RADIATION ENVIRONMENT RESULTING FROM MAIN INJECTOR BEAM EXTRACTION TO THE NUMI BEAM LINE *

A. I. Drozhdin, P. W. Lucas, N. V. Mokhov†, C. D. Moore, S. I. Striganov, FNAL, Batavia, IL

Abstract

A 120 GeV Main Injector proton beam will be delivered to the NuMI beam line at Fermilab at the rate of 3.7×10^{20} per year. Realistic Monte Carlo simulations have been performed to examine the radiation environment in the beam extraction system and NuMI beam line elements. A complete 3-D model of the 160 meter extraction region has been implemented utilizing the computer code MARS. The model includes a description of the field of the electrostatic septa and POISSON calculated field maps of the Lambertson magnets and the other lattice components in the area. The beam element alignment and the source term have been simulated using the code STRUCT. Results on beam losses in the system, energy deposition in the core elements and residual dose rates on the components are presented.

1 INTRODUCTION

The projected intensity for the NuMI project of 4×10^{13} protons extracted at 120 GeV from the Main Injector every 1.867 s[1] can result in a severe radiation environment[2]. To explore this, full-scale Monte Carlo simulations with the STRUCT[3] and MARS[4] codes are performed for the beam loss and showers induced in the Main Injector and NuMI beamline elements.

2 SOURCE TERM AND BEAM LOSS

The Main Injector lattice with all the optics elements in the extraction system region, electrostatic deflector, three modules of the Lambertson magnet, and the NuMI beamline components have been implemented into the simulation codes. The Lambertson magnet modules are rotated with respect to the longitudinal axis by 0.22 rad, 0.098 rad and 0.037 rad, correspondingly, to bend the extracted beam out of the accelerator in both vertical and horizontal planes. All essential details of the accelerator and NuMI beamline elements are taken into account in the simulations. The beamline is aligned with respect to the extracted beam axis to prevent primary proton loss anywhere but at the electrostatic deflector wires. Extracted and circulating beam densities at the entrance to the electrostatic deflector ES are calculated as in[5] for the Main Injector circulating beam emittance of 30π mm·mrad and shown in Fig. 1.

The ES wire distribution and other septum details are assumed as in[6]. Two cases of septum wires are studied, 2 and 4 mil, or 0.0508 and 0.1016 mm, correspondingly. A 10^5 proton sample in the extracted beam is taken in the calculations. About 2.5% of those hit the 2-mil electrostatic deflector wires, and twice that fraction the 4-mil wires. Some of these protons interact inelastically with the tungsten nuclei generating secondary particles responsible for radiation fields in the immediate vicinity of the ES. The others lose a small fraction of their energy, getting an angular kick due to multiple Coulomb and elastic scattering and electric field, resulting in long-range beam losses both in the machine and the NuMI beamline. Fig. 2 shows the calculated proton flux at the downstream end of the 2-mil

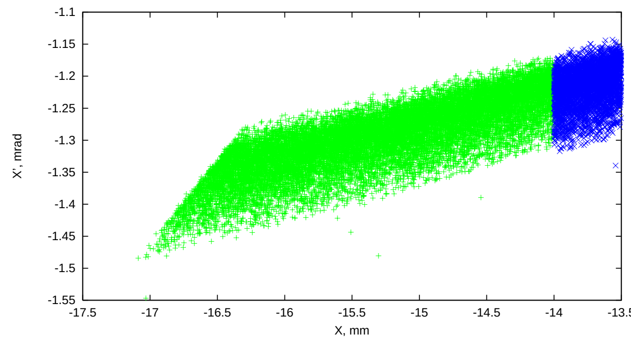

Figure 1: Circulating (black) and extracted (gray) beam horizontal phase space on the ES septum.

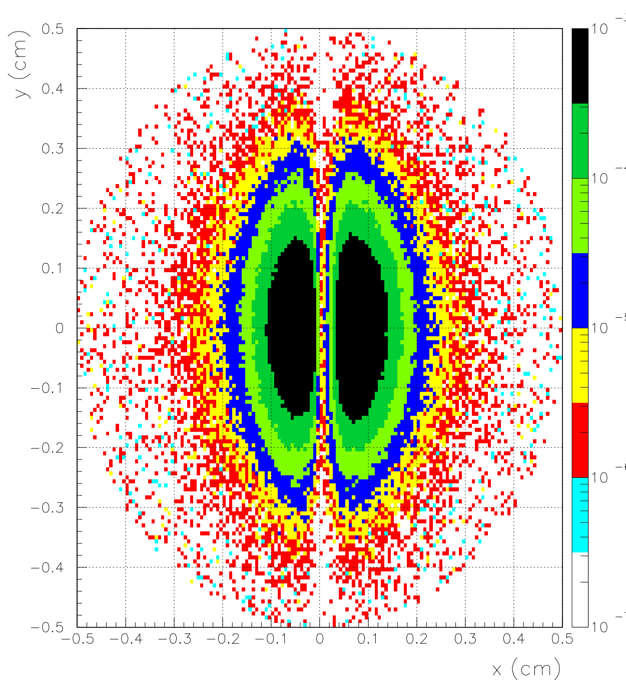

Figure 2: Proton flux (cm^{-2}) at the ES exit.

* Work supported by the Universities Research Association, Inc., under contract DE-AC02-76CH00300 with the U. S. Department of Energy.

† Email: mokhov@fnal.gov

wire septum. The β-function in the beamline after the ES and calculated heat load to the beam pipe due to high energy protons lost in the studied sections are shown in Fig. 3.

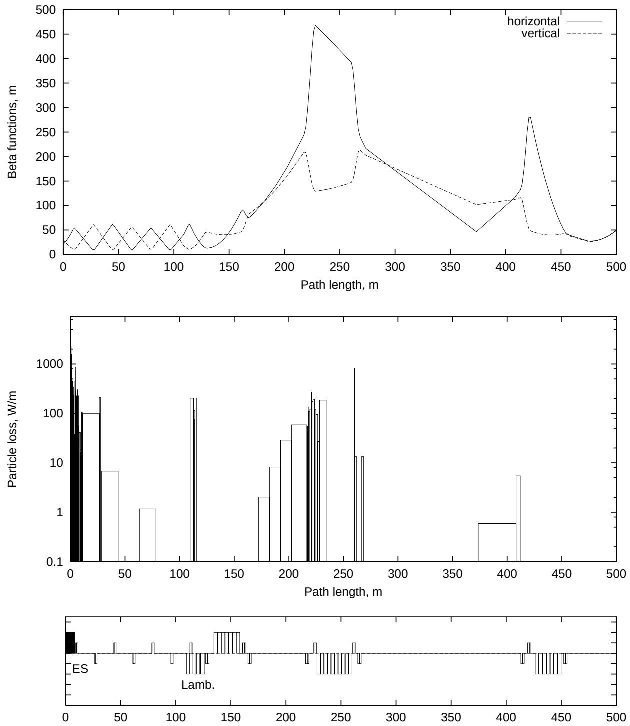

Figure 3: NuMI beamline β-function (top) and beam loss distribution in the accelerator and in the beamline (bottom).

A fine structure of the lost proton distribution along the first 160 m of the beampipe is given in Fig. 4 for 4-mil wires. One sees that most protons are lost on the septum and immediately downstream resulting in high radiation levels in the first 50 meter region. The second peak is at the Lambertson magnet as expected. In the 2-mil wire case, the particle loss on the pipe in the first 50 meter region is about three times lower, resulting in a more favorable radiation environment. The peak at the Lambertson is about the same. Fig. 5 shows calculated proton beam densities at the Lambertson magnets. The aperture of the quadrupole between the first and second Lambertson magnets is an ellipse of $R_x \times R_y$=61×27 mm^2. To eliminate the extracted proton loss in the quadrupole, the beam orbit needs to be moved at extraction by δx=-4.5 mm and δy=-11.5 mm, using for example the Main Injector beam orbit correctors.

3 PROMPT AND RESIDUAL RADIATION

3.1 Septum Heating

Although a fraction of the beam hitting the 4-mil wires is twice that of the thinner wire case, the peak energy deposition density is about the same in both cases. It peaks at the beam center at about 10 cm from the upstream end and decays exponentially along the septum to negligible values at about 200 cm. Thermal analyses have been performed

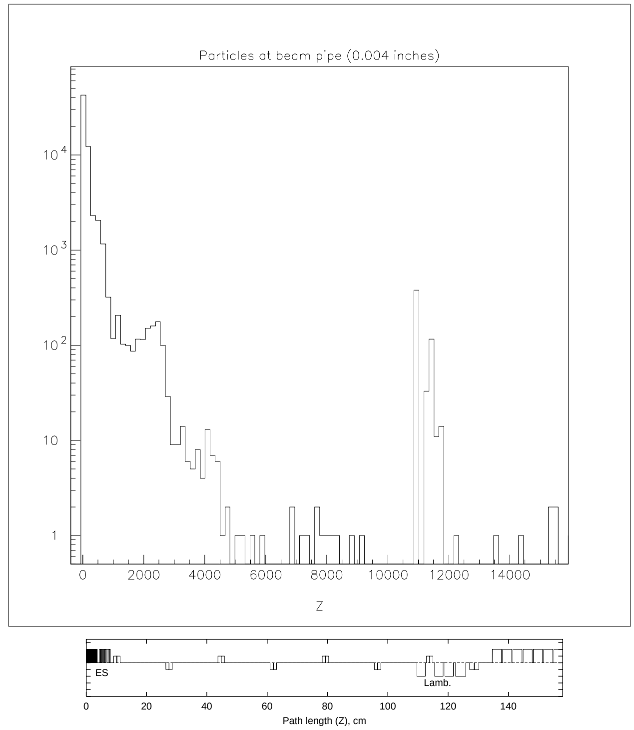

Figure 4: Proton distribution along the beampipe for the 4-mil wires of the electrostatic septum.

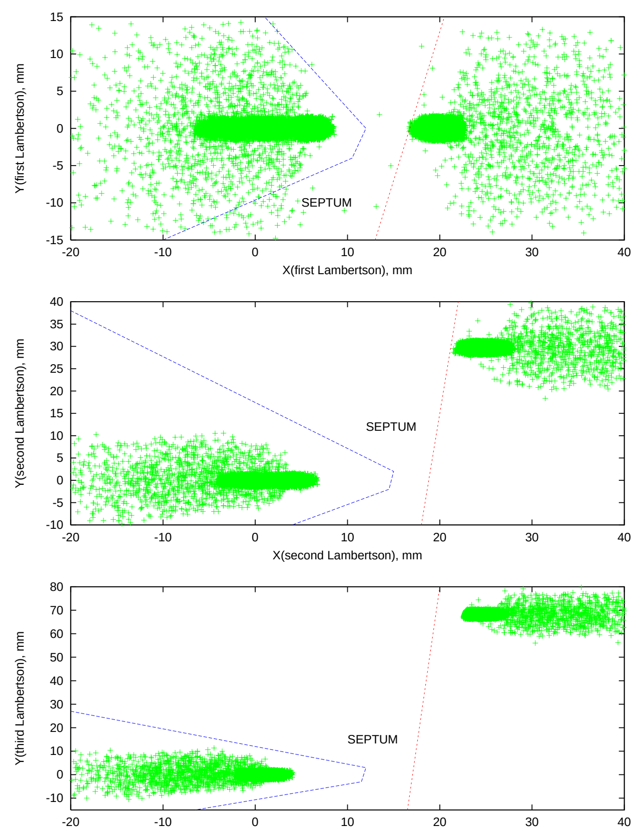

Figure 5: Proton beam transverse distribution at the first, second and third Lambertson magnets.

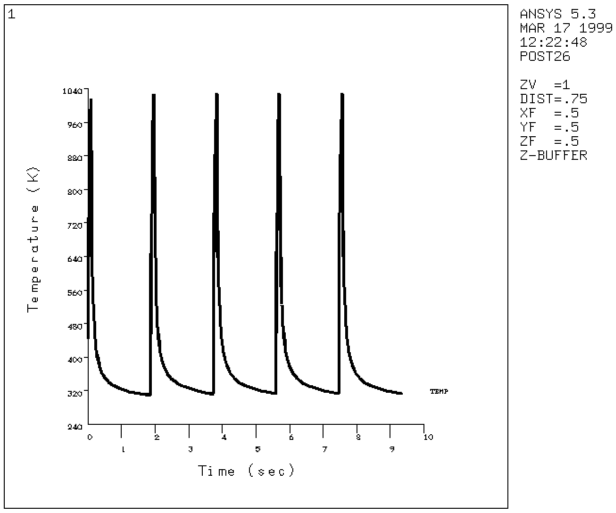

Figure 6: MARS-ANSYS calculated peak temperature in the 2-mil ES septum wires *vs* time for five sequential 120 GeV proton pulses of 4×10^{13} ppp separated by 1.867 s.

with ANSYS using the MARS calculated energy deposition density distribution in the wires made of 75% tungsten and 25% rhenium. It is assumed that the initial temperature is 300 K, and the wire ends are kept at the handler temperature of 300 K. The calculated peak temperature at the wire/beam center at the shower maximum (z$\sim$10 cm) for the 2-mil case is shown in Fig. 6 *vs* time for five sequential pulses separated by 1.867 s. The wires are cooled nicely between the pulses with no temperature build-up. The maximum temperature rise is 720 K, which corresponds to the maximum temperature of 747°C.

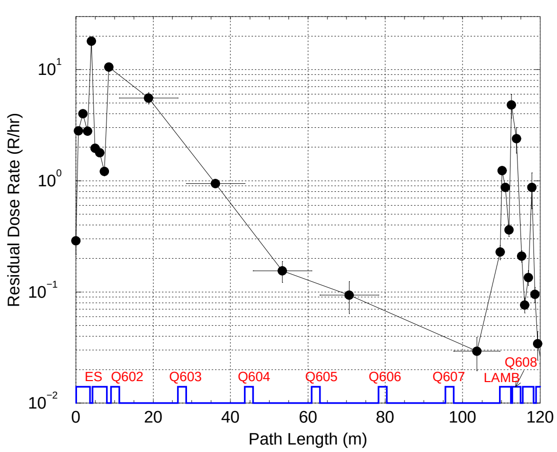

Figure 7: Residual dose rate on the outer surface of the Main Injector and NuMI beamline components due to 30 days of irradiation at the averaged over that period proton intensity of 1.6×10^{13} p/s and after 1 day cooling.

3.2 Equipment Activation

Equipment activation is rather high in the vicinity of the ES and in the Lambertson magnet region. The calculated residual dose rate on the outer surface of the components is presented in Fig. 7 for t_i=30 day irradiation and t_c=1 day cooling. The rates at the two hot locations are rather high. They go down approximately as $1/r$ with distance from the beamline, and can be re-scaled to other irradiation/cooling conditions via $\log(t_i/t_c)$.

4 CONCLUSION

The results of this study indicate that there will be manageable thermal effects from the desired intensity but the residual radiation levels in the extraction area will be very high. For the case given in Fig. 7 one observes that maintenance issues must be addressed for both the extracted beam line components and the near by components of the Main Injector itself. Longer irradiation times and a desire for access after shorter cooldown periods could lead to a several-fold increase in the dose rates shown in Fig. 7.

5 ACKNOWLEDGMENTS

We express our gratitude to J. Johnstone for information on resonant extraction and useful discussions, T. Kobilarcik for POISSON calculated magnetic field maps and I. Novitski for the help with ANSYS calculations.

6 REFERENCES

[1] "The Fermilab Main Injector Project, Technical Design Handbook", (1995).

[2] C. M. Bhat and N. V. Mokhov, "Radiation Levels around the Fermilab Main Injector Extraction Septa", *Proceedings of the 1997 IEEE Particle Accelerator Conference*, Vancouver, May 1997.

[3] I. Baishev, A. Drozhdin, and N. Mokhov, "STRUCT Program User's Reference Manual", SSCL–MAN–0034 (1994).

[4] N. V. Mokhov, "The MARS Code System User Guide, Version 13(95)", Fermilab-FN-628 (1995); N. V. Mokhov et al., Fermilab-Conf-98/379 (1998); LANL Report LA-UR-98-5716 (1998); *nucl-th/9812038 v2 16 Dec 1998*; http://www-ap.fnal.gov/MARS/.

[5] J. A. Johnstone, "A Simplified Analysis of Resonant Extraction at the Main Injector", Fermilab-MI-Note-91 (1993).

[6] A. I. Drozhdin, M. Harrison, and N. V. Mokhov, "Study of Beam Losses During Fast Extraction of 800 GeV Protons from the Tevatron", Fermilab-FN-418 (1985).