Maximum Credible Incident Analysis for the MeV Test Area (MTA) Beamline and Enclosure

Version 1.4

January 3, 2024

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1 Introduction

This document presents an analysis of the current MeV Test Area (MTA) shielding and credited device configuration under the newly established Maximum Credible Incident (MCI) intensity defined below. The mitigation approach, described here, implements additional credited devices in order to comply with the ASE accident condition requirement at all accessible locations.

The MTA beamline starts at the beginning of the first C magnet in the Linac enclosure and ends with the high intensity beam absorber buried in the berm at the end of the MTA experimental hall – the beamline, hall, absorber and enclosures are displayed in Attachment A. The total length of the beamline to the end of the MTA Hall is approximately 200'. The C magnets (2) operate at 15 Hz and can divert the full 60 μsec Linac pulse into the MTA beamline which in turn can transmit the entire Linac beam through the Hall and into the beam absorber without significant losses. Therefore, the MCI intensity defined for Linac operation is applied along the entire MTA beamline. The new MCI intensity used for the Accelerator Safety Envelope (ASE) for MTA operation is 4.78 x 10^{13} p/pulse or 2.58 x 10^{18} p/hour from the 400-MeV 15 Hz Fermilab Linac. This document addresses the increased radiological protections required under this ASE intensity based on an analysis of beam accident conditions along the beamline.

2 Boundaries

This note covers the MTA beamline from the Linac enclosure (from Z = 0' which coincides with upstream first C magnet in the Incremental Shielding Analysis spreadsheets) through the MTA experimental hall, berm pipe, and into the beam absorber (which ends at Z = 203'). The Incremental Shielding Assessment spreadsheets (ISA) are referenced to the Radiation Safety drawings 9-4-1-35 and 4-1-35, which detail the as-built shielding configuration and existing labyrinths and penetrations. New MTA-specific credited devices for radiological protection would begin in the Linac high ceiling enclosure section. The part of the MTA beamline housed in the Linac enclosure is protected by Linac radiological controls.

3 Beam Parameters

This section describes the underlying beam parameters and assumptions used to determine the MCI and what is required for ASE compliance (5R/hr or 500 mr/hr for the open space limit on potential exposure from a MCI).

3.1 Normal and Accident Conditions

Shielding for the MTA beamline is evaluated for the ASE for 400 MeV protons at 2.58 x 10^{18} per hour, which is calculated as follows. The full Linac MCI intensity is currently defined as:

$$54000\,\frac{pulses}{hour} \times 4.78 \times 10^{13}\,\frac{protons}{pulse} = 2.58 \times 10^{18}\,\frac{protons}{hour}$$

This intensity limit represents the highest Linac intensity or MCI that can be delivered in an hour.

The shielding required under accident conditions (100% beam loss) then assumes 4.78 x 10^{13} protons per pulse lost on a magnet, or a beam pipe in an enclosure, or a buried beam pipe (the pipe in the berm which connects the hall to the high intensity absorber), or the front steel entrance to the absorber. An accident is assumed to last for one hour, unless its duration is limited by the use of interlocked detectors which is the approach proposed for the new intensity values required to evaluate the ASE. The highest losses are always generated by accidents on beamline magnets or experimental targets or locations with reduced installed shielding.

4 Shielding Requirements

The initial shielding requirements can be assessed using *the MTA ISA Summary* spreadsheets and, per above, calculated for 400 MeV protons, 4.78 x 10^{13} protons per pulse, and 54000 pulses per hour (2.58 x 10^{18} protons per hour). The amount of shielding is scaled from a set of generic shielding criteria developed from Monte Carlo simulations [3] tabulated for 120 GeV protons at 1.6 x 10^{14} protons per pulse and 2700 pulses per hour. The scaling assumes that dose rates decrease by an order of magnitude for every 3.38 feet of soil-equivalent shielding. The 120 GeV dose rates are then scaled to 400 MeV. [4]

The new MCI intensity requires minimally 17.5 efd (effective feet of dirt) at these beam intensities to restrict the exterior open-space surfaces to 500 mr/hr for the case of the MCI worst- case accident condition (beam on a magnet core or equivalent object). To prepare against any disturbance of the berm and taking into account the steep slope on either side of the accelerator enclosure, an additional 1.5’ is added to the 17.5’ to establish a conservative cutoff point for additional radiological protection of ≤19 efd.

Installed shielding ranges from 10.4’ to 21.7’ radially with the minimum directly above the beamline in all but one location (the Ceiling Vent penetration). Locations with deficiencies in shielding are addressed using a credited radiation detector (Chipmunk). This detector can trip the beam within 3 sec, or 45 pulses, maximum 2.15 x 10^{15} protons for a MCI after detection.

5 Longitudinal Shielding Summary

The longitudinal summary spreadsheets range from the point of extraction in the Linac enclosure to the entrance of the high intensity beam absorber. Based on the new ASE accident intensity (2.58 x 10^{18} versus the previous 2.11 x 10^{16} p/hr) and imposing the ASE condition of 500 mr/hr for open spaces, this summary sheet indicates that inadequate shielding exists from the Linac high ceiling enclosure up to the entrance to the beam absorber with the exception of the hatch (Z = 106 to 115’) and the absorber (Z = 103 to 193’). The individual longitudinal sections defined in the ISA spreadsheets with ≤19' efd must be individually covered by credited radiation detectors (Chipmunks).

6 Transverse Shielding Summary

Similarly, the transverse summary spreadsheet lists 11 stations and summarizes the radial distribution of shielding that surrounds the beamline and enclosure. The transverse stations are identified by their distances in feet along the beamline from the designated C magnet origin.

This summary sheet indicates that inadequate shielding exists at all transverse stations of the beamline, with the exception of four stations in the hatch which contain the waveguide penetrations and the absorber which have the >19' requisite shielding. Note that the part of the beamline housed in the Linac enclosure is covered by Linac credited radiological protections. Transverse locations can be protected by the chipmunks positioned longitudinally along and above the beamline on the berm with appropriate settings – settings are adjusted to reflect the minimal radial shielding thickness as discussed below.

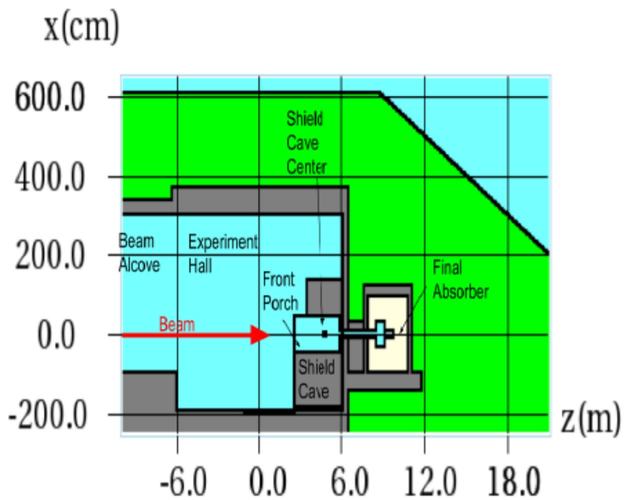
7 MARS Simulations

7.1 Overview

MARS [4] simulates electromagnetic and hadronic showers, including processes such as gamma emission following neutron capture. For the studies here, a proton beam intensity of 7.15×10^{11} protons per second is assumed, corresponding to the current operational limit of 2.70×10^{15}p/hr. Prompt dose would need to be scaled to 7.17×10^{14} p/sec to convert values to the new MCI intensity. A short beamline component section referred here as the upstream MTA stub is just downstream of the shield wall. This MTA stub opens up into the higher ceiling MTA Hall.

The model consists of the following elements:

- Beamline components in the primary beamline which are confined to the MTA stub (sometimes referred to as beamline alcove)
- targets up to 1.6' of steel
- detailed model of installed concrete shielding blocks including
    - hatch shield blocks with installed coaxial and waveguide penetrations
    - roll-up door shielding blocks
    - target concrete cave
    - pipe between hall and absorber
- concrete walls, floor, and roof of enclosures
- surrounding berm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Center
Beam
Alcove
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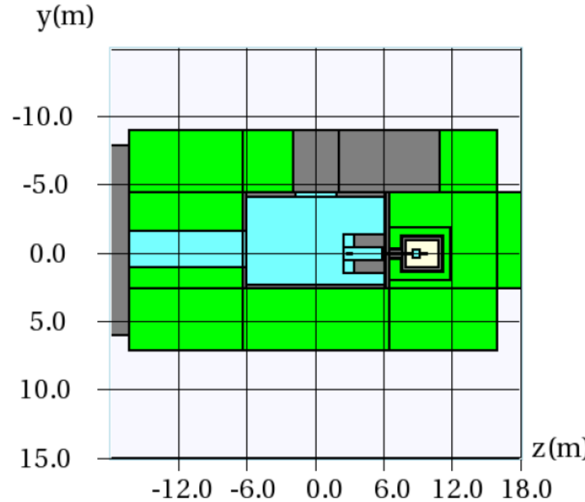
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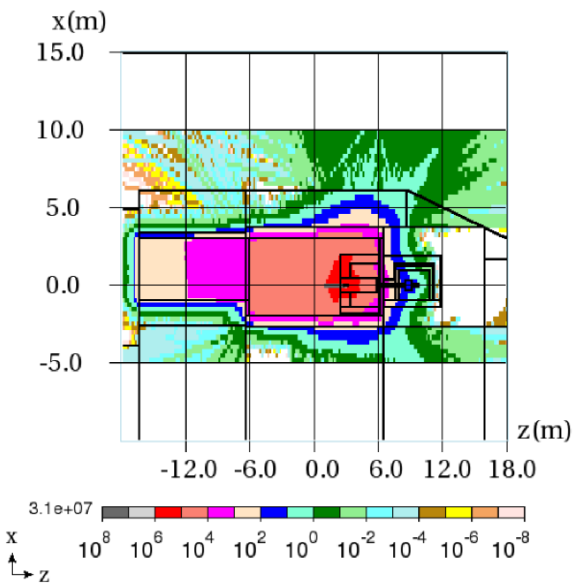
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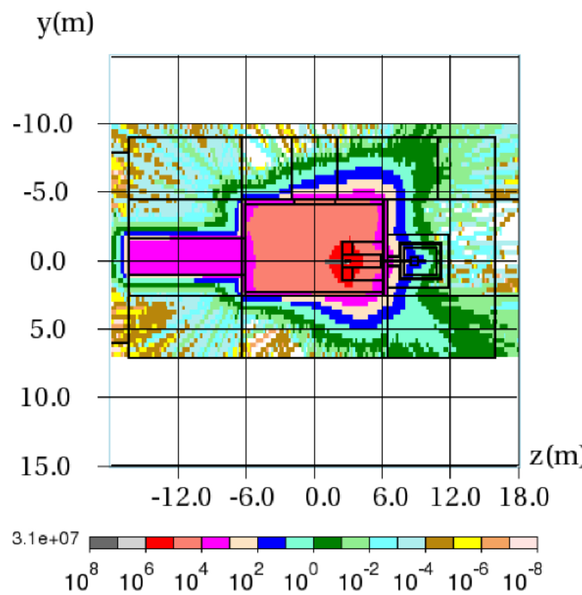
z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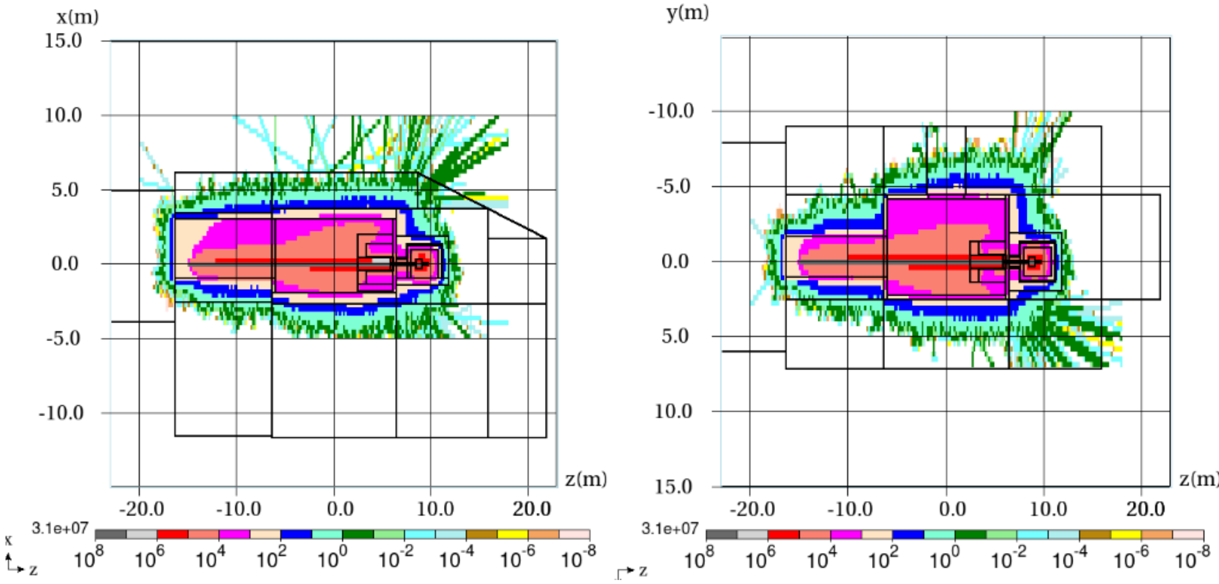

Figure 1: Plan and elevation view locations of MARS geometry (top set), prompt dose using 1.6’ of steel on front porch (middle set) and a 3cm tungsten target midpoint of MTA Hall (bottom set).

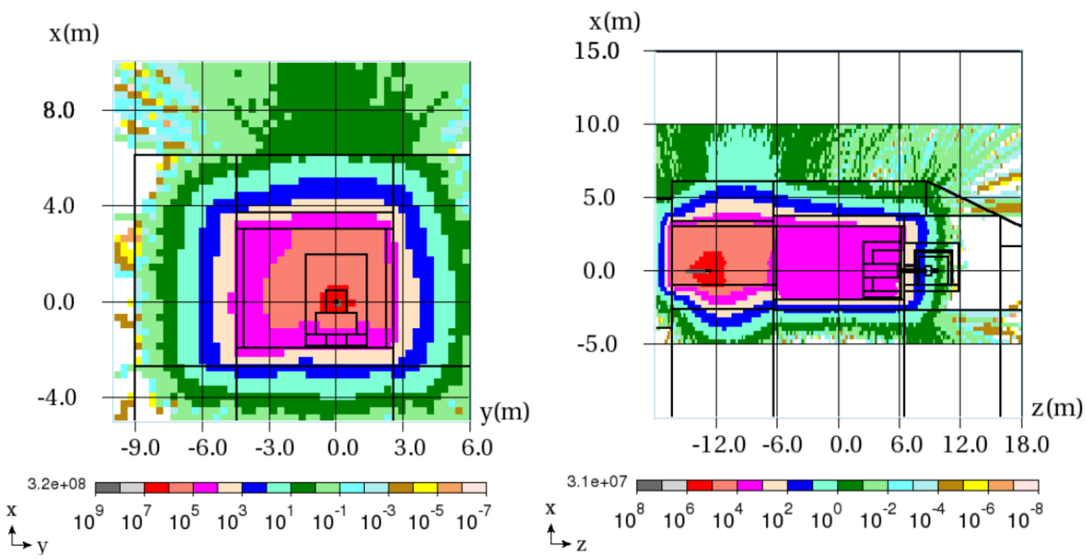

Figure 2: Transverse slice of 1.6’ of steel on front porch (left) and elevation view of beam hitting a magnet in the beamline stub.

7.2 Prompt Dose Rates

Prompt dose rates are calculated using MARS for the broad dose distributions outside the enclosure shielding (open spaces) and then using the ISA spreadsheets for prompt doses at the exit of labyrinths and penetrations (which include both open and enclosed spaces). The prompt dose profiles indicate a sensitivity of at least a 10’ radius on the berm which translates into an ~20’ spacing between chipmunks along the berm for complete radiological protection against a MCI.

8 Labyrinths and Penetrations

There are two personnel labyrinths and eight sets of straight or single-leg penetrations and eight 4-leg penetrations within the boundaries of this addendum. Individual analyses of all penetrations have been performed with the exception of the 4-leg utility/cabling penetrations which are identical. In all cases but the 4-leg penetrations, the penetrations were filled with poly beads and also sand in the case of the ceiling vent. The highest dose rates remain with the straight through penetrations even after filling with sand and poly. The single-leg penetrations to the Counting House are grouped in one location allowing single point monitoring. A Chipmunk positioned at the exit of the largest 8” diameter penetration provides comprehensive protection for the entire Counting House.

9 Active Shielding Controls and Monitoring

9.1 Radiation Detectors

Radiation detectors will be placed on the berm along the primary beamline up to the absorber and inside the Counting House at locations capable of detecting all MCI conditions and limiting prompt dose to ensure compliance with the ASE limits. The radiation detectors will be interlocked to the Radiation Safety Interlock System (RSIS). This system is routinely tested and certified to turn off critical device(s) for the beamline and stopping the beam within one second. The RSIS trip level will be set by the Radiation Safety Officer.

Radiation detectors (chipmunks) are capable of disabling beam within 3 seconds to the MTA, allowing only 45 pulses into the MTA beamline after detection of an accident condition, or 2.15 x 10^{15} additional protons. Radiation detectors on the berm have at least a 10’ radius of prompt dose detection per the MARS analyses and are therefore spaced ~20’ apart on top of the berm. A placement accuracy of 1-2’ is conservative given the 10’ radial sensitivity. These detectors also protect and limit prompt dose in the transverse direction. Two chipmunk settings were reduced to protect two transverse locations with a radial shielding thickness that was less than the longitudinal shielding for that section. Based on the MARS and ISA labyrinth and penetration studies the chipmunk locations listed in Tables 1 and 2 are required to detect a MCI at any MTA location. Note that the Ceiling Vent chipmunk (which is southeast of the beamline against the upstream enclosure wall) protects transverse location Z=157' as it has the lowest effective shielding and represents the highest radiation point for any upstream MTA Hall accident.

Table 1: Chipmunk locations, number and Dose Rate settings for ASE accident conditions

No. of Chipmunks	Coverage area as defined in ISA spreadsheets	FRCM (mrem/hr)
1	Linac High Ceiling	DR≤177*
2	Linac Ramp Upstream Downstream	 DR<165** DR≤500
1	Beam Stop Alcove	DR≤500
1	MTA Upstream Stub (above UQ111 (SQA)	DR≤500
3	MTA Hall – Ceiling Vent, Mid-hall, Front Porch	DR≤500
1	Absorber Upstream	DR≤500
1	Counting House Single-leg Penetrations	DR≤5000

* Chipmunk setting scaled from 13.3 efd (longitudinal) to 11.9 efd (transverse, Z=45') to limit transverse dose to 500 mr/hr for an MCI condition.
** Chipmunk setting scaled from 15.9 efd (longitudinal) to 14.2 efd (transverse, Z=57') to limit transverse dose to 500 mr/hr for an MCI condition.

Table 3: Chipmunk locations in DUSAF – plus is downstream and minus upstream along beamline trajectory.

Coverage area	Easting m	Northing m	Elevation Approx, ft.	Positional Tolerance
Linac High Ceiling	30327.450002	30355.351172	763'	±2'
Linac Ramp – Upstream Downstream	 30323.645715 30319.871072	 30350.974804 30347.685172	 763' 763'	 ±2' ±2'
Beam Stop Alcove	30315.865645	30343.805880	763'	-2'
MTA Upstream Stub	30308.8044463	30336.919941	763'	±2'
MTA Hall – Ceiling Vent Mid-hall Front porch	 30308.199127 30301.049725 30299.342129	 30330.831729 30329.355422 30327.694450	 763' 763' 763'	 1' SE* ±2' -2'
Absorber upstream	30295.74008	30324.18469	763'	-2'

* Ceiling vent chipmunk can be moved SE by ~1' to clear vent cover if needed.

10 Conclusions

The shielding for the MTA beamline has been analyzed under the MCI intensity conditions, 4.78 x 10^{13} protons per pulse, 2.58 x 10^{18} protons per hour (54000 pulses per hour). The analyses and calculations performed indicate complete protection against violating the ASE* in the event of a MCI at any MTA location based on the installation of radiation detectors.

11 References

[1] *Incremental Shielding Assessment Methodology*, W. Higgins and P. Kasper, November 10, 1997, https://esh-docdb.fnal.gov:440/cgi-bin/ShowDocument?docid=3843

[2] *Update to the Generic Shielding Criteria,* FERMILAB-TM-2550-ESH, S.D. Reitzner, November 6, 2012

[3] *The MARS Code System User's Guide*, FERMILAB-FN-628 (1995), N. V. Mokhov, https://mars.fnal.gov/

[4] 2020 "Shielding Assessment Document for the MeV Test Area at the Fermilab Linac Endstation

[5] *Radiation Physics for Personnel and Environmental Protection*, FERMILAB-TM-1834, J.D. Cossairt, https://esh-docdbcert.fnal.gov/cgi-bin/cert/ShowDocument?docid=1007

[6] *Fermilab Radiological Control Manual* (*FRCM*), http://eshq.fnal.gov/manuals/fcm/

Attachment A: MTA Beamline, Hall, Absorber, and Civil enclosures