Z materials can slow down the neutrons but cannot effectively shield against gammas. Only a carefully optimized multiple shield can minimize the dose.

Table 1. Photon and Neutron Dose Rates in the FOE for a 20% Beam Loss in the Insertion Device Transition Region

Shielding Material	Thickness (cm)	Dose in the FOE (mrem/h)		Total
		Gamma	Neutron	
None (a)	—	575.0	676.0	1251.0
Lead (b)	15 cm	0.6	150.0	150.6
Iron (c)	15 cm	23.6	138.9	162.5
Lead / Iron (d)	5.0 / 10.0 cm	7.0	142.5	149.5
Iron / Poly (e)	15.0 / 5.0 cm	21.9	62.3	84.2
Lead / Poly (f)	15.0 / 5.0 cm	0.6	74.0	74.6
Lead / Iron / Poly (g)	5.0 / 10.0 / 5.0 cm	6.6	63.8	70.4

- (a) 56 cm of concrete (3.7 gm/cm^3).
- (b) Lead followed by 56 cm of concrete.
- (c) Iron followed by 56 cm of concrete.
- (d) Lead, iron followed by 56 cm of concrete.
- (e) Iron, 56 cm of concrete followed by polyethylene (1.01 gm/cm^3).
- (f) Lead, 56 cm of concrete followed by polyethylene.
- (g) Lead, iron, 56 cm concrete followed by polyethylene.

For the present study, we chose three shielding materials, lead, iron, and dense polyethylene (density 1.01 gm/cm^3). Lead is an excellent gamma-radiation absorber, and polyethylene is a good neutron absorber. Iron is low-Z relative to lead and can act as a neutron slowing down agent. In this respect, it is better than polyethylene because of its higher density. The concrete wall is part of the permanent shielding. The maximum attenuation lengths of these materials [9] for neutron and gamma radiation

are given in Table 2. The attenuation lengths for gamma and neutrons of the three energy intervals are given (0-25, 25-100, and 100-400 MeV).

Table 2. Radiation Attenuation Lengths of the Selected Shielding Materials

Shielding Material	Radiation Attenuation Lengths(gm/cm^2)			
	Gamma	Neutrons (MeV)		
		(0-25)	(25-100)	(100-400)
Concrete	50.0	45.0	125.0	125.0
Lead	25.0	161.0	191.0	191.0
Iron	37.0	100.0	138.0	138.0
Polyethylene	70.0	6.3	62.0	62.0

The results of this optimization study are also given in Table 1, where it shows that 15 cm of both lead and iron inside the ratchet wall can bring down the dose rates inside the FOE significantly. A combination of lead and iron shows a further 10% improvement in the shielding performance. In this case, 10 cm of iron also helps to soften the neutron spectrum by elastic scattering. Another possible shielding combination is 5 cm of high density polyethylene ($1.01 \text{ gm}/\text{cm}^3$) with lead and iron, which enhances neutron absorption and reduces the neutron dose in the FOE. This study was limited to a total shield thickness of 20 cm, because of the space limitation between the transition piece and the ratchet wall. The dose per injection corresponding to the best shielding solution for the filling time of 42 seconds is 0.82 mrem.

However, there are several unknown parameters in these calculations. The 20% loss of beam at the ID transition region during injection is one of them. If this is considerably smaller than 20%, the dose rates can be an order of magnitude smaller and vice versa. There is also uncertainty in the high-energy neutron dose rates, which are the dominant factors in the total dose rates in the FOE in the event of a beam loss at the transition region. The

photoneutron production cross section at higher energies (>50 MeV) are not available as a function of energy. The information on neutron transport cross sections above 20 MeV is also not precise. These factors make it difficult to do an accurate neutron slowing down and transport calculation in the shield. The present neutron dose rate results are based on the integral neutron parameters [7].

The photon and neutron dose rates in the FOE of the first few sectors are to be carefully monitored during injection, in the commissioning phase of the ID vacuum chamber. If the dose rates are indeed higher, remedial action can be taken based on one or more of the solutions suggested in this note. A solution acceptable from all points of view, like space conservation, ease of fabrication, and low cost, can be chosen.

References

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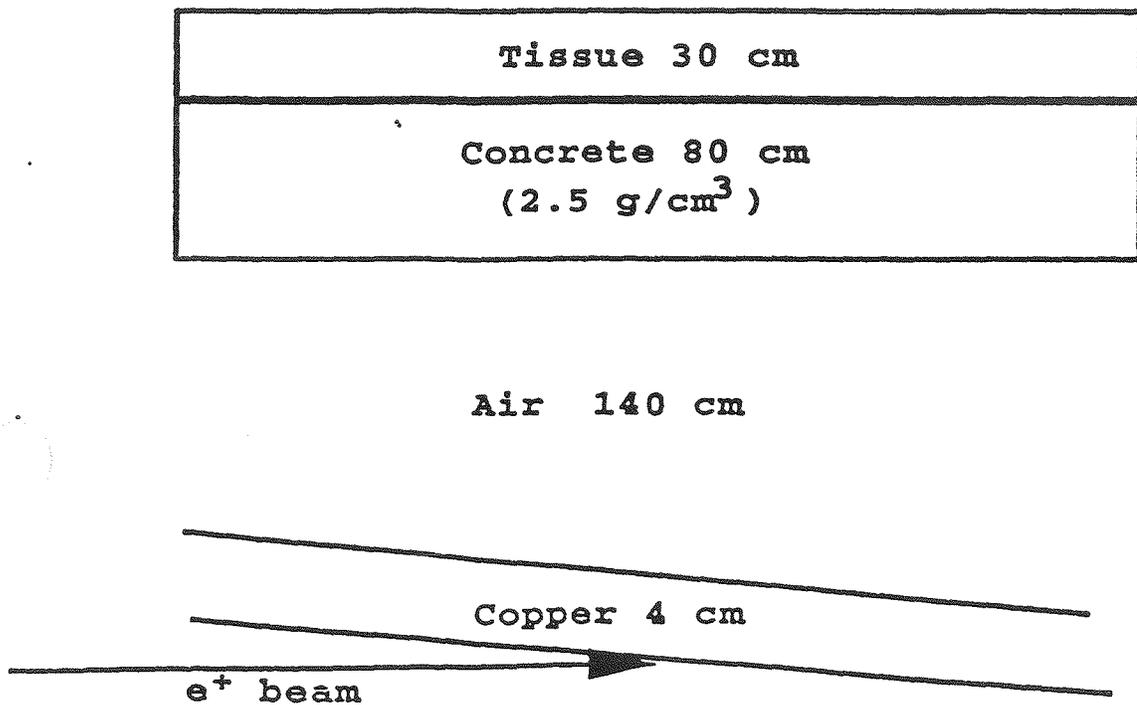


Figure 1. Configuration used for the EGS4 calculation. The positron beam is incident on the copper transition region at an angle of incidence of 7 degrees.

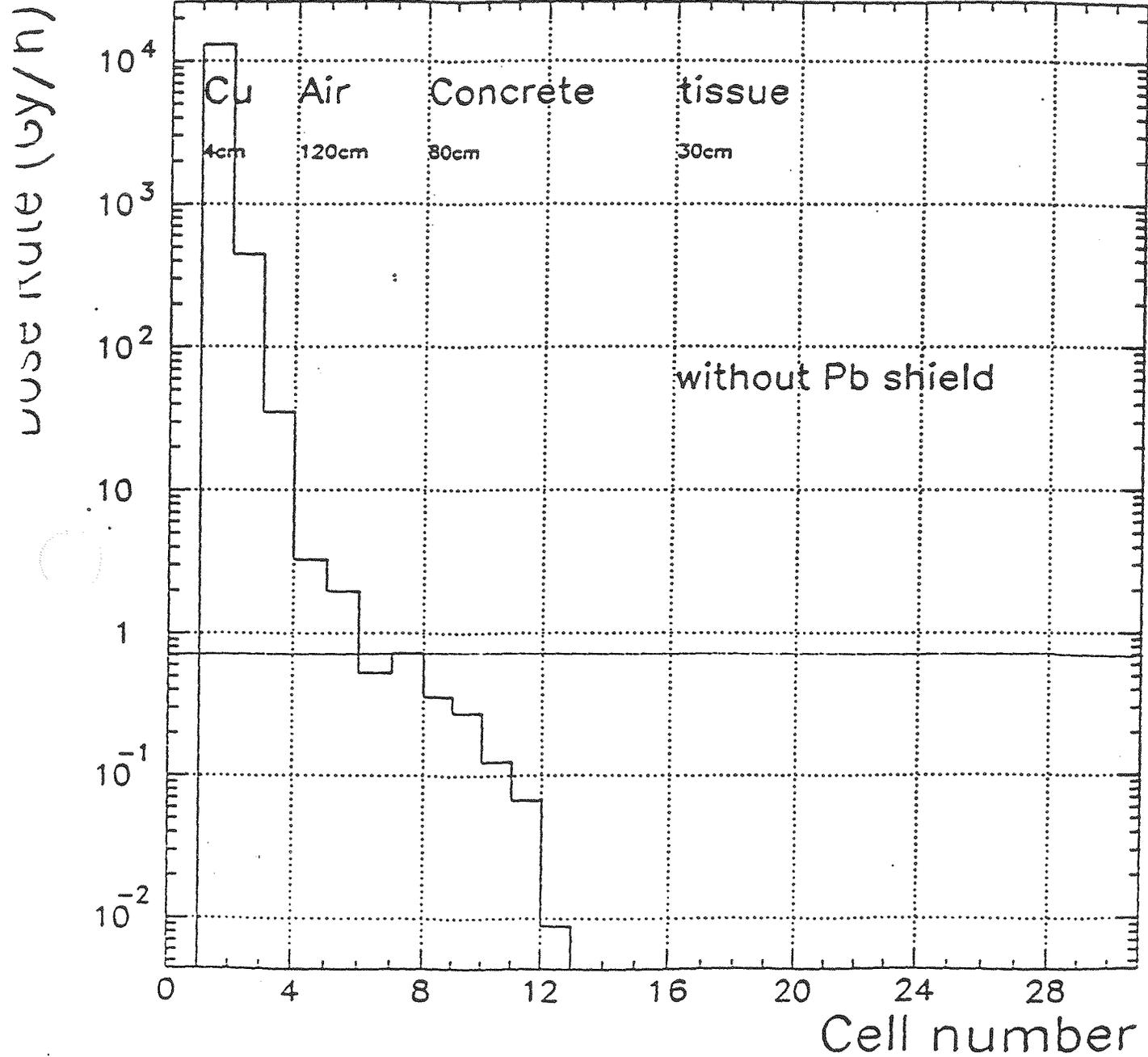


Figure 2. Dose Rates calculated by EGS4 as a function of the material thickness. Beyond cell number 12, the dose rates are unreliable due to poor statistics.