Fermi National Accelerator Laboratory

8-GeV Line Maximum Credible Incident (MCI)

Martin Murphy

Fermilab
Accelerator Directorate
Beams Division
Main Injector Dept.

Version 1.0
February 2, 2024

Managed by Fermi Research Alliance, LLC for the
U.S. Department of Energy Office of Science
www.fnal.gov

Definition of Maximum Credible Incident for the "8-GeV Line" Segment

This section of the "8-GeV Line" SAD evaluates the maximum credible incident (MCI) scenario that could happen in the 8-GeV Line, which is the Main Accelerator Segment that connects the Booster to the MI/RR/BNB. 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 8-GeV Line is designed to transport only 8-GeV protons from the Booster accelerator for injection into either the BNB beamline, the Main Injector or Recycler rings. It is comprised primarily of combined function (both bend and focus) permanent magnets (not electro-magnets). It also employs controllable electromagnets for local beam position adjustments and beam focusing.

The 8-GeV Line segment is 630 meters in length and extends from the interlocked gate at Cell 810 to MI-10 Main Injector accelerator enclosure. There it has two bifurcation nodes. The first node allows for beam to be sent to the Recycler storage ring injection Lamberton or straight ahead toward the second bifurcation node. At this point beam can be bent horizontally to the right toward the BNB beam line segment or straight ahead to the Main Injector Injection Lamberton magnet.

There are many devices that focus & steer 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 8-GeV Line 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 an extremely large number of individual beam loss events that can be imagined. The energy of the beam in 8-GeV Line is always 8-GeV. The 8-GeV line receives beam from the Booster accelerator at a maximum rate of 15Hz and a maximum intensity of 7E12 protons per pulse. Using these parameters and 100% transmission efficiency to the point of beam loss gives us:

15 [pulses/second] * 7 $x10^{12}$ [protons/pulse] * 3600 [seconds/hour] = 3.78 $x10^{17}$ [protons/hour]

This analysis concludes that the maximum credible incident for the Fermilab MI-8 beam line is a beam with an intensity of 3.78 $x10^{17}$ protons per hour at an energy of 8 GeV persistently incident on a beamline component.

Event Causes:

1. The Booster accelerator is delivering beam with intensity of 7E12 protons per pulse.
2. Beam mis-steered with an energy of 8 GeV continually via any of the following events:
    a. Failed component (magnet/power supply/mechanical part/beam diagnostic tool/etc.).
    b. Operator error.
    c. Autotune error.

Assuming no shielding is present, this incident would result in a dose to any individual higher than 8 x10^{6} rem/hr.

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

- Less than 500 mrem in one hour in all Laboratory areas to which the public is assumed to be excluded.
- Less than 100 mrem in one hour at Fermilab's site boundary and/or in any areas onsite in which the public is authorized.
- Less than 5 rem in one hour in any area accessible by facility workers or co-located workers

Dose analysis for a facility worker on the 8-GeV berm, a facility worker at interlocked tunnel gates inside the MI20-62 enclosure or a member of the public at the nearest publicly accessible spot to the 8-GeV Line follow.

Dose/hour to Facility Worker on the 8-GeV Line Berm

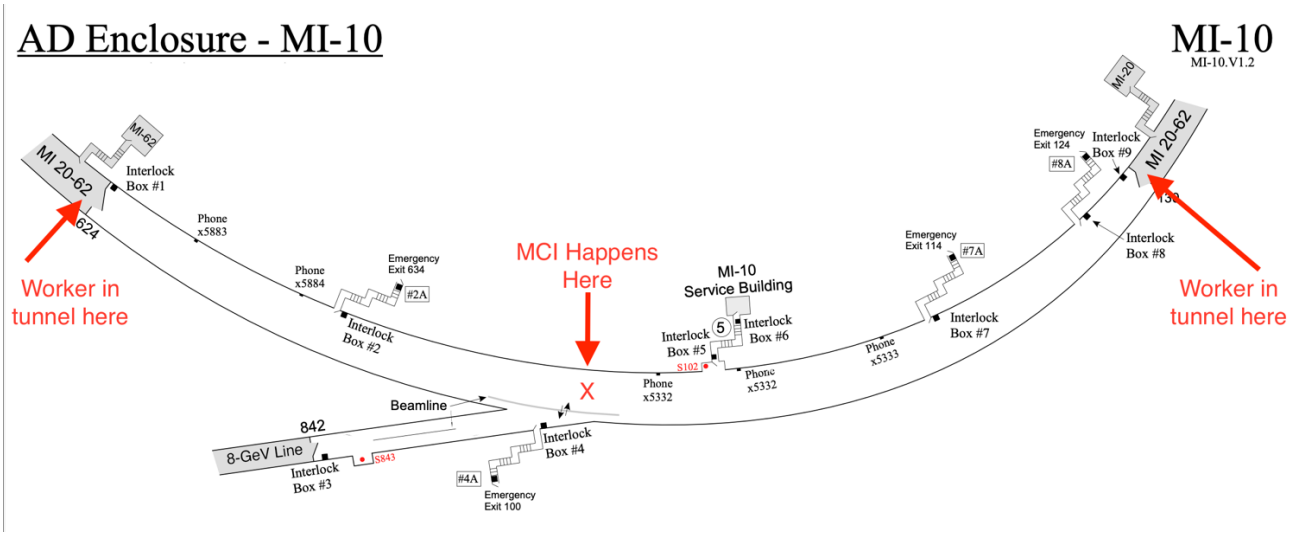
These credited controls are discussed in Section III-5.4 of the 8-GeV Line section of the SAD. An analysis of MCI condition in the beamline concludes that 17.9 EFD is needed to protect a MOI on the berm from receiving a total dose greater than 500 mrem. As stated in section III-5.1.3 of the SAD there is presently a minimum of 24.5 EFD shielding the 8-GeV Line enclosure. **Fermilab ES&H analysis shows that a person on the least shielded location of the 8-GeV Line berm during on MCI condition would receive an expected total dose of 28.6 mrem over the period of one hour.**

Dose/hour to a Facility Worker in the Tunnel

The 8-GeV Line terminates inside the MI10 enclosure at Main Injector Cell 101. The MI-10 enclosure is one of two radiological enclosures of the Main Injector/Recycler segment. It is separated from the MI20-62 enclosure by a gate at either end; at cells 624 and 130, respectively. See figure 1.

Appropriately trained workers allowed in the MI20-62 enclosure while the 8-GeV Line is sending protons to BNB. Those gates are very far from the worst possible 8-GeV Line MCI for this instance; cell 624 is at least 900 feet away from the worst possible MCI location while cell 130 is at least 1,600 feet away from the same MCI point. **Fermilab ES&H Dose calculations for the 8-GeV Line MCI for a worker at gate 624 are 1.4 x10^{-5} mrem. For a facility worker at gate 130 the calculated dose is 3.1 x10^{-13} mrem.**

Figure 1: Map of MI10 enclosure showing location of worst case 8-GeV MCI for a worker in MI20-62 beam enclosure



Dose/hour to a Member of the Public at Point Nearest Publicly accessible point to 8-GeV Line Segment

The entirety of the 8-GeV Line is inside the non-public boundary of Fermilab. Consequently, members of the public are neither invited nor expected. The closest a member of the public can get to the 8-GeV Line is over 600 feet way in the West Wilson Hall parking lot. **Fermilab ES&H calculations show that such a person would receive a total dose of 0.0093 mrem in one hour.**

Credited Engineering Controls

The purpose of this section is to provide the information necessary to understand the engineering controls that are used to prevent or mitigate the consequences of the maximum credible incident. Engineering controls can be classified as passive or active. This section presents a separate discussion of the engineering controls that fall under each classification.

Passive Credited Engineering Controls

Passive controls are elements of facility design that require no action to function properly. These are fixed elements of the beam line that take direct human intervention to remove. The 8-GeV Line segment enclosures are designed and constructed as a permanent concrete and earth-covered radiation shield that uses a combination of permanent shielding and penetration shielding to protect personnel from radiological exposure due to the MCI.

Permanent Shielding – Including Labyrinths

The permanent shielding encompasses the structural elements surrounding the beamline components.

This includes the walls, ceilings, doors, berms, labyrinths for both access and penetrations and shielding blocks. Topographical surveys of the 8-GeV Line segment enclosures and berm conclude that there is a minimum of 24.5 Equivalent Feet of dirt (e.f.d.) shielding between the interior surface of the enclosure walls and the surface of the berm.

The efficacy of this permanent shielding has been quantitatively analyzed to simulate the MCI as defined in Section III-5.3.1.1. This analysis finds that, under the conditions present in the MCI, a peak dose rate of 500mrem/hr would occur on the berm on the 8-GeV Line segment, which is a non-public area of the campus. In this condition, a MOI would receive a dose of 500 mrem in one hour if there were 17.9 e.f.d.

The credited control for the permanent shielding is thus defined as 17.9 e.f.d. shielding between the interior surface of the enclosure walls and the surface of the berm. As mentioned above, the 8-GeV Line enclosures have minimum of 24.5 e.f.d. The credited shielding present on the berm of the 8-GeV Line enclosures is therefore adequate to protect the MOI from receiving a dose of 500 mrem of dose in an hour under an MCI condition.

Penetration Shielding

The beamline has several utility penetrations at the MI-8 service building routing between the exclusion areas and occupied areas that were analyzed for required shielding. These penetrations were designed to eliminate the need for additional penetration shielding. In summary, the prompt dose rates at the exits of the penetrations are within the limits established in the FRCM.

Additionally, the MI8-Line has sight riser penetrations that are used for survey and alignment to connect the survey network in the tunnel to the outside. These penetrations have been analyzed and filled with steel plugs (2600 lbs.) and or polyethylene beads to provide the required shielding to keep the MCI below the 500 mrem limit. A complete inventory of the sight riser penetrations can be found in Table 1 below. Locally, penetration shield plugs are identified as credited controls and that are not to be tampered with.

Table 1: Inventory of sight-riser penetrations along the 8-GeV Line beam enclosure

Location	Shielding Type	Quantity	Purpose	Preferred Method of Configuration (if specified)	Comments
Cell 812	Steel and Poly	1	Site Riser penetration		A solid steel cylinder 11 5/8” dia x 62 5/8” long followed by a poly bead plug 11” dia. x 30” long
Cell 816	Steel and Poly	1	Site Riser penetration		a solid steel cylinder 11 5/8” dia x 62 5/8” long followed by a poly bead plug 11” dia. x 30” long
Cell 831	Poly	1	Site Riser penetration		Completely filled with loose poly beads.
Cell 833.5	Steel and Poly	1	Site Riser penetration		a solid steel cylinder 11 5/8” dia x 62 5/8” long followed by a poly bead plug 11” dia. x 30” long

Conclusion

To ensure operations within bounding conditions used in the MCI analysis, the following intensity shall not be exceeded: 3.78 x1017 protons per hour.