RADIATION LEVELS AROUND THE FERMILAB MAIN INJECTOR EXTRACTION SEPTA

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Abstract

The Fermilab Main Injector extraction system will be capable of delivering a uniform 120 GeV beam of $\sim 3 \times 10^{13}$ protons per spill to the fixed target experiments (with spill time of 1 sec). Up to 2% of the beam is expected to be lost at the extraction septum and the Lambertson magnet. As a result, one expects increased radiation levels around the septa compared to other parts of the Main Injector. Realistic Monte-Carlo simulations have been performed to estimate the instantaneous and residual radiation levels in the beam extraction region. The results of these studies are presented and implications are discussed.

1 INTRODUCTION

The Fermilab Main Injector (MI) is being built as a high intensity 150 GeV proton and antiproton injector to the Tevatron [1]. The MI is also capable of providing year-round 120 GeV proton beam with fast spill with a spill time of 0.04 sec, and a slow spill with a spill time of $\approx$ 1 sec [2]. In both of these cases the final extraction takes place at the MI52 straight section. During the extraction we expect beam induced radioactivity in the extraction septa and the down-stream beamline elements due to unavoidable beam losses at the septum wires. In this paper we present the estimated radioactivity in the vicinity of the extraction septa arising from the slow resonant extraction of the beam and its consequences on the operation of the MI.

The design beam intensity of the MI for the fixed target experiments with slow spill operation mode is 3×10^{13} for every 2.9 sec. The accelerator is also capable of providing beam in mixed modes where only about 80 % of the beam is extracted in slow extraction mode. However, we take the worst case beam loss scenarios for our calculations.

2 EXTRACTION SEPTA AND THE BEAM LOSSES IN MI

The extraction system comprises of three 12 ft long electrostatic septa, Lambertson magnets and a "C" magnet. Each of the electrostatic septa is designed to produce about 200μr kick on 120 GeV beam. A schematic view of the extraction region near MI52 location of MI is shown in Fig. 1. Two of the three extraction septa are located in straight section of MI-52. The third septum is situated at MI-30 which is at about n×360^o phase (or $\approx$ 920 meters up-stream of MI52) away from either of the two. This arrangement is done because there is not enough space to install all three septa at MI-52.

Each septum has a wire plane 3.048 m long with a high voltage gap of 10 mm. These wires are made of tungsten-rhenium and are of 0.1 mm dia. The maximum voltage gradiant in the septum gap is about 70 kV/cm.

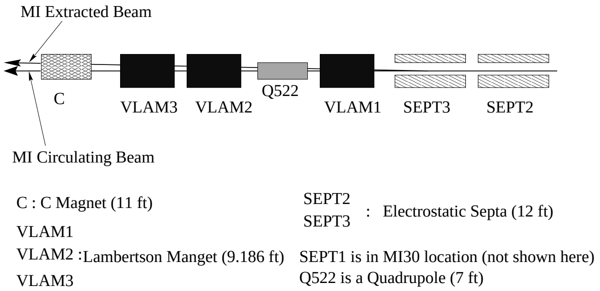

Figure 1: A schematic view of the Main Injector slow extraction region at MI52 straight section. One of the electrostatic septum is located in MI30 straight section and not shown here. The longitudinal dimension of each of the devices are also shown. The total extent of this region is about 60 meters.

The displacement of one of the septum magnet may be beneficial because the beam loss will be less local. Also, the part of the beam kicked by the electrostatic septum at MI-30 will gain a displacement of dx = $\theta\sqrt{\beta_{sept}\beta_Q}\ sin(\Delta\phi)$. Hence by selecting proper phase advance $\Delta\phi$ at MI-52, we can choose dx $\geq$0.1 mm ($\approx$ diameter of the septum wire). This helps to reduce or eliminate the beam losses at the MI-52 extraction region. However in our estimation of the beam loss and the induced radioactivity, rearrangement of the exectrostatic septa mentioned above are ignored. Also in reality, all particles that hit the septum wire may not be entirely lost during extraction process. Hence results presented here are highly conservative.

The particles that hit the septum wire are taken to be the extraction losses and this defines the extraction inefficiency. The minimum extraction loss, ζ_{min} (percentage loss), is related to the aperture between wire and the cathode Δx, and the wire size w [3].

$$\zeta_{min} = \frac{2w}{\Delta x}$$

In the present case $\Delta x = 10$ mm and the wire size w = 0.1 mm. Hence, we expect a minimum of about 2 % beam loss for steady-state density distribution of the particles. Alternatively it has been shown [2] that quantity $\zeta_{min} \approx w\sqrt{\beta\epsilon}$ which indicates that the inefficiency can be reduced only by increasing the emittance and/or β before extraction.

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3 MONTE CARLO CALCULATIONS AND RESULTS

3.1 Monte Carlo Code - MARS

The Monte Carlo code MARS [4] employs inclusive simulation of the hadron-nucleus interactions and uses statistical weights method. A phenomenological description [5] of the inclusive particle distributions is adopted and on the average the energy-momentum conservation is satisfied. This program is most suitable for evaluating shielding problems encountered in high-energy (E$\geq$10 GeV) accelerators. For the cases discussed here, the primary proton energy is 120 GeV. The hadron energy cutoff and star prouction energy cutoff are taken to be 14.5 MeV and 300 MeV, respectively. The properties of the septum wires are externally supplied to the code during the calculations. The atomic number and the mass are taken to be 74 and 180, respectively. Since the wires in the septa are widely separated, their effective density is taken as 0.31 g/cc. For other beamline materials the calculations use the necessary information from the MARS code.

3.2 Conversion Factors

The instanteneous and residual radioactivity of the beamline components are determined by using calculated energy deposition densities and hadron fluxes. The required conversion factors have been extracted in a seperate set of Monte Carlo calculations performed with incident proton energy 120 GeV on material of the beamline elements such as Fe, Cu and Al. The quantities are extracted from locations of shower maximum. The results of these calculations have been listed in Table I. It is important to note that the dose equivalent (i.e., Rem/p) in this table is valid in tissue like region only.

Table 1. Useful conversion factors from MARS. p.p stands for per incident proton.

Type of Conversion	Fe	Cu	Al
$\frac{Hadronflux/cm^2}{GeV/gm\ p.p}$	110.28	133.6	88.4
$\frac{Star/cc}{GeV/cc\ p.p}$	2.11	2.31	1.53
$\frac{Rem/p}{GeV/gm\ p.p}$	6.11E-5	6.0E-5	4.8E-5

3.3 Instanteneous Radiation Dose

To estimate instantaneous (and residual) radioactivity we have used exact geometry of the electrostatic septa and the Lambertson magnet in our model. The quadrupole magnet is assume to have cylindrical symmetry. The kick on the beam induced by electric field of the wire is replaced by equivalent magnetic field. The magnetic fields are $B_x = 0.0265$ Tesla and $B_y = 0.0$ Tesla. The extracted beam is bent vertically in the Lambertson magnet. The corresponding x and y components of the field in the Lambertson are $B_x = 0.0$ Tesla and $B_y = 0.749$ Tesla, respectively. In the program MARS the instantaneous dose is determined assuming time of irradiation $T_i = \infty$ and cooling time $T_c = 0$.

Table 2. Instantaneous maximum radiation dose in the down-stream quadrupole. The nomenclature : “S” for septum magnet, “Q” for quadrupole magnet and “o” for drift space.

Configuration	Drift Space (Meters)	Instantaneous Dose (KRad)
SooQ	6.9	5.8
oSoQ	3.7	6.4
ooSQ	0.4	6.5
oSSQ	0.4	6.5
Lambertson[a]	0.4	1880.0

[a] Maximum dose near the intersection of no field and field region

Presently the exact location of the electrostatic septum in the MI30 straight section is not well determined. But we know that it will be installed between MI-quadrupoles Q305 and Q306 which are separated by a distance of approximately 17.3 meters. Depending upon the location of the electrostatic septum, the down-stream quadrupole will be activated differently. The maximum dose for different configurations are shown in Table 2. The Main Injector enclosure is built with a minimum radiation shielding of 7.5 m of soil equivalant which provides sufficient radiation shielding at the surface.

3.4 Residual Activity of the Extraction System

Estimation of the induced radioactivity of an irradiated target involves detailed calculation of production of various types of radioactive nuclei and their dacay. Previously such a calculation has been carried out to the Fermilab antiproton production target [6] and compared with experimental data. Here we adopt a method described by Barbier[7] which states that the dose rate $\dot{D}$ is given by,

$$\dot{D} = \frac{\Omega}{4\pi} \times \Phi \times I \times danger\ parameter$$

where Ω is the solid angle at the source and Φ is the hadron flux calculated using MARS. The quantity I is the beam inensity. The *danger parameter* is a function of the target material, duration of exposure of the material to the primary radiation (T_i) and total cooling time (T_c). The quantity $\frac{\Omega}{4\pi}$ = 0.5 if radiation level is measured at contact. Figure 2 displays the worst case residual radioactivity in the downstream quadrupole which is adjacent to the first electrostatic septum (configuration ooSQL). Four different scenarios of T_i and T_c are indicated.

Figure 3 shows the cross-sectional view of the Lambertson magnet. Various partitions (in the first 10 cm depth) examined by Monte Carlo calculations are numbered as separate regions. The residual activity as a function of region number is shown in Fig. 4. We find that after continuous extraction of the beam for 30 days and cooling it for one day, one expects a maximum radiation level to be about 10 Rad/hour around the region number 14. The radiation dose

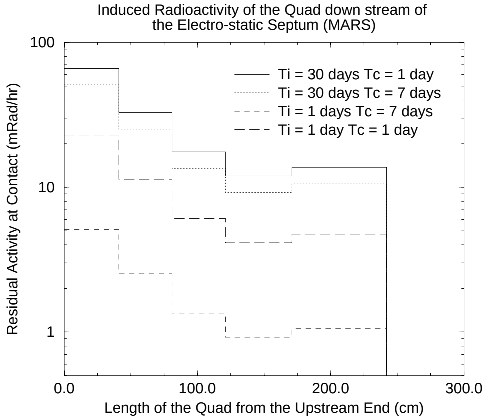

Figure 2: Worst case residual activity of the down-stream quadrupole magnet due to the beam extraction loss at the electro static septum. The data shown are radiation dose as a function of the distance along the magnet.

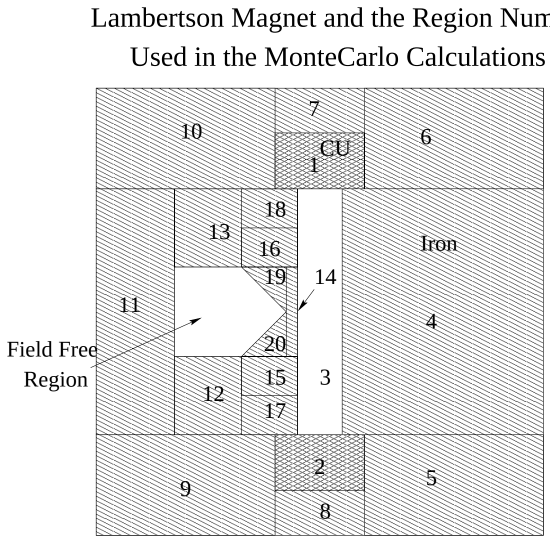

Figure 3: Schematic view of the Lambertson magnet and the partitions used in the Monte Carlo calculations.

on the body of the Lambertson at contact is found to be less than 10 mRad.

4 SUMMARY

We have performed detailed Monte Carlo calculations of the radioactivity at three different devices in the Main Injector extraction system. We find that the instantaneous and the residual activity of the extraction devices do not pose any potential problem from the point of view of operation.

Authors would like to thank P.S. Martin for useful discussions.

5 REFERENCES

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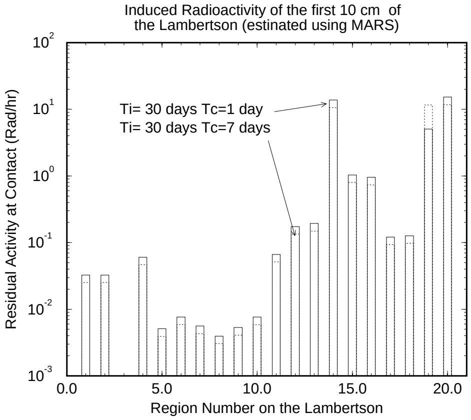

Figure 4: Radiation dose in the first 10 cm length of the Lambertson magnet. The region numbers are shown in Fig. 3.

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