Fermi National Accelerator Laboratory

Fermilab

Switchyard Fixed Target Beamlines Maximum Credible Incident (MCI)

Michael K. Olander, T. Kobilarcik

Fermilab
Accelerator Directorate
Beams Division
External Beam Delivery Dept.
Neutrino & Test Beams Group

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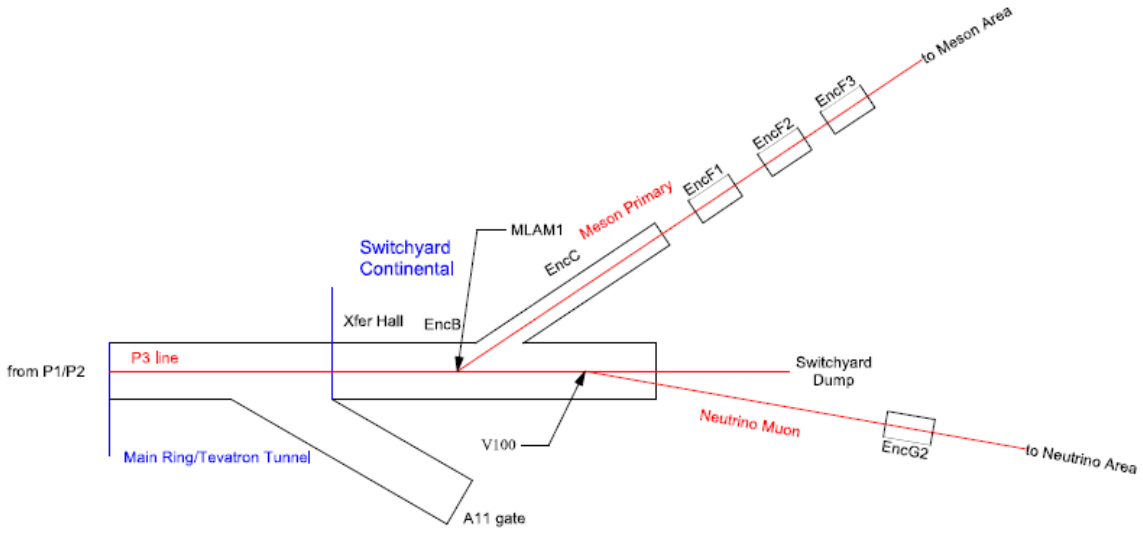
Scope

This document describes the Maximum Credible Incident (MCI) for the Switchyard Fixed Target Beamlines.

The Switchyard Fixed Target Beamlines segment includes the following: geographic areas, as shown in Figure1

- The Main Ring/Tevatron tunnel from the downstream end of the B17B3 magnet, through Transfer Hall, to the A11 gate in the Main Ring/Tevatron tunnel.
- Switchyard Continental.

Figure 1: Schematic layout of the Switchyard Fixed Target Beamlines



The beamlines, also shown in Figure 1, are:

- The P3 beamline, from the downstream end of the F17B3 magnet to the downstream end of the MLAM1 magnet.
- The Meson Primary beamline, from the downstream end of the MLAM1 magnet to the upstream wall of Enclosure M01 in the Meson Area segment.
- The Switchyard Dump beamline, from the downstream end of the MLAM1 magnet to the Switchyard Dump.
- The Neutrino Muon beamline, form the downstream end of the V100 magnet to the upstream wall of Enclosure NM1 in the Neutrino Area segment.

Beam Parameters

The P3 beamline receives 120 GeV beam from the P1/P2 segment and transfers beam via Switchyard Continental, to the Switchyard Dump, Meson Area, or Neutrino Area. Because these are transfer lines, there is no intrinsic intensity limit for the beamlines; the limit is taken as that of the upstream segment.

The MCI scenario for the "Switchyard 120 Fixed Target Beamlines segment is 2.75E15 protons per hour, 4.2E13 protons per cycle, 55 second cycle, 120GeV beam energy, missteered into a magnet, beam pipe in an enclosure, or buried pipe, for one hour.

The MCI scenario would result in an unprotected exposure of approximately 10E08 mrem in one hour. As such, protective measures are necessary.

Calculating Dose Where Interlocked Detectors are Deployed

Calculations for Interlocked Detectors

The "chipmunk trip calculator_7_21_15.xlsx" spreadsheet provided in Beams Document 4732-v8, "Chipmunk and TLM radiation detector trip calculators" is used to calculate the expected dosed base on a specified trip level.

The model assumes four seconds of non-MCI beam, 51 seconds without beam (consistent with a 55 second cycle time), then 55 second accident cycles (four seconds at MCI intensity and 51 seconds without beam). This continues until a "trip" is indicated, after which the model assumes no beam for the remainder of the hour.

Calculations for Total Loss Monitors

The "TLM trip calculator_7_21_15.xlxlsx" spreadsheet provided in Beams Document 4732-v8, "Chipmunk and TLM radiation detector trip calculators" is used to calculate the expected dose based on a specified trip level.

The model assumes four seconds of non-MCI beam, 51 seconds without beam (consistent with a 55 second cycle time), then 55 second accident cycles (four seconds at MCI intensity and 51 seconds without beam). This continues until a "trip" is indicated, after which the model assumes no beam for the remainder of the hour.

Calculations for Shielding Failures

Information from the ISA Spreadsheets is used to calculate the anticipated dose when there is insufficient shielding. The calculation is:

$D = L * 10^{(-t/3.38)}$

Where:

- D = expected dose, mrem = mrem/hr * 1 hour duration
- L = dose limit, mrem
- t = difference between required and existing shielding, efd.
- 3.38 is the tenth-value layer for soil, efd.

Shielding Requirements

The public is assumed to be excluded from the majority of Switchyard Fixed Target Beamlines. Areas within the Switchyard Fixed Target Beamlines segment in which the public is authorized are the Helen Edwards building parking lot, Pine St., and the bike path. See Figure 2.

Figure 2: Photograph showing the Helen Edwards Building parking lot and adjacent sections of Pine Street and the bicycle path.

Permanent Shielding Including Labyrinths

The required amount of shielding is determined using the Incremental Shielding Assessment (ISA) spreadsheets. The required amount of shielding varies based on one of three categories of losses: loss on a magnet within an enclosure, loss on a long, thin pipe within an enclosure, and loss on a thick pipe buried in soil. The required amount of shielding also varies depending on the exposure limit. The amount

of shielding is specified in terms of equivalent feet of dirt (efd), which takes into account the effectiveness of various materials compared to soil (for example, concrete is more effective than soil).

Table 3 lists the minimum amount of efd required to remain below a given exposure assuming the MCI.

Table 1 Minimum Equivalent feet of dirt required to remain within an exposure range based on loss category. The 120 GeV MCI is assumed.

Dose	Beam on Magnet in Enclosure	Beam on Pipe in Enclosure	Beam on Buried Pipe
	[efd]	[efd]	[efd]
100 ≤ D < 500 mrem	13.9	11.4	16.3
500 ≤ D < 1000 mrem	12.9	10.4	15.3

Exposure at a labyrinth is assessed using the ISD spreadsheets. This exposure is determined by the geometry of the labyrinth, which is fixed.

Where sufficient shielding is lacking, as shown in Table 4, an additional credited control is used.

Adequate permanent shielding exists in the Switchyard Fixed Target Beamlines with four exceptions, listed below. An additional credited control is needed, which will be discussed in later sections.

Table 2 Locations with inadequate shielding

Location - Station	Location - Name	Maximum Exposure	Shielding - Required	Shielding - Present	Additional Credited Control
		[mrem]	[efd]	[efd]	[]
20390	Transfer Hall	500	13.9	12.0	Chipmunk
124	TG Annex	500	13.9	12.7	Chipmunk
273	WH-C-1 Manhole	500	16.3	15.5	TLM – Encl. B
3005-3350	Pipe - Master Substation	500	16.3	15.5	Fence

Exposure due to an MCI at all labyrinths remains below 500 mrem, the level appropriate for areas to which the public is assumed to be excluded.

The Switchyard Fixed Target Beamlines Shielding Assessments contain transverse and longitudinal shielding summaries. Credited levels of shielding are based on the ES&H shielding assessment categories from the Incremental Shielding Assessment Methodology. Tables of credited shielding follow.

Areas onsite in which the public is authorized are evaluated at categories 3A, 3B, or 3C, representing shielding for a dose of 100 mrem in an hour on a magnet, beam pipe in an enclosure, or buried pipe, respectively. Areas to which the public is assumed to be excluded are evaluated at categories 4A, 4B, and 4C, representing a dose of 500mrem in an hour on a magnet, beam pipe in an enclosure, or buried pipe, respectively.

In the event a region does not have sufficient shielding for the aforementioned shielding categories, an additional credited control is required. Once the control is in place, the shielding category changes to categories 8A, 8B, or 8C for a dose of 100 mrem in an hour on a magnet, beam pipe in an enclosure, or buried pipe, respectively, or 9A, 9B, or 9C for a dose of 500 mrem in an hour on a magnet, beam pipe in an enclosure, or buried pipe, respectively. These areas have been identified in Table 4, and are bold in the tables.

For the P3 Beamline to the Switchyard Absorber:

The following longitudinal ranges, shielding category, and credited shielding are provided:

Table 3: P3 to Switchyard Absorber Longitudinal Credited Shielding

Z-Range		Credited
(cell or ft)	Category	Shielding (ft)
17880-18550	4A	13.9
18550-18600	4A	13.9
18600-19332	4A	13.9
19332-19345	4A	13.9
19345-19815	4A	13.9
19815-19867	4A	13.9
19867-20114	4A	13.9
20114-20128	4A	13.9
20128-20313	4A	13.9

20313-20370	4A	13.9
20370-20376	4A	13.9
20376-00130	4A	13.9
130-175	4A	13.9
175-215	4A	13.9
215-265	4A	13.9
265-360	4A	13.9
360-740	3C	18.7
740-750	3C	18.7
750-807	3C	18.7
807-920	3C	18.7
920-1250	3C	18.7
1250-1265	3C	18.7
1265-1290	3C	18.7
1290-1333	3C	18.7
1333-1495	3C	18.7
1495-1520	4C	16.3

The following Transverse stations, shielding category, and credited shielding are provided:

Table 4: P3 to Switchyard Absorber Transverse Credited Shielding

Transverse Station	Shielding Category	Credited Shielding (ft)
17910	4A	13.9
18100	4A	13.9
18302	4A	13.9
18355	4A	13.9
18410	4A	13.9
18535	4A	13.9
18569	4A	13.9
18605	4A	13.9
18695	4A	13.9
18753	4A	13.9
18811	4A	13.9
19050	4A	13.9
19317	4A	13.9
19342	4A	13.9
19367	4A	13.9
19650	4A	13.9
19750	4A	13.9
19842	4A	13.9
19925	4A	13.9
20098	4A	13.9
20122	4A	13.9
20148	4A	13.9
20390	**9A**	**5.5**
0	4A	13.9

85	4A	13.9
124	**9A**	**5.5**
175	4A	13.9
184	4A	13.9
200	4A	13.9
236	4A	13.9
251	4A	13.9
260	4A	13.9
273	**9A**	**5.5**
300	4A	13.9
385	3C	18.7
400	3C	18.7
438	3C	18.7
500	3C	18.7
600	3C	18.7
700	3C	18.7
800	3C	18.7
814	3C	18.7
900	3C	18.7
948	3C	18.7
986	8C	10.2
1000	3C	18.7
1100	3C	18.7
1200	3C	18.7
1280	3C	18.7
1330	3C	18.7
1510	4C	16.3

For the Neutrino Muon beamline:

The following longitudinal ranges, shielding category, and credited shielding are provided:

Table 5: Neutrino Muon Longitudinal Credited Shielding

Z-Range (cell or ft)	Category	Credited Shielding (ft)
1520-1536	4C	16.3
1536-1633	4C	16.3
1633-1708	4B	11.4
1708-1752	4C	16.3
1752-2070	4C	16.3
2070-2224	4A	13.9
2224-2285	4A	13.9
2285-2390	4A	13.9
2390-2417	4A	13.9
2417-2420	4A	13.9
2420-2430	4C	16.3
2430-2690	4C	16.3
2690-2763	4C	16.3
2763-3090	4C	16.3
3090-3110	4C	16.3
3110-3146	4C	16.3
3146-3179	4C	16.3

The following Transverse stations, shielding category, and credited shielding are provided:

Table 6: Neutrino Muon Transverse Credited Shielding

Transverse Station	Category	Credited Shielding (ft)
NC11330	3C	18.7

NC11510	4C	16.3
NC11700	4C	16.3
NC11800	4C	16.3
NC11900	4C	16.3
NC12180	4A	13.9
NC12260	4A	13.9
NC12285	4A	13.9
NC12400	4A	13.9
NC12460	4C	16.3
NC12600	4C	16.3
NC12720	4C	16.3

For the Meson Primary beamline:

The following longitudinal ranges, shielding category, and credited shielding are provided:

Table 7:Meson Primary Longitudinal Credited Shielding

Z-Range (cell or ft)	Shielding Category	Credited Shielding (ft)
1237-1335	3A	16.3
1335-1615	3C	18.7
1615-1635	4C	16.3
1635-2058	4C	16.3
2058-2130	4C	16.3
2130-2308	4C	16.3
2308-2350	4A	13.9
2350-2370	4C	16.3
2370-2413	4A	13.9

2413-2480	4C	16.3
2480-2850	4C	16.3
2850-2950	4C	16.3
2950-3005	4C	16.3
3005-3350	**4C**	**15.5**
3350-3475	4C	16.3
3475-3558	4C	16.3
3558-3950	4C	16.3
3950-3967	4C	16.3

The following Transverse stations, their category, and credited shielding are provided:

Table 8: Meson Primary Transverse Credited Shielding

Transverse Station	Category	Credited Shielding (ft)
M001280	3A	16.3
M001330	3A	16.3
M001500	4A	13.9
M001600	4A	13.9
M001620	4A	13.9
M001640	4A	13.9
M002050	4A	13.9
M002100	4A	13.9
M002200	4C	16.3
M002340	4A	13.9
M002360	4A	13.9
M002400	4C	16.3
M002600	4C	16.3

M002750	4C	16.3
M002950	4A	13.9
M003200	4C	15.05
ME13353	4C	16.3
ME13400	4C	16.3
ME13450	4C	16.3
ME13500	4C	16.3
ME13550	4C	16.3
ME13552	4C	16.3
ME13600	4C	16.3
ME13650	4C	16.3
ME13700	4C	16.3
ME13750	4C	16.3
ME13800	4C	16.3

Penetration Shielding

Exposure at a penetration is assessed using the ISD spreadsheets. The exposure is determined by the geometry of the penetration, amount of fill, and moveable shielding at the penetration.

Table 13 summarizes the penetrations which require shielding ("fill" – shielding material inside the penetration) or a detector. "N/N" indicates no detector is required.

Table 9 Penetrations requiring fill

Cell or Z-Location	Location or Enclosure	Fill	Detector

18569	F25 Cryo 48"	48" filled with sand, 12" 8" 5" and 3" penetrations within unfilled	chipmunk
19368	F35 Cryo 48"	48" filled with sand, 12" 8" 5" and 3" penetrations within unfilled	chipmunk
20121	F45 Cryo 48"	48" filled with sand, 12" 8" 5" and 3" penetrations within unfilled	chipmunk
0	A-0 Kicker Building Short Circuit (South)	3' of Poly Rods with 10% packing factor in three 7" penetrations	chipmunk
0	A-0 Kicker Building Short Circuit (Middle)	3’ of Poly Rods with 10% packing factor in three 7” penetrations	chipmunk
0	A-0 Kicker Building Short Circuit (North)	3’ of Poly Rods with 10% packing factor in three 7” penetrations	chipmunk
745	EncB Cryo	Sand	TLM1 (EncB)
2333	SY Encl. G2: cryo pen	The 8” header is filled with 24 ft. of sand. Polyethylene beads fill the annulus between 18” carrier and 8” header. Also, a 3 ft. thick sand shield, followed by a 3 ft. thick sand plug, exist at the end of the carrier pipe.	chipmunk
2337	SY Encl. G2: cryo pen	The 8” header is approximately 50% full of piping and insulation. Polyethylene beads fill the annulus between 18” carrier and 8” header. Also, a 3 ft. thick sand shield, followed by a 3 ft. sand plug, exist at the end of the carrier pipe.	chipmunk

Active Controls

Radiation Detectors

The following radiation detectors are required

Location		Limit	Shielding		Baseline		Detector		
station	name		existing	required	exposure		type	trip level	exposure
		[mrem]	[efd]	[efd]	[mrem/cycle]	[mrem/hr]		[mrem/hr] (chipmunk) nC/min (TLM)	[mrem]
18569	F25 Cryo 48"	5000			523	34300	chipmunk	4810	1572
19368	F35 Cryo 48"	5000			162	10600	chipmunk	4940	1296
20121	F45 Cryo 48"	5000			162	10616	chipmunk	4950	1298
20390	Transfer Hall	500	12	13.9	27.9	1824	chipmunk	490	139
0	A0 Kicker Bld Short Cct	5000			272	17800	chipmunk	4900	1360
124	TG Annex / TG N. Addition	500	12.7	13.9	17.3	1132	chipmunk	24.5	17.3
273	WH-C-1 Manhole	500	13.5	13.9	10.0	657	TLM1	3400	10.0
745	Enc B Cryo	100			12.7	834	TLM1	3400	12.7
2333	SY Encl. G2: cryo pen 1	500			13.3	871	chipmunk	495	133
2337	SY Encl. G2: cryo pen 1	500			15.0	979	chipmunk	495	134

In the event of an MCI in the Switchyard Fixed Target Beamlines a member of the public would receive 12.7 mrem in one hour if that person were next to the Enclosure B cryo penetration located on the berm adjacent to the Helen Edwards building during an MCI (see Figure 3). The location is presently protected by an interlocked Total Loss Monitor. This Total Loss Monitor will be credited, and it will limit the MCI to a single pulse. See figure xxx below.

Figure 3: Location of the Enclosure B cryo penetration located on the berm adjacent to the Helen Edwards building.

Passive Controls

Fencing

The ISA spreadsheet indicates a deficit of shielding in some regions of the berm through the Master Substation. In consultation with the Radiation Analysis Department, the dose was estimated at the top of the berm, then scaled to the location of the metal fence surrounding the master substation. The resulting dose was 66 mrem/hr. This is below the required 500 mrem for an MCI. The fencing surrounding the Master Substation will be credited.

Conclusion

In the event of an MCI in the Switchyard Fixed Target Beamlines with all credited controls in place, a member of the public would receive 12.7 mrem in one hour if that person were next to the Enclosure B cryo penetration located on the berm adjacent to the Helen Edwards building during an MCI.

In the event of an MCI in the Switchyard Fixed Target 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 F25 cryo penetration inside F2 Refrigerator Building. This would result in a dose to an individual of 1572 mrem in an hour.