Fermi National Accelerator Laboratory

Fermilab

Switchyard Fixed Target Beamlines Maximum Credible Incident (MCI)

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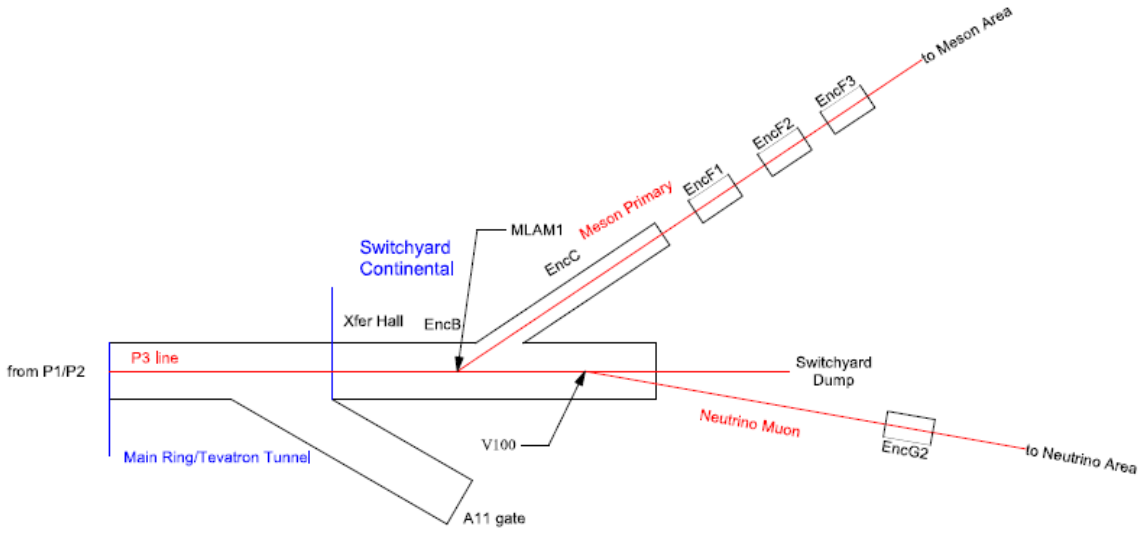
Scope

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]
5 ≤ D < 100 mrem	16.3	13.8	18.7
100 ≤ D < 500 mrem	13.9	11.4	16.3

Exposure at a labyrinth is assessed using the ISA 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	Allowed 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
1520-1536	Beam Pipe after Switchyard Dump	100	18.7	18.5	Fence
3005-3350	Pipe - Master Substation	100	18.7	15.5	Fence
3350-3967	Berm Pipe	100	18.7	17.7-18.6	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. These areas are bold in the tables; an '(F)' indicates a fence will be used.

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	3C	18.7

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
0	4A	13.9
85	4A	13.9

175	4A	13.9
184	4A	13.9
200	4A	13.9
236	4A	13.9
251	4A	13.9
260	4A	13.9
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	3A	16.3
1000	3C	18.7
1100	3C	18.7
1200	3C	18.7
1280	3C	18.7
1330	3C	18.7
1510	3C	18.7

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	**3C**	**17.5 (F)**
1536-1633	3C	18.7
1633-1708	3B	13.8
1708-1752	3C	18.7
1752-2070	3C	18.7
2070-2224	3A	16.3
2224-2285	3A	16.3
2285-2390	3A	16.3
2390-2417	3A	16.3
2417-2420	3A	16.3
2420-2430	3C	18.7
2430-2690	3C	18.7
2690-2763	3C	18.7
2763-3090	3C	18.7
3090-3110	3C	18.7
3110-3146	3C	18.7
3146-3179	3C	18.7

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	3C	18.7
NC11700	3C	18.7
NC11800	3C	18.7
NC11900	3C	18.7

NC12180	3A	16.3
NC12260	3A	16.3
NC12285	3A	16.3
NC12400	3A	13.9
NC12460	3C	18.7
NC12600	3C	18.7
NC12720	3C	18.7

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	3C	18.7
1635-2058	3C	18.7
2058-2130	3C	18.7
2130-2308	3C	18.7
2308-2350	3A	13.9
2350-2370	3C	18.7
2370-2413	3A	13.9
2413-2480	3C	18.7
2480-2850	3C	18.7
2850-2950	3C	18.7
2950-3005	3C	18.7
3005-3350	**3C**	**14.5 (F)**
3350-3475	**3C**	**14.5 (F)**

3475-3558	**3C**	**14.5 (F)**
3558-3950	**3C**	**14.5 (F)**
3950-3967	**3C**	**14.5 (F)**

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	3A	16.3
M001600	3A	16.3
M001620	3A	16.3
M001640	3A	16.3
M002050	3A	16.3
M002100	3A	16.3
M002200	3C	18.7
M002340	3A	16.3
M002360	3A	16.3
M002400	3C	18.7
M002600	3C	18.7
M002750	3C	18.7
M002950	3A	16.3
M003200	**3C**	**15.5 (F)**
ME13353	**3C**	**14.5 (F)**
ME13400	**3C**	**14.5 (F)**
ME13450	**3C**	**14.5 (F)**
ME13500	**3C**	**14.5 (F)**

ME13550	**3C**	**14.5 (F)**
ME13552	**3C**	**14.5 (F)**
ME13600	**3C**	**14.5 (F)**
ME13650	**3C**	**14.5 (F)**
ME13700	**3C**	**14.5 (F)**
ME13750	**3C**	**14.5 (F)**
ME13800	**3C**	**14.5 (F)**

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. Additional controls, when needed, are also listed.

Table 9 Penetrations requiring fill

Cell or Z-Location	Location or Enclosure	Fill	Additional Control
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.	fence
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.	fence

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

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 1 below.

Figure 1: 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 100 mrem for an MCI. The radiation fence around the Master Substation will be credited.

The ISA spreadsheet indicates a deficit of shielding in several locations between the Master Substation and Enclosure M01. The existing fence surrounding berm, from the Master Substation, to M01, will be

credited. The largest deficit is one foot, which would result in an MCI exposure of 197 mrem. The fence is always at least 39 feet from the beamline. Scaling by 1/r results in an exposure of 5.1 mrem.

The ISA spreadsheet indicates a deficit of shielding extending 16 feet downstream of the Switchyard Dump when evaluated for a 100 mrem exposure. In this case, a fence placed 10 feet from beam center would reduce the exposure to less than 100 mrem. However, if the area is evaluated for a 500 mrem exposure, there is adequate shielding.

Location	Shielding (efd)		
	Existing	500 mrem	100 mrem
Downstream of SY Dump	18.5	16.3	18.7

The ISA spreadsheet indicates a deficit of penetration fill for the Enclosure G2 cryo penetrations. These penetrations are located behind an existing radiation fence. At the exit of the penetrations, the combined exposure is 1850 mrem for an MCI (one hour duration). The fence is located approximately 20 ft. from the penetration. Scaling by 1/20 results in a combined exposure of 92.5 mrem. We also note that the Feynman center parking lot is approximately 175 ft. from the penetration, where the combined exposure would be 11 mrem; Discovery Rd is approximately 200 feet distant, with a 30 foot thick berm intervening, resulting in a combined exposure of 1 mrem.

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.

Critical Devices

Overview – HP3US & HP3DS

The critical devices HP3US and HP3DS compose the bend of the P3 beamline.

HP3US consists of 58 dipoles wired in series; each bends the beam by 7.8 mradian. HP3DU consists of 46 dipoles wired in series; each bends the beam by 7.8 mradian. Each magnet is rotated by 3.9 mradian in the bend plane, with respect to the incoming beam, thus following the beam trajectory. The dipoles is either a B1- or B2-style dipole, having a 126 mm or 99 mm aperture, respectively, in the bend plane. Both B1 and B2 dipoles are 6.1 meters (20 feet) long.

The periodic structure of the P3 line is four dipoles followed by a quadrupole.

Determining where the beam will impact is a geometric construction. Assume the beam enters the first dipole at the inner-most edge of the aperture, and all magnets in the string have the larger (126 mm) aperture. In this case, the beam will impact the third magnet of the string. Beam cannot be transported beyond this point.

The P3 beamline resides in tunnel formerly occupied by the Main Ring and Tevatron. The tunnel is approximately 10 ft. in diameter. The distance from the HP3US loss point to Transfer Hall is 2559 ft.; the distance from the HP3DS loss point to Transfer Hall is 1430 ft.

Dose in Adjacent Enclosures – Transfer Hall

The dose in Transfer Hall was calculated using the Lab. & Pen. Worksheet (below). The actual distance between the loss-point and Transfer Hall should be represented by seven legs, however, the spreadsheet is unable to accommodate this. Therefore, five legs are used. The resulting exposure is 115 mrem for a one-hour duration.

Due to limitations of the spreadsheet, HP3US is not analyzed. However, as HP3US is 1129 ft. upstream of HP3DS, the exposure resulting from beam impacting HP3US is less than the exposure resulting from beam impacting HP3DS.

Summary

Assuming an MCI of 4.2E13 protons per cycle, 55 second cycle, 120 GeV protons, and one hour duration, the dose at Transfer Hall resulting from a loss caused by HP3DS is 115 mrem.

Title:	**Switchyard HP3US and HP3DS**		**PWKS -**
Description:	Dose rate in Transfer Hall is estimated for MCI in Switchyard critical devices. Line-of-sight distance in tunnel of 200 ft is chosen as common leg length. Assume 10 ft. diameter tunnel; cross-sectional area is calculated at right. HP3DS geometry approximated below. HP3US dose rate is less than half of value shown.		
Originated:	W. Schmitt	**Reviewed:**	

E_p =	120.0000	GeV
N_{ppp} =	4.20E+13	
Cycle Time =	55.00	seconds
R =	0.00	ft
S =	200.00	ft
T =	0.00	ft
Empirical Source =		mrem/pulse
Shielded Source =		mrem/pulse
Source Term =	1.64E+05	mrem/pulse
Number of Legs =	5	

Leg 1 Area =	67.357	ft²
Leg 2 Area =	67.357	ft²
Leg 3 Area =	67.370	ft²
Leg 4 Area =	67.370	ft²
Leg 5 Area =	67.370	ft²

Leg 1 Length =	200.00	ft
Leg 2 Length =	200.00	ft
Leg 3 Length =	200.00	ft
Leg 4 Length =	200.00	ft
Leg 5 Length =	200.00	ft

Leg 1 "Units" =	24.37
Leg 2 "Units" =	24.37
Leg 3 "Units" =	24.37
Leg 4 "Units" =	24.37
Leg 5 "Units" =	24.37

	90° Attenuation
Leg 1	1.00E+00
Leg 2	1.00E+00
Leg 3	1.00E+00
Leg 4	1.00E+00
Leg 5	1.07E-05

	Attenuation Factors
Leg 1	1.00E+00
Leg 2	1.00E+00
Leg 3	1.00E+00
Leg 4	1.00E+00
Leg 5	1.07E-05

Net Attenuation = 1.07E-05

	Effective Dose After Leg (mrem/pulse)
Leg 1	1.64E+05
Leg 2	1.64E+05
Leg 3	1.64E+05
Leg 4	1.64E+05
Leg 5	1.76E+00

	Effective Dose Rate After Leg (mrem/ hr)
Leg 1	1.08E+07
Leg 2	1.08E+07
Leg 3	1.08E+07
Leg 4	1.08E+07
Leg 5	1.15E+02

Eff. Dose After Final Leg (mrem/pulse)	1.76E+00
Eff. Dose Rate After Final Leg (mrem/hour)	1.15E+02

Collinear legs detected.

Beam Power =	1.47E+01	kilowatts
N_{pps} =	7.64E+11	protons per second
N_{pph} =	2.75E+15	protons per hour
f_p =	65.45	beam pulses per hour

Source-to-Mouth Distance =	200.00	ft
Θ_{source} =	0.00	degrees
Sullivan Correction Factor =	850.81	

Projections of Leg 1 Length

$L1_R$ =		ft
$L1_S$ =	200.00	ft
$L1_T$ =		ft

Loss-to-Wall Leg 2 Short Circuit Proj.

SC_R =		ft
SC_S =		ft
SC_T =		ft

Subsequent Leg Angles

α_1 =	0.00	degrees
ϕ_2 =	3.60	degrees
ϕ_3 =	3.30	degrees
ϕ_4 =	3.60	degrees
ϕ_5 =	3.60	degrees
D_{sc} =		ft

Leg 2 Short Cir. Contribution = mrem/pulse

Notes

Further information about this worksheet can be found in the 12-11-2020 memo from M. Vincent entitled "Modifications to the Labyrinth & Penetration Worksheet."

Overview – MLam and V204

The critical devices MLam and V204 allow beam to the Meson Primary beamline.

MLam consists of two “two-way Lambertson” magnets wired in series; they are treated as dipoles. Each dipole bends the beam 4 milliradians. V204 consists of two dipoles wired in series; each bends the beam 6 mradian.

When MLam is de-energized, the beam continues forward to the Switchyard Dump. The beam is not transported further.

When V204 is de-energize, beam is no longer bent vertically toward the Meson Area. Instead, it impacts the downstream Enclosure C wall, approximately 1’4” feet below the berm pipe between Enclosure C and Enclosure F1.

Dose in Adjacent Enclosures

Enclosure F1

Case 1

The first case assumes MLam is off, and beam is lost in the Switchyard Dump.

The Switchyard Dump is approximately 850 ft. south, 138 ft. east, and 4 ft. below Enclosure F1; the straight-line distance is 861 ft. Using the TVL of dirt (3.38 ft.), this equates to approximately 250 TVLs, or a reduction in dose of 10^-250. Assuming an unshielded dose of 9.95E+08 mrem for an MCI of one hour, the dose at Enclosure C is reduced to 9.95E-242 mrem.

Note that these exponents are below the reckoning of even an astrophysicist.

Case 2

The second case assumes V204 is off, and beam is lost on the downstream face of Enclosure C.

The point where beam in lost on the downstream face of Enclosure C is approximately 157 ft. downstream, 95 feet lateral, and 4 feet below Enclosure F1; the straight-line distance is 183 ft. Using the TVL of dirt (3.38 ft.), this equates to approximately 54 TVLs, or a reduction in dose of 10^-54. Assuming an unshielded dose of 9.95E+08 mrem for an MCI of one hour, the dose at Enclosure C is reduced to 9.95E-46 mrem.

Enclosure G2

Case 1

The first case assumes MLam is off, and beam is lost in the Switchyard Dump or MuLam.

The Switchyard Dump is approximately 725 ft. south and 10 ft. below Enclosure FC; the straight-line distance is 725 ft. Enclosure G1 intervenes approximately 170 ft. The total length of dirt between the Switchyard Dump and Enclosure G2 is 555 ft. Using the TVL of dirt (3.38 ft.), this equates to approximately 165 TVLs, or a reduction in dose of 10^-165. Assuming an unshielded dose of 9.95E+08 mrem for an MCI of one hour, the dose at Enclosure C is reduced to 9.95E-153 mrem.

Case 2

The second case assumes V204 is off, and beam is lost on the downstream face of Enclosure C.

The point where beam in lost on the downstream face of Enclosure C is approximately 108 ft. south, 56 feet east, and 8 feet below Enclosure G2; the straight-line distance is 122 ft. Using the TVL of dirt (3.38 ft.), this equates to approximately 36 TVLs, or a reduction in dose of 10^-36. Assuming an unshielded dose of 9.95E+08 mrem for an MCI of one hour, the dose at Enclosure C is reduced to 9.95E-28 mrem.

Summary

Table 1 lists the distances between loss points and nearest accessible enclosures. Also listed is the number of TVLs. An unshielded exposure is assumed to be 9.95E+08 mrem for a one hour duration. To reduce this exposure to 5 rem, a factor of 5.03E-04 is required, which equates to 3.29 TVL. All listed TVLs are exceed this requirement.

Critical Device	Loss Point	Enc F1		Enc G2	
		distance [ft.]	TVL	distance [ft.]	TVL
MLam off	SYDump	861	255	725	165
V204 off	EncC	184	54	122	36

Overview – V100

The critical devices V100 allows beam to Enclosure G2 and the Neutrino Area. V100 consists of two dipoles wired in series. When V100 is de-energized, the beam continues forward to the Switchyard Dump. The beam is not transported further.

Dose in Adjacent Enclosures

Enclosure F1

The Switchyard Dump is approximately 850 ft. south, 138 ft. east, and 4 ft. below Enclosure F1; the straight-line distance is 861 ft. Using the TVL of dirt (3.38 ft.), this equates to approximately 250 TVLs, or a reduction in dose of 10^-250. Assuming an unshielded dose of 9.95E+08 mrem for an MCI of one hour, the dose at Enclosure C is reduced to 9.95E-242 mrem.

Enclosure G2

The Switchyard Dump is approximately 725 ft. south and 10 ft. below Enclosure G2; the straight-line distance is 725 ft. Enclosure G1 intervenes approximately 170 ft. The total length of dirt between the Switchyard Dump and Enclosure G2 is 555 ft. Using the TVL of dirt (3.38 ft.), this equates to approximately 165 TVLs, or a reduction in dose of 10^-165. Assuming an unshielded dose of 9.95E+08 mrem for an MCI of one hour, the dose at Enclosure C is reduced to 9.95E-153 mrem.

Summary

Table 1 lists the distances between loss points and nearest accessible enclosures. Also listed is the number of TVLs. An unshielded exposure is assumed to be 9.95E+08 mrem for a one hour duration. To reduce

this exposure to 5 rem, a factor of 5.03E-04 is required, which equates to 3.29 TVL. All listed TVLs are exceed this requirement.

Critical Device	Loss Point	Enc F1		Enc G2	
		distance [ft.]	TVL	distance [ft.]	TVL
V100 off	SYDump	861	250	725	165

Overview - MuLam

The critical devices MuLam allows beam to Enclosure NM1 in the Neutrino Area. MuLam is a single dipole which deflects beam from the Neutrino Center trajectory to the Neutrino Muon trajectory. When MuLam is de-energized, the beam continues along the Neutrino Center trajectory until it is absorbed by the beam stop in G2. The beam stop is 90'7" from the upstream wall of the G2 Enclosure.

Dose in Adjacent Enclosures

Enclosure N01

Enclosure N01 is located 423 downstream of Enclosure G2. Enclosure G2 is approximately 10 feet wide, eight feet tall, and 350 feet long. The enclosures are connected by a berm pipe, varying in diameter from 16 inches to 30 inches. The dose in N01 is calculated using the Lab. & Pen. Worksheet (below). The resulting exposure is 28 mrem for a one-hour duration.

Enclosure F1

The F1 and G2 Enclosures are separated by a minimum of 114 ft. Both enclosures are underground. Assuming a TVL for dirt of 3.38 ft., this separation equals 33 TLV, or a reduction in dose of 10^-33. The exposure in Enclosure F1, due to an MCI loss in Enclosure G2, will be below background.

Summary

Assuming an MCI of 4.2E13 protons per cycle, 55 second cycle, 120 GeV protons, and one hour duration, employing the critical device, MuLam, would result in an exposure at N01 of 28 mrem.

Title:	**MCI dose in N01 for beam lost on G2 beam stop**		MuLam-G2 Beam Stop to N01
Description:	Beam incident upon G2 beam stop creates dose rate at nearest location in N01 approximately XXX feet downstream. Assume 10'x8' upstream tunnel cross-section; 12" berm pipe.		
Originated:		**Reviewed:**	

E_p =	120.0000	GeV
N_{ppp} =	4.20E+13	
Cycle Time =	55.00	seconds
R =	0.00	ft
S =	259.00	ft
T =	0.00	ft
Empirical Source =		mrem/pulse
Shielded Source =		mrem/pulse
Source Term =	9.80E+04	mrem/pulse
Number of Legs =	1	
Leg 1 Area =	4.981	ft^2
Leg 1 Length =	424.00	ft
Leg 1 "Units" =	189.98	

Eff. Dose After Final Leg (mrem/pulse)	4.32E-01
Eff. Dose Rate After Final Leg (mrem/hour)	2.83E+01

Beam Power =	1.47E+01	kilowatts
N_{pps} =	7.64E+11	protons per second
N_{pph} =	2.75E+15	protons per hour
f_p =	65.45	beam pulses per hour

Source-to-Mouth Distance =	259.00	ft
Θ_{source} =	0.00	degrees
Sullivan Correction Factor =	850.81	

Projections of Leg 1 Length		
$L1_R$=	0.00	ft
$L1_S$=	424.00	ft
$L1_T$=	0.00	ft

α_1 = 0.00 degrees

Subsequent Leg Angles

Notes

	90° Attenuation
Leg 1	4.41E-06

	Attenuation Factors
Leg 1	4.41E-06

Net Attenuation = 4.41E-06

	Effective Dose After Leg (mrem/pulse)
Leg 1	4.32E-01

	Effective Dose Rate After Leg (mrem/ hr)
Leg 1	2.83E+01

Further information about this worksheet can be found in the 12-11-2020 memo from M. Vincent entitled "Modifications to the Labyrinth & Penetration Worksheet."