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DESIGN OF THE MI40 BEAM-ABORT DUMP

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Abstract

A beam-abort dump for the Fermilab Main Injector to handle 3E13 protons per pulse at 150 GeV has been designed. A 120 GeV beam line goes through the beam-dump off-set by 27cm from its center. The design and the environmental safety aspects of the beam-dump are described here.

I. Introduction

A beam-abort dump or beam stop is an important part of a high energy accelerator. In an accidental condition the beam must be automatically deflected on to a dump to avoid any damage to the accelerator components. Even during routine accelerator studies low intensity beam gets frequently aborted. In any of these cases, the beam-dump should be able to handle the aborted beam. Also, the area around it should have enough radiation and environmental protection.

Fermilab Main Injector (FMI) is a 8-150GeV proton synchrotron that is being built as a high intensity injector to the Tevatron. The Main Injector beam-dump is to be built near the MI40 straight section and has the base elevation of 214.27 m (703ft). It is planned to be a water-cooled dump. The maximum number of protons per machine cycle on the beam-dump exceeds 3E13@150 GeV. Since this beam-dump will be much closer to the aquifer than any existing beam-dumps in the Fermilab accelerator complex, it is extremely important that the design minimize the soil activation and reduce the ground water contamination.

To establish As Low As Reasonably Achievable (ALARA) radiation exposure to Fermilab workers and visitors a number of guidelines have been worked out and they are stated in FERMILAB RADIOLOGICAL CONTROL MANUAL. According this, the on-site and off-site radiation level should be less than 0.025 mrem/hr and 10 mrem/year respectively. The allowed ground water radioactive contamination should be less than 20pCi/ml-year. Also, the policy of Fermilab is, not to accelerate beams for which there is not a user. Aborting the maximum number of protons per hour, while not strictly an accident condition, is a violation of that policy.

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II. Design

We started out with the design of the presently existing beam-dump[1] in the Tevatron (near the C0 straight section) and arrived at an optimized design for the MI beam-dump. However, unlike the buried C0 Tevatron beam-dump, the FMI beam-dump will be placed in an accessible enclosure. The optimization has been carried out using the Monte Carlo code CASIM[2]. The total radiation dose above the berm of the beam-dump which is at an elevation of 227.38 m (746 ft) and the total number of stars in the soil is designed to be at least a factor of two below the acceptable limit. To have the ability for easy access, a 1.1 m wide walking space will be allowed around the beam-dump. The design of the beam-dump is shown in Fig.1. Provision has also been made for a 7.62 cm beam pipe through the iron core of the beam-dump for future extracted beam. The core of the beam-dump will be of high melting point graphite embedded in a 2.74 m aluminum box. This box will be cooled by 40^{o}C low conductivity water (LCW). In front of the aluminum box concrete bricks will be hand stacked. The aluminum box is surrounded by layers of 0.84 m thick steel and 1.1 m thick concrete. The total length of the beam-dump will be 10.7 m. The LCW cooling system will be installed behind the beam-dump in the available space.

The transverse emittance of the beam[3] in the Main Injector is expected to be 12π or larger. The horizontal and vertical β-functions at the surface of the graphite core is 225 m. This makes the minimum beam spot size on the beam-dump about 0.15 cm. The instantaneous maximum temperature rise in the core within the area occupied by the beam due to the interaction of 3E13 protons at 150GeV is about 100^{o}C. This beam will deposit about 330 kW of power in the beam-dump. Out of that about 55% of the energy (i.e. 200 kW) will be deposited in the graphite and aluminum core box alone. Hence we have planned to have an LCW cooling system which is capable of extracting at least 300 kW.

III. Estimation of Radiation Level

The radioactivity in and around a beam-dump can be categorized into two classes. The first one is for the beam on conditions (prompt radiation), i.e., the instantaneous electromagnetic and hadronic showers developed due to interactions of the high energy particles with the beam-dump. The second arises from the residual radioactivity of the dump. Both of these are dependent upon the total number of primary protons aborted and the beam energy. The average number of protons to be aborted on the FMI beam-dump per year under normal operating conditions[4] is about 3.26E18 @150 GeV. The maximum number of protons continuously aborted in any one incident is estimated to be 6.0E16 @150 GeV per hour.

Table I. Dose due to prompt radiation around FMI beam-dump and ground water activity.

Concern	Radiation dose
Neutrons : Max. Rad. Dose (Allowed dose Unlimited Occp. Limit.=0.025 mrem/hr for N.O. and 1 mrem/accident	 1.1E-5(mrem/hr) (For N.O.) 1.2E-3(mrem/acc.) (Maximum Beam Abort)
Muons : On-site (Allowed dose Unlimited Occp. Limit=0.025 mrem/hr for N.O. and 1 mrem/accident Off-site muons Annual Limit= 10 mrem/y	 5.4E-5(mrem/hr) (For N.O.) 6.0E-3(mrem/acc.) (Maximum beam Abort) $\leq$3.2E-5(mrem/y)
Ground Water : Annual Activation (Annual Limit 20 pCi/ml-y of ^{3}H 0.4 pCi/ml-y of ^{22}Na)	 ^{3}H 2.12pCi/ml-y ^{22}Na 0.07pCi/ml-y (A) ^{3}H 0.01pCi/ml-y ^{22}Na 0.148pCi/ml-y (B)

(A) Single Resident Well Model (B) Concentration Model

A. Prompt Radiation

The prompt radiation dose is calculated using the number of "stars" (interaction points) produced in a unit volume per incident particle. With a soil equivalent shielding thickness between the FMI beam-dump and the berm of about 9.75 m, the low energy neutrons and muons are the main contributors to the radiation dose at the surface level. Here, these two contributions have been evaluated in separate sets of Monte Carlo calculations. Figure 2 displays isodose contours obtained using CASIM. The results for muons are displayed in Fig. 3 along with a sectional view of earth in the downstream of the beam-dump. Using these results, the expected radiation dose for normal and maximal beam loss conditions have been evaluated. The results are listed in Table I along with the standards adopted at Fermilab.

Radioactive contamination of the ground water is one of the major considerations in designing a beam-dump. The aquifer around FMI is only about 4.88 m below the FMI beam-dump. Of all the radioactive nuclei produced in the spallation reactions the greatest hazards in ground water are from ^{3}H and ^{22}Na. The EPA-allowed limits for these nuclides in ground water are listed in Table I. There are two methods to determine the increase in the concentrations of these nuclides in the aquifer viz., A) the single resident well model and B)the concentration model[5] (which was developed very recently and is more suitable for an accelerator complex like Fermilab). The first one depends upon the total amount of stars in the soil and the second method uses the maximum star density in the soil near the base of the beam-dump. The results obtained from these two models are displayed in Table I. We find that they are at least a factor of two below the allowed limits.

B. Induced Radioactivity in the Beam-dump

As a result of hadronic showers developed in the beam-dump a variety of short and long lived radioactive nuclides will be produced. These give rise to residual radioactivity. Here we use the method suggested by Barbier[6] to estimate it.

Table II. Residual radioactivity for MI Beam-Dump at contact. T_i = irradiation time in days (d). T_c = cooling time.

Description	Dose on Contact (rad/hr)	
	T_i=360d T_c=1d (7d)	T_i=30d T_c=1d (7d)
Carbon Front Back	 10 (10) 10 (10)	 3.3 (3) 3.3 (3)
Al. Box Top Front Top Back	 26 (4) 26 (4)	 0.4 (0.4) 0.4 (0.4)
Iron Front Middle Top Back	 0.2(0.1) 0.02 (0.02) $\leq$4E-3 ($\leq$1E-3)	 0.1 (0.07) 0.01(0.007) $\leq$2E-3 ($\leq$1E-3)
Concrete (Max) Concrete Wall (Max)	 $\leq$2E-3 ($\leq$4E-4) $\leq$8E-4 ($\leq$2E-4)	 $\leq$2E-3 ($\leq$4E-4) $\leq$8E-4 ($\leq$2E-4)

The radiation dose $\dot{D}$ is given by,

$$\dot{D}(rad/hr) = \Omega/4\pi \times \Phi \times d$$

where Φ is the hadron flux (which related to the star density and the incident proton flux). For dose measurements at contact, $\Omega/4\pi = 0.5$. d is referred to as the danger

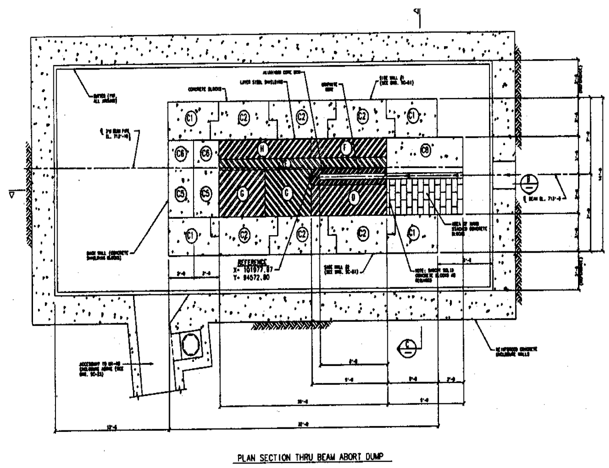

Figure 1: Longitudinal section of FMI beam-dump.

parameter which depends upon the material which is being irradiated, the duration of irradiation, T_i, the production cross section for various radioactive spallation products and the cooling time, T_c, of the target. For FMI beam-dump, the danger parameters are taken from Ref.6. The results of calculations have been listed in Table II.

IV. Summary

A beam-dump suitable for the Fermilab Main Injector that can handle 3E13p/pulse has been designed and is presently under construction. We have allowed for a beam line to go through the iron core without affecting the radiation level at the berm. There is enough clearance around the beam-dump for easy access and maintenance. We estimated that the prompt radiation dose level and the ground water contamination level is at least a factor of two less than the prescribed limits in FERMILAB RADIOLOGICAL CONTROL MANUAL. The residual radioactivity around the beam-dump will be less than 2 mr/hour after one day of cooling.

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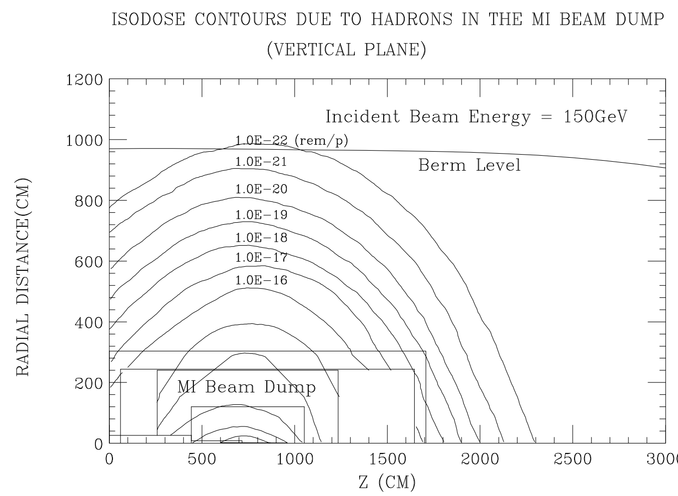

Figure 2: Iso-dose contours for 150GeV proton beam aborted on FMI beam-dump.

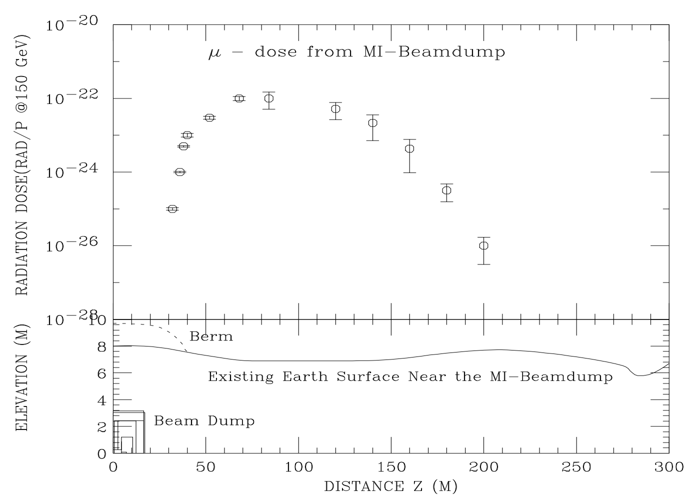

Figure 3: The muon dose in the vicinity of FMI beam-dump for 150GeV proton beam abort.