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Radiation shielding of the beam absorber in the MI 8 GeV beam line*

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Abstract

Results of Monte Carlo radiation shielding calculations performed for the beam absorber of the MI 8 GeV beam line are presented and discussed. The possibility to reach the level of 10^{19} protons per year is investigated.

1 Introduction

The beam absorber used in the MI 8 GeV beam line was initially designed to take 3.8×10^{18} protons/year without contaminating the ground water above the EPA allowed limits [1]. At present an upgrade of the absorber is in progress and re-evaluaton of shielding around the absorber is required to estimate the possibility to reach the level of 10^{19} protons/year. We describe results of radiation shielding calculations performed with the MARS15 [2] code for both normal operation and an accident scenario.

2 Geometry Model

The beam absorber is installed at location 833 in the beam line tunnel. Fragments of the three-dimensional calculation model of the tunnel with the beam absorber are shown in Figs. 1 and 2. As for the color scheme employed to denote materials in the model, the following convention applies: blue–air, brown–graphite, gray–concrete, green–soil, pink–iron, white–vacuum. The modified absorber design shown in these Figures includes several improvements to the previous one:

- Extra steel, in the form of a 6-inch slab, was added underneath the absorber and underneath the wedge of steel it sits on.
- The absorber was moved by 6 inches off the wall.

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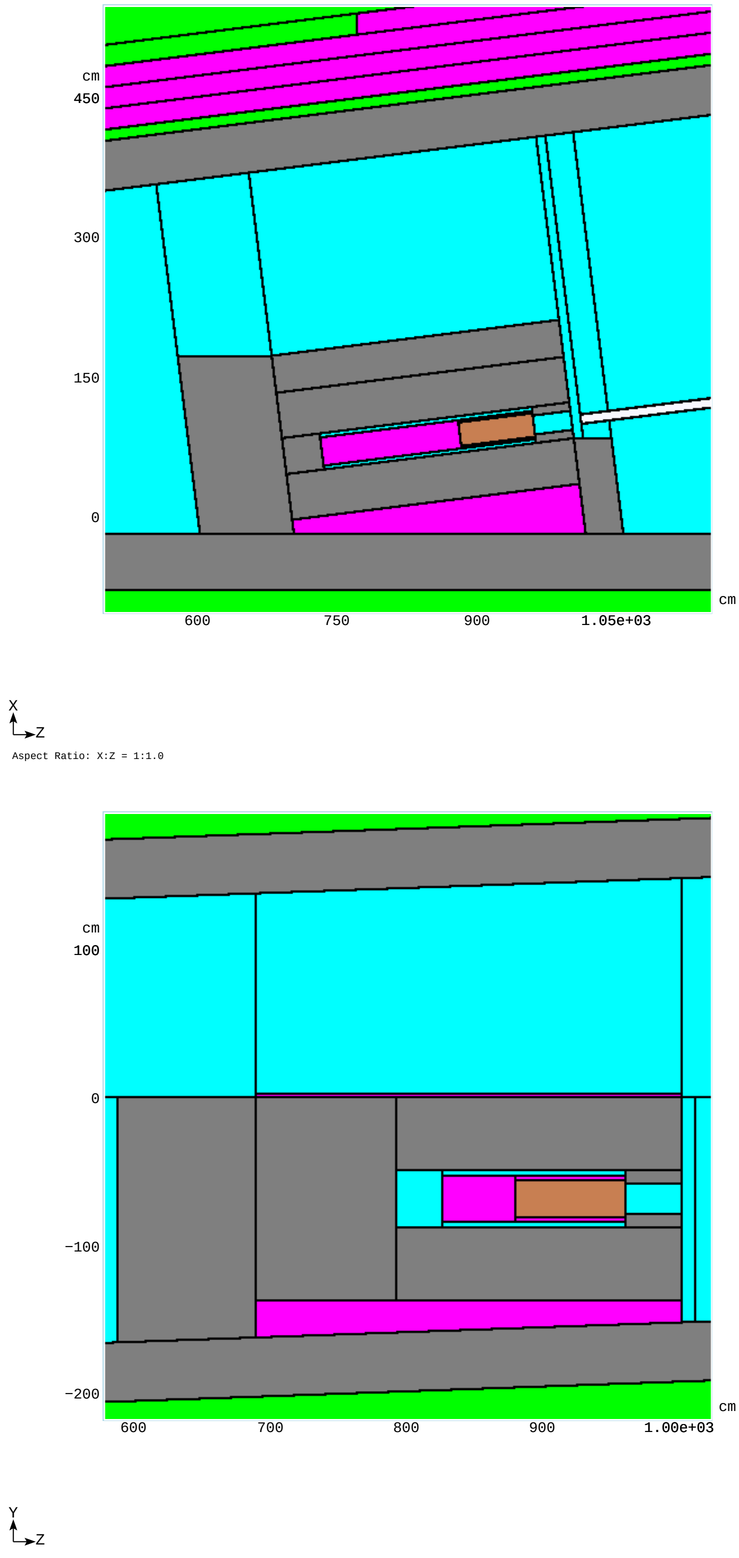

Figure 1: An elevation (top) and plan (bottom) view of the MARS15 geometry model of the beam absorber in the MI 8 GeV beam line.

- Sixteen inches of concrete were added to the top.
- More concrete was added to the downstream end.
- Some concrete was added to the upstream end.
- A one-inch slab of steel was added to the right side (looking downstream).
- The front section of the absorber steel core 32 inches in length was cut away and replaced by a graphite section with the same length.

The absorber is rotated slightly (by 1.88°) off the axis of the tunnel because the incoming beam line is not parallel to the walls of the enclosure (see plan view in Fig. 1). The modifications described above can be implemented without significant additional investments and re-building the absorber as well as are acceptable from operational standpoint.

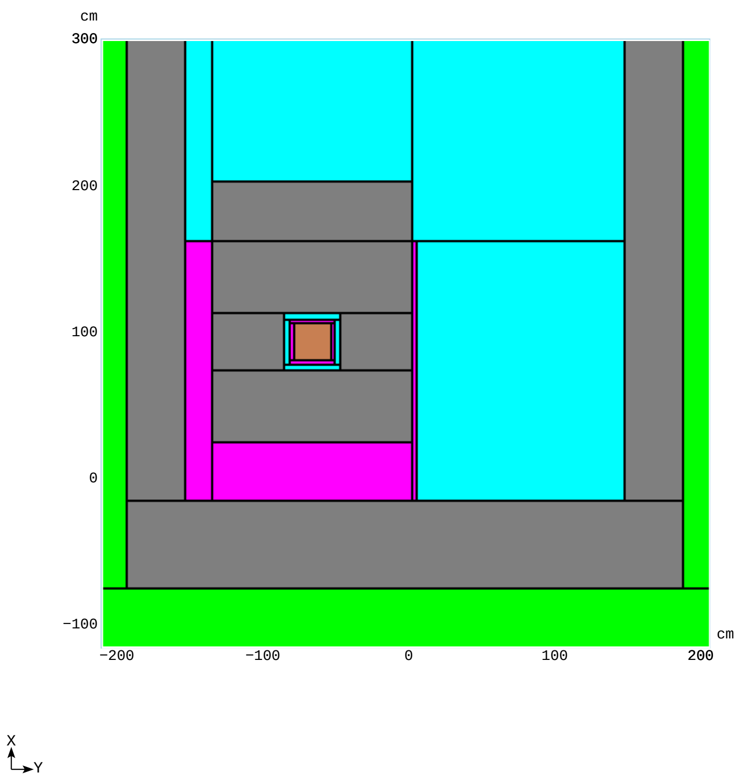

Figure 2: A cross section of the MARS15 geometry model of the beam absorber in the MI 8 GeV beam line.

3 Normal Operation

In this study we address the following two major concerns relevant to normal operation of the MI 8 GeV beam line: soil and ground water activation as well as residual activation of the absorber and tunnel.

3.1 Soil and ground water activation

In order to determine soil and ground water activation usually the Concentration Model is employed [3, 4]. The *highest* star density in the uncontrolled soil and *average* star density over the "99% volume" (*i.e.* volume that contains 99% of all generated stars) [3] are the key quantities to the model. Calculated distributions of star density around the beam absorber and tunnel are shown in Fig. 3.

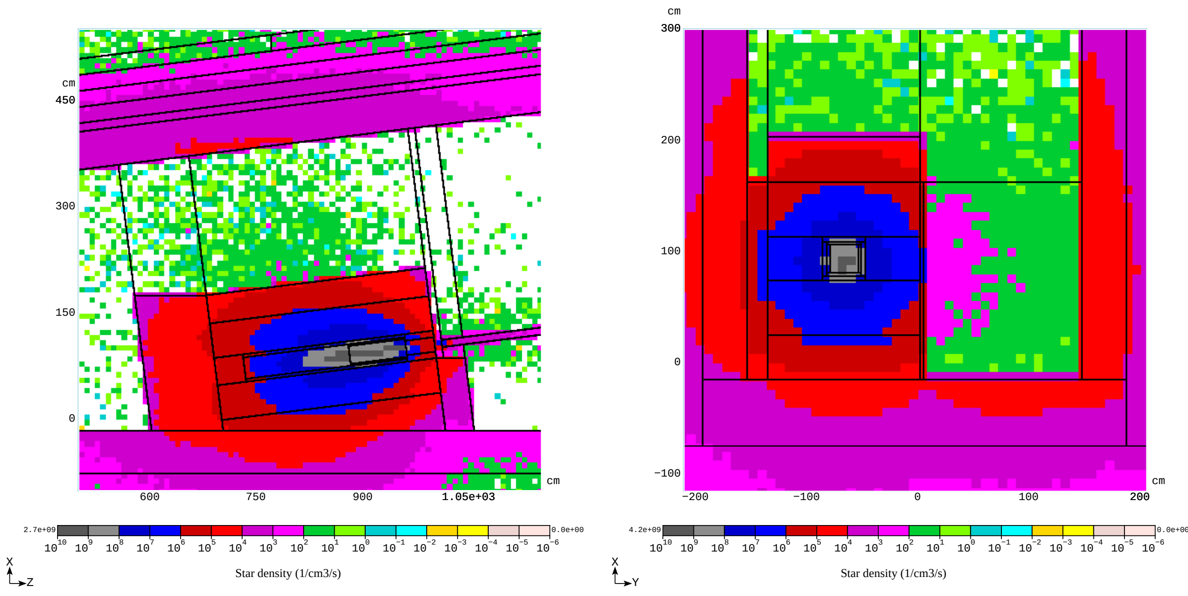

Figure 3: Calculated star density distributions around the beam absorber in the MI 8 GeV beam line. The data are averaged over the vertical slice 12 inches in thickness and going through the absorber steel core (left) and over vertical slice 25 inches in thickness and going through the shower maximum (right). The normalization is per 10^{19} proton/year.

As a result of the calculations, one obtains 6.0×10^{-8} and $2.4 \times 10^{-9} star/(cm^3 proton)$ for the above-mentioned *highest* and *average* star density, respectively. Using the data in the surface water calculation and allowing for a safety margin, one obtains that about 80% of the surface water limit would be reached if 6.8×10^{18} protons per year were directed into the absorber [5]. The effect on the deeper ground water was found to be negligible.

The result indicates that the level of 10^{19} protons per year can not be reached by means of the suggested shielding improvements and, therefore, more essential re-building of the beam absorber is required in order to reach the level.

3.2 Residual activation around the absorber

Handling and maintenance of various beam line components activated due to normal accelerator operation or beam accidents can be extremely difficult. Therefore, correct prediction of their residual activity is of primary importance when planning on various hands-on and maintenance procedures. At Fermilab the policy is to keep residual activation under 100 mrem/hr whenever possible [6] because above this level the handling and maintenance procedures get more complicated. Calculated distributions of residual activity around the beam absorber are shown in Fig. 4.

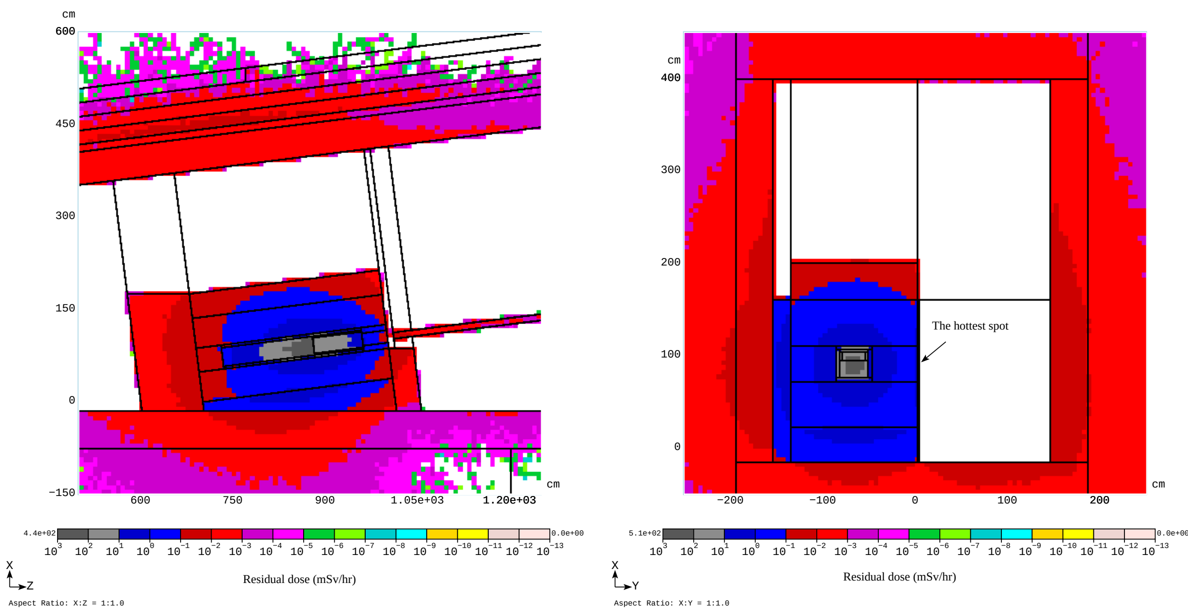

Figure 4: Calculated distributions of residual activation inside the tunnel around the MI-8 beam absorber at standard conditions—after a 30-days irradiation and 1-day cooling. The data are averaged over the vertical slice 12 inches in thickness going through the absorber steel core (left) and over vertical slice 25 inches in thickness going through the shower maximum (right). The normalization is per 10^{19} proton/year.

One can see that the hottest spot on the isle side of the absorber is about 180 mrem/hr and tunnel activation is at most 2.5 mrem/hr. Front and back of the absorber reveal activation of about 5.0 and 0.3 mrem/hr, respectively. As long as we are restricted by the above-mentioned amount of 6.8×10^{18} protons per year, a straightforward scaling down should be applied to the data. Thus, the hottest spot reduces to 122 mrem/hr which is still off the acceptable limit so that some additional cooling is required in this case.

4 Worst Case Accident Scenario

An accident scenario has been investigated to determine the power that the beam absorber can take without the steel absorber core being melted down. In this case the peak amount of protons directed into the absorber for a period of time (typically one hour) significantly exceeds the average amount corresponding to the allowed annual intake of 6.8×10^{18} protons. It is assumed that in the worst case accident the beam will be dumped into the absorber for about an hour at the repetiton rate of 10 Hz and with 6.0×10^{12} protons per pulse. In other words, this scenario means that for the same period of time the amount of dumped protons is increased approximately by a factor of 280 when compared to the average amount corresponding to the allowed annual intake of 6.8×10^{18} protons.

As a result of coupled MARS-ANSYS initial calculations it was found that, in this scenario, due to the energy deposition the temperature of the front section of the pure steel absorber core (*i.e.* without any graphite) reaches the melting point (about 1000 degrees C) approximately in 30 minutes [7]. It was assumed in the two-dimensional ANSYS calculations that the energy deposition is distributed uniformly along the beam direction which, in reality, is not the case. According to the MARS calculations, in the steel absorber core the energy is deposited mostly along the first 20 inches and power density at the depth of 20 inches in the core is about 10% of that at the depth of 0. Taking into account the non-uniform energy distribution, we estimate that the steel core will survive for about 10 minutes.

In order to mitigate the problem, the effect of the front graphite insert was studied (see Fig. 1). The purpose of using the insert is to intercept a part of the deposited energy. Graphite has very high melting temperature—about 4000 degrees C—and, due to lower material density when compared to steel, gives rise to increased particle outscattering off the steel core. The results of the calculations are given in Table 1.

Table 1: Power (W) deposited in the steel absorber core and graphite insert calculated with the MARS15 code for several lengths of the graphite insert. The normalization is per 10^{19} proton/year.

Graphite length (inch)	0	16	32	48
Graphite insert	0	33	72	105
Steel absorber core	228	184	118	65
Total	228	217	190	170

In final design the graphite insert 32 inches in length was chosen (see Fig. 1). In this case the reduction in energy deposited in the steel core is within a factor of two and, according to the two-dimensional ANSYS calculations with uniform energy distribution (see Fig. 5), the steel melting temperature will be reached in the core in about an hour [7]. However, taking into account the above-mentioned realistic longitudinal distribution of the energy deposited in the core, we estimate that the survival time for the steel core will be about 20 minutes. The estimate is not beyond debate due to various uncertainties involved in the studies. In particular, it is assumed that there is no heat transfer between the steel core and surrounding concrete and front graphite insert as well. In other words, the heat transfer calculations with ANSYS were performed only within the volume of the steel core which gives rise to an overestimate of the temperature. In order to mitigate the steel core overheating problem, the beam can be swept over the absorber face to increase the spot size and, therefore, reduce the power density. Another option is using an additional graphite insert in front part of the absorber (see Fig. 1).

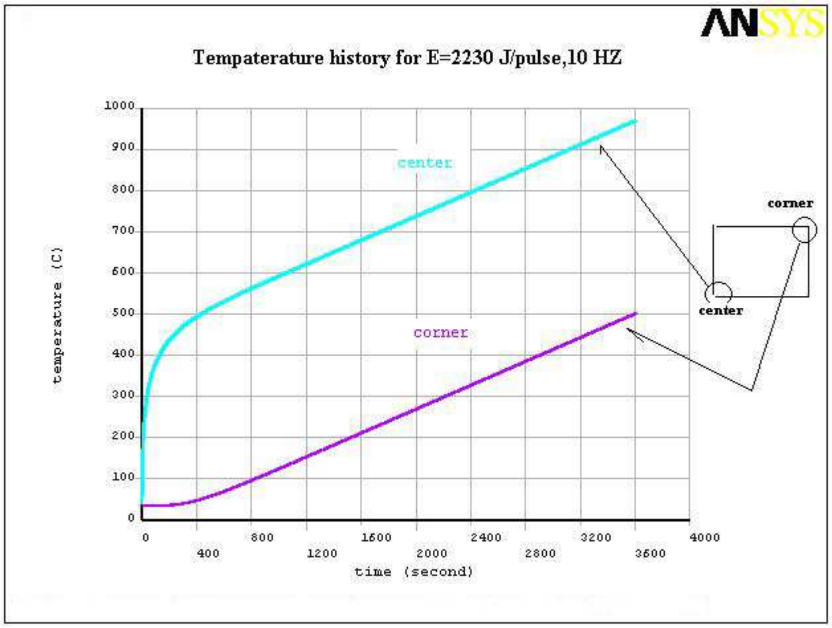

Figure 5: Temperature in the steel absorber core *vs* irradiation time calculated with the ANSYS code for the worst case accident scenario.

5 Conclusions

It is shown that at normal operation the beam absorber in the MI 8 GeV beam line can take no more than 6.8×10^{18} protons per year without contaminating the soil and surface water at Fermilab above the allowed limits. Further increase in the annual proton intake would be possible if we moved the absorber further off the nearest wall and applied extra steel shielding from both sides of the absorber.

In the worst case accident scenario and according to the most conservative estimate the steel absorber core corresponding to the final considered design can survive without melting down for about 20 minutes. The survival time can be increased by means of sweeping the beam over the absorber face as well as using an additional graphite insert in front of the absorber.

6 Acknowledgements

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