P1 and P2 Beamlines Maximum Credible Incident (MCI)

Michael K. Olander, Thomas R. Kobilarcik, Gerald Annala

Fermilab
Accelerator Directorate
Beams Division
External Beam Delivery Dept.

Version 2.0
March 7, 2024

Scope

This document describes the Maximum Credible Incident (MCI) for the P1 and P2 Beamlines.

The P1 and P2 Beamlines segment includes the following, shown in Figure 1:

- The P1 Beamline (also known as the P150 Beamline) from the wall separating the Main Injector from the Tevatron, to F11 of the Main Ring/Tevatron in the F-Sector Enclosure.
- The P2 Beamline from F11 to F17 of the Main Ring/Tevatron in the F-Sector Enclosure.
- The Muon Campus M1 Beamline from F17 of the Main Ring/Tevatron in the F-Sector Enclosure, at switch magnet F17B3, to the buried beam pipe at the wall of the F18 cell.

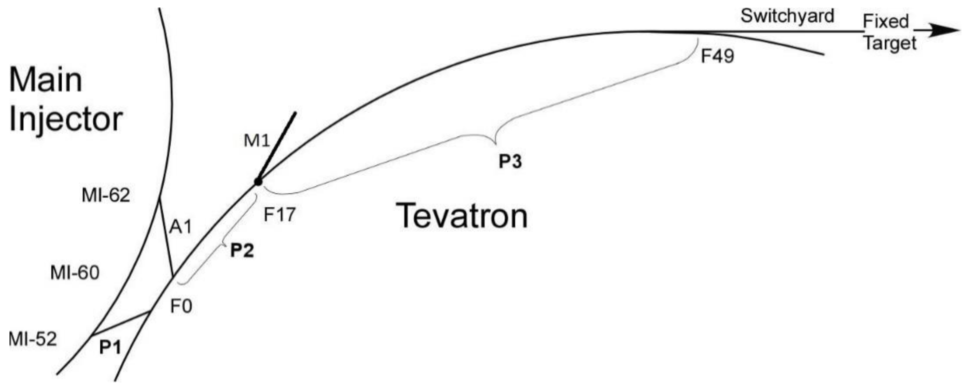

Figure 1: P1 and P2 Beamlines in relation to Main Injector / Recycler, P3 to Switchyard, and M1 to Muon Campus

Beam Parameters

The P1 and P2 Beamlines are responsible for delivery of 120-GeV beam to the P3 Beamline for the Switchyard Fixed-target Areas, and 8-GeV beam to the M1 Beamline for Muon Campus.

The Switchyard Fixed-target Areas are designed for 120-GeV protons slow-spilled from the Main Injector at intensity up to 3 E13 once per minute. Since there is no full-machine, fast-extraction device to deliver beam to the P1 line from Main Injector, it is not credible that full beam destined for NuMI could enter the P1 line. The maximum-credible intensity at 120 GeV would result from six Booster batches of 7 E12 protons, or 4.2 E13 protons per cycle. A Repetition Rate Limiter in the P1 line set for a period of 55s between ramps will be used as a credited control; the maximum possible repetition rate without this in place is unknown. The maximum intensity with the repetition rate limiter is 2.75 E15 protons per hour.

The Muon Campus is designed for 8 pulses of 8-GeV protons from the Recycler at an intensity of 1 E12 every 1.33s. This is a proton delivery rate of 2.17 E16 protons/h. The maximum-credible beam power at 8 GeV would result from a large orbit distortion in the Recycler that could be caused by one or more correction elements being energized incorrectly. If the orbit was distorted such that the first turn of beam injected into the Recycler was steered into the extraction channel of the Lambertson at MI-52, all the beam getting to the Recycler could be sent to the P1 and P2 Beamlines. This scenario could result in 7 E12 protons being delivered at 15 Hz, or 3.78 E17 protons/h.

Note that an incident involving both 120-GeV and 8-GeV beam would require failures in multiple machines and is therefore not credible.

The MCI scenario for the P1 and P2 Beamlines is 134.6 kW beam power, 3.78 E17 protons per hour, 7 E12 protons per pulse, 15-Hz repetition rate, 8-GeV beam energy missteered into a magnet or buried pipe for one hour.

Assuming no shielding is present, this incident would result in a dose to an individual higher than 8 E6 rem in an hour.

Shielding Requirements

Since the public is assumed to be excluded from the P1 and P2 Beamlines, shielding is required to reduce the dose on the berm under the MCI condition to 500 mrem in an hour. For the buried pipe in the 520-701 region, 20.3 equivalent feet of dirt (e.f.d.) is required. Other areas of the P1 and P2 Beamlines, where the incident would involve beam hitting a magnet, require 17.9 e.f.d. Sufficient shielding is present in all locations on the berm, other than the penetrations discussed below.

Within service buildings, all labyrinths and penetrations conform to the requirements of limiting the dose under the MCI condition to 5 rem in an hour. All outdoor penetrations conform to the requirements of limiting a dose of 500 mrem in an hour, except for the Main Ring/Tevatron F15 Air Handler penetration, where an active credited control is required. The F13 10” diameter Cryo penetration is filled with at least 16.8 feet of sand. The F13 6” diameter Cryo penetration is filled with at least 14.7 feet of sand. The F15 48” diameter Cryo penetration is filled to the top of the berm with sand. No other penetrations are filled. Access is allowed into the Muon Campus Pre-Vault enclosure while beam is operating int the P1 and P2 Beamlines as long as two critical devices (I:F17B3 and M:HV100) are in the off state. A MARS simulation documented in the critical device justification documents that maximum dose that could reach the Pre-Vault boundary gate with M:HV100 of would be 0.0058 mrem per E12 protons. At the MCI intensity of 3.78 E17 Protons/hr at 8 GeV, the maximum dose would scale to 2200 mrem in one hour. This simulation does not take advantage of several physical objects that increase the shielding. This choice in the simulation both simplifies the model and makes it more conservative. This simulation also requires that I:F17B3 be powered, which it would not be when access is allowed into the Pre-Vault area. With I:F17B3 off, beam continues past the Muon Campus extraction point and never reaches M:HV100. This eliminates the source of loss that would cause the maximum dose in the Pre-Vault enclosure. The critical device justification documenting this simulation is part of the Muon Campus Shielding Assessment. In conclusion, the dose to a worker in the Pre-Vault enclosure is significantly less than 2200 mrem in an hour, and therefore less than the 5000 mrem in an hour limit.

Active Controls

Radiation Detectors

An active radiation detector at the F15 Air Handler penetration is required, as shown in Table 1.

Table 1: Credited radiation monitors for the P1 and P2 Beamlines

Device Type	Location	Credited Control Limit
Chipmunk	F15 Air Handler	440 mrem/hour

Repetition Rate Limiter

For 120-GeV beam to be extracted from the Main Injector, the magnet Lam52 must be energized. Lam52 resides in the Main Injector. As such, if Lam52 is not energized, then beam is not extracted from the Main Injector, and does not enter the P1 beamline.

For 120 GeV beam to traverse Switchyard Continental, the magnet VH94 must be energized. VH94 is a ramped magnet. The beginning of the magnet ramp is chosen such that the magnet is at the 120 GeV current before extraction from the Main Injector begins.

The repetition rate limiter monitors the current of VH94. VH94 is a ramped magnet, that is, the magnet does not operate DC.

When the current through VH94 exceeds a specified threshold ("ON"), two counters begin: an "ON" counter and a "cycle" counter. The "ON" counter continues until the current through VH94 falls below the specified threshold. The "ON" counter is reset at the end of the "cycle". The "cycle" counter continues through the specified cycle time.

The "ON" threshold and duration are chosen so that VH94 may ramp up before extraction, hold during extraction, and ramp down. If the "ON" counter exceeds a specified duration, then Lam52 is inhibited, that is, 120 GeV extraction from the Main Injector is inhibited.

The “cycle” counter is chosen to limit the number of cycles extracted from the Main Injector into Switchyard. If the "ON" counter begins a second time during the cycle, then Lam52 is inhibited.

As such, the repetition rate monitor prevents more than one Main Injection extraction per specified cycle.

We assume a 55 second cycle time and a seven second “ON” time. The 55 second cycle time is slightly shorter than the nominal 60 second cycle time which allows for small variations in the placement of the slow extraction cycle. The seven second “ON” time is the minimum time necessary for VH94 to ramp up, hold, and ramp down, during the slow extraction process.

Conclusion

In the event of an MCI in the P1 and P2 Beamlines with all credited controls in place, a worker in a service building would receive a total dose less than 5 rem in one hour and an individual on the berm would receive a total dose less than 500 mrem. The location with the highest possible dose resulting from the MCI would be the F17 transverse location 17683 which has only 0.1 e.f.d. more than is required. This would result in a dose to an individual of just under 500 mrem in an hour.