Fermi National Accelerator Laboratory

Fermilab

Main Injector/Recycler Ring Maximum Credible Incident (MCI)

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Maximum Credible Incident Analysis

This document evaluates the maximum credible incident (MCI) scenario that could happen in the lifetime of the MI/RR. Consideration and analysis of this MCI is focused on an onsite facility worker, onsite co-located worker, and a maximally exposed off-site individual (MOI).

Radiological Hazard

The MI/RR are designed to transport and accelerate protons to downstream machines. There are many devices in these accelerators that accelerate, focus, and shape the beam pulses to ensure that a maximum number of protons reach the intended destination. Misdirection of this beam so that it impacts surrounding structures inside the accelerator enclosure can occur from a single failure of many of these devices or erroneous operation of them. An MCI would be one that produces the greatest prompt ionizing radiation from the beam loss.

There are a near-infinite number of individual beam loss events that can be postulated. The energy of these accelerators ranges between 8 and 120 GeV. The accelerators receive beam from the Booster accelerator at a maximum rate of 15Hz and a maximum intensity of 7E12 protons per pulse. Beam loss can occur at any energy, but the MCI for these accelerators will be that of 120 GeV beam loss. These accelerators can deliver 12 Booster batches of 120 GeV beam every 1.067 seconds. Using these parameters and 100% transmission efficiency in the accelerators gives us:

12 [Booster batches/MI cycle] * 7 $x10^{12}$[protons/batch] * 3600 [seconds/hr] / 1.067[seconds/MI cycle] = 2.83 $x10^{17}$ [protons per hour].

This analysis concludes that the maximum credible incident for the Fermilab MI/RR is a beam with an intensity of 2.83 $x10^{17}$ protons per hour at an energy of 120 GeV persistently incident on a beamline component for one hour.

Event Causes:

1. The Booster accelerator is delivering beam with intensity of 7 $x10^{12}$ protons per pulse.
2. Beam transmission through the MI8 beamline, Recycler, and Main Injector is 100%.
3. Beam mis-steered at 120 GeV continually via any of the following events:
    a. Failed magnet.
    b. Operator error.
    c. Autotune error.

Assuming no shielding is present, this incident would result in a dose to any individual higher than 5.23 $x10^{7}$rem. The result is that the uncontrolled baseline qualitative risk level associated with this accident is not acceptable.

Fermilab uses Credited Controls that flow down to the Accelerator Safety Envelope (ASE) to mitigate the consequences of the MCI to the following conditions:

- **Worker Basis:** Mitigated consequence of any credible postulated accident scenario at maximum operating intensity that could potentially result in 5 rem in one hour in any area accessible by facility workers and co-located workers.
- **General Site Basis:** Mitigated consequence of any credible postulated accident scenario at maximum operating intensity that could potentially result in 500 mrem in one hour in areas to which the public is assumed to be excluded.
- **Public Area Basis:** Mitigated consequence of any credible postulated accident scenario at maximum operating intensity that could potentially result in 100 mrem in one hour at Fermilab's site boundary AND/OR in any areas onsite in which the public is authorized.
    - Batavia Road, Illinois Prairie Path (MBO), parking lots open to the public.
    - All General Access Areas including, but not limited to, the following:
        - Wilson Hall
        - Ramsey Auditorium
        - Lederman Science Center
        - Building 327

These credited controls are discussed in Section III-7.4 of the Fermilab SAD.

The accumulated dose outside of the shielding on the Main Injector berm is mitigated, by use of Credited shielding of 20.7 e.f.d., to less than 500 mrem in an MCI. The calculation below shows a person on the berm directly above the location of the MCI, near cell 611 which is the location of minimum shielding, would receive an approximate total dose of 271 mrem in one hour.

$$500 \text{ mrem} * 10^{-((21.6-20.7)/3.38)} = 271 \text{ mrem}$$

The closest location a member of the public is allowed to be, with respect to the MI/RR enclosure, is the site boundary near the MI30 section at Cell 318. The site boundary is approximately about 200 feet away from the Main Injector berm at its closest point. The dose at the berm in this location would be:

$$500 \text{ mrem} * 10^{-((24.1-20.7)/3.38)} = 49.3 \text{ mrem}$$

The calculation assumes the dose will be a line source, which is the worst case and least likely. As such one would expect the dose to fall as 1/r, where r is the distance from the closest point of the berm to the site boundary. **Therefore, a person at the site boundary would receive an approximate total dose of 0.25 mrem in one hour.**

The Illinois Prairie Path, which is a publicly accessed trail near of the Fermilab site boundary, is further away from the Cell 318 berm than the site boundary. At its closest point the trail is about 300 feet from the berm at MI Cell 318. **Assuming an MCI happened at that distance from the Illinois Prairie Path, a person would receive an approximate total dose of 0.16 mrem in one hour.** The calculation assumes the dose will be a line source, which is the worst case and least likely. As such one would expect the dose to fall as 1/r, where r is the distance from the closest point of the berm to the Illinois Prairie Path.

MCI Analysis of Critical Devices

The Main Injector and Recycler occupy the same physical tunnel. The machines are both over two miles in circumference. The Recycler is fixed energy (8 GeV) proton storage ring. 8-GeV protons are extracted from the Recycler for use in the Muon Campus experiments via the P1 beam line.

The Main Injector accepts protons at 8-GeV and accelerates them up to 120 GeV for use in NuMI and Switchyard experimental users via the NuMI and P1 beamlines, respectively.

The MI/RR ring is divided into two radiological enclosures. They are named MI10 and MI20-62, respectively. MI10 is roughly 1/5 of the ring and MI20-62 the other 5/6 of the ring. Critical devices for the MI20-62 enclosure are the injection lambertson magnets and beam stops at the end of the RR and MI 8-GeV Lines inside the MI10 enclosure. MCI analysis for beam on these beam stops is contained in the *8-Gev Line Segment MCI Analysis* document.

The critical devices for NuMI Pre-Target/Target Hall enclosures are I:LAM60/61 and E:HV101. These power supplies feed power to a string of bend magnets at the very upstream on of the NuMI and are located in the MI20-62 enclosure starting at the Q607 location.

Fermilab RPO calculations show that a person in the most upstream end of NuMI Pre-Target enclosure would receive a dose on the order of 664 **mrem in the event of an MCI condition at any of these unpowered critical device magnets. This satisfies the requirement of a dose rate of less than 5,000 mrem/hour for a worker.**

The P1 beamline critical devices are I:LAM52 and I:V701, a string of lambertson and dipole magnets, which are located starting at the MI Cell 522 location in the Main Injector. These critical devices protect people in both Muon Campus Pre-Target Enclosure and the SY Transfer Hall enclosures, several thousand feet away.

Fermilab RPO calculations show that a person in either the Muon Pre-Target or SY Transfer Hall would get a dose on the order of **7.5E-03 mrem/hour or less in the event of an MCI condition at any of these unpowered critical device magnets. This satisfies the requirement of a dose rate of less than 5,000 mrem/hour for a worker.**

Dose Calculation Mythology

Please see *Radiation Physics Note 118*, revised by J. Donald Cossairt, M. Quinn, & K. Vaziri.

Conclusion

To ensure operations within bounding conditions used in the MCI analysis, the following intensity shall not be exceeded: 2.83 x10^{17} protons per hour.

In the event of an MCI in the MI tunnel, in one hour a worker in a Main Injector service building would receive a total dose less than 5 rem. A worker on the berm would receive a total dose less than 500 mrem. Because the Main Injector exists behind controlled gates members of the public are neither invited nor expected in the Main Injector area of the site. Therefore, the radiological hazards to the public are limited to areas near the site boundary, especially the Illinois Prairie Path, which is 300 feet from the nearest

point to the Main Injector/Recycler Ring tunnel. Conservative analysis shows a member of the public in this area would receive a total dose less than 100 mrem/hour in an MCI condition.