Fermi National Accelerator Laboratory

Meson Area Maximum Credible Incident (MCI)

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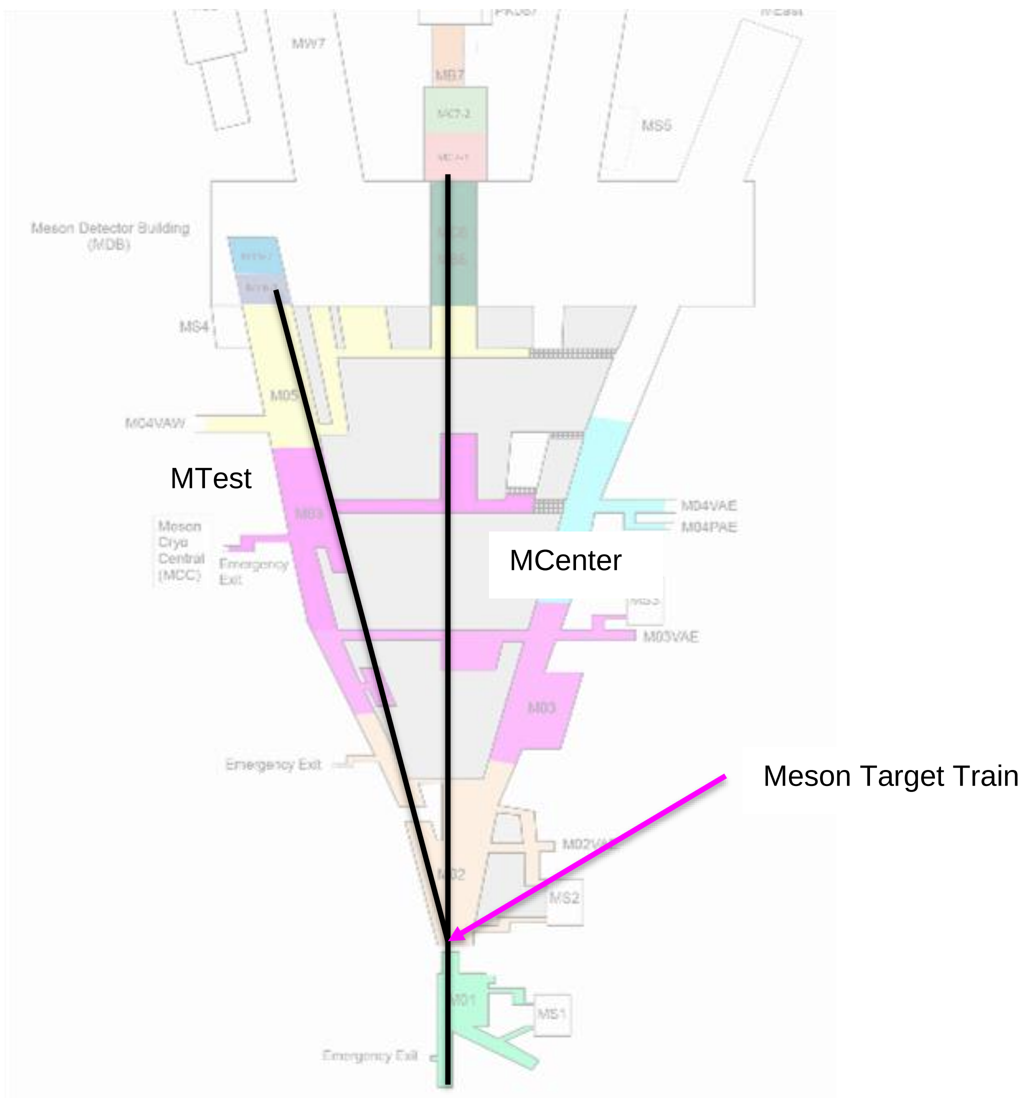
Scope

This document describes the Maximum Credible Incident (MCI) for the Meson Area.

The Meson Area segment includes the following:

- The Meson Primary beamline (MPrimary), from M01 to the downstream end of the Meson Target Train, which terminates at the upstream end of the M02 enclosure.
- The Meson Test beamline (MTest), from the upstream end of M02 through M05.
- The Meson Center beamline (MCenter), from the upstream end of M02 through MC6.



Beam Parameters

The Meson Area segment receives primary beam (120 GeV protons) from the Switchyard Fixed Target Beamlines segment and delivers secondary beam to the Meson Switchyard 120 Experimental Areas.

The Meson Primary beamline receives beam from the Switchyard Fixed Target Beamlines segment and delivers beam to the Meson Test or Meson Center beamlines. Simultaneous delivery is possible. The Meson Test and Meson Center beamlines contain targets. When the primary beam strikes the target, "secondary beam" is produced. The secondary beam is then transported through a beamline to the Meson Switchyard 120 Experimental Areas. The Meson Test beamline delivers secondary beam to the MT6 sections, located in the Meson Switchyard 120 Experimental Areas; the Meson Center beamline delivers secondary beam to the MC7 sections, located in the Meson Switchyard 120 Experimental Areas.

The MCI scenario for the Meson Area is 2.75E15 protons per hour, 4.2E13 protons per cycle, 55 second cycle time, 120GeV beam energy, missteered into a magnet, beam pipe, or buried pipe.

The MTest beamline evaluation considers three operating modes: "Diffracted Proton Mode", "High Energy Pion Mode", and "Low Energy Pion Mode". Diffracted Proton Mode uses the MTest M01 Target and the M03 Pinhole Collimator to attenuate the beam by a factor of 8.4E-6. High Energy Pion Mode does not use the pinhole collimator; however, production rates have shown that the attenuation of the beam in this mode at 66GeV, the upper limit of the beam energy in this mode, is 2E-7. In Low Energy Pion mode, the primary beam is allowed past the M01 Target and is delivered to the MT4 Low Energy Pion Mode Target, located at FSCSz=5164'. This target attenuates the primary beam by a factor of 1E-5.

Table 1 compares the unprotected exposure in each of the above modes. To obtain exposure from secondary beam, the primary beam exposure is scaled by the yield and the ratio of the secondary to primary energy raised to the 0.8 power.

Table 1: Comparison of MCI Exposure for Various MTest Modes. Primary beam is included for comparison only

Mode	**Energy**	**Intensity**	**Yield**	**Exposure**	
	[GeV]	[protons per cycle]	[]	[mrem/cycle]	[mrem/hr]
Primary Beam	120	4.2E+13	1.0E+00	1.52E+07	9.95E+08
Meson Test - Diffracted Proton	120	4.2E+13	8.4E-06	128	8357
Meson Test - High Energy Pion	66	4.2E+13	2.0E-07	1.88	123
Meson Test - Low Energy Pion	30	4.2E+13	1.0E-05	50.1	3282

The ISA spreadsheets indicate that for any secondary beam 3 efd is required, regardless of mode or loss type, for the 100 <= D <= 500 range. We assume a hybrid scenario where primary beam is transported to the Low Energy Pion target, located in MT3 (the furthest primary beam may be transported), and Diffracted Proton mode thereafter (which give the maximum exposure per cycle).

The MCenter beamline evaluation assumes that the primary beam reaches the MC6 Target, in the MC6 Enclosure at FSCSz=5728'. The MC6 Target is required to be in place before beam operation is authorized; if the target is not in place, then the secondary beam is not produced. The MC6 Target attenuates the primary beam by a factor of 4.7E-4. The upper limit of the secondary beamline energy is 90GeV.

Table 2 compares the unprotected exposure in each of the above scenarios. To obtain exposure from secondary beam, the primary beam exposure is scaled by the yield and the ratio of the secondary to primary energy raised to the 0.8 power.

Table 2 Comparison of MCenter in Various Modes.:

Mode	**Energy**	**Intensity**	**Yield**	**Exposure**	
[]	[GeV]	[protons per cycle]	[]	[mrem/cycle]	[mrem/hr]
Primary Beam	120	4.2E+13	1.0E+00	1.52E+07	9.95E+08
Meson Center - Pion	90	4.2E+13	4.7E-04	5.68E+03	3.71E+05

Meson Primary

Meson Primary extends from the upstream end of Meson Enclosure M01 to the end of the Meson Target Train, which terminates at the upstream end of Enclosure M02.

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 in Meson Primary. 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 element of the 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 enclosures are designed and constructed as permanent concrete and earth-covered radiation shielding that use a combination of permanent shielding, movable shielding, and penetration shielding to protect personnel from radiological exposure due to the MCI.

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 accounts for the effectiveness of various materials compared to soil (for example, concrete is more effective than soil).

Meson Primary is assessed using the ISA spreadsheets. The relevant sections of the longitudinal and transverse sheets are shown in Tables 3 and 4.

Table 3: Longitudinal Sections for Meson Primary

Longitudinal Range	Location	Fixed Shielding (efd)	Movable Shielding (efd)	Current Shielding (efd)	Category	Required (efd)	Difference (efd)
3967-4003	M01	15.7		15.7	3A	16.3	-0.6
4003-4062	M01	16.5		16.5	3A	16.3	0.2
4062-4160	M01	20.4		20.4	3A	16.3	4.1
4160-4300	M01	16.4		16.4	3A	16.3	0.1
4300-4340	meson target train	25.8		25.8	3A	16.3	9.5

Table 4: Transverse Sections for Meson Primary

Transverse Station (ft)	Location	Fixed Shielding (efd)	Movable Shielding (efd)	Current Shielding (efd)	Category	Required (efd)	Difference (efd)
ME13975	M01	15.8		15.8	3A	16.3	-0.4
ME14000	M01	15.7		15.7	3A	16.3	-0.6
MC14035	M01	20.7		20.7	3A	16.3	4.4
ME14050	M01	21.3		21.3	3A	16.3	5.0
ME24250	M01	19.0		19.0	3A	16.3	2.8

Meson Primary does not have adequate shielding to insure less than 100 mrem exposure outside the berm. An additional credited control is needed, which will be discussed in the "Fences" section.

Movable Shielding

The access door to the Meson Target Train rail spur must contain 13.1 efd. Although assessed as a penetration (refer to worksheet MCP06), the shielding is design to be moved, and is included here.

Penetration Shielding

The following penetrations are required to be filled/shielded.

Table 5: Meson Primary Penetrations Requiring Shielding

Location		**Removable Shielding**
Enclosure	**Z-Location**	
	(feet)	**(efd)**
M01	4128 (MS1)	2.65
M01	4144 (MS1)	2.65
M01	4158 (MS1)	2.65

Fences

The existing radiation fencing surrounding the Meson Area berm will be credited (this includes the Meson Primary area).

At its closest approach, the fencing is approximately 53 feet from the Meson Primary beamline enclosure. The minimum required shielding is 16.3 efd. Additionally, we “remove” an additional one foot of shielding for defense-in-depth, resulting in 15.3 efd. The distance from this edge to the fence is 38 ft., which is used to further scale the exposure by 1/r. Under this condition, the worst exposure would be 5 mrem for an MCI of one hour duration.

Credited Shielding and Defense-in-Depth

As explained in “Fences”, due to the distance between the credited fence and berm, one may reduce the required amount of shielding. The credited shielding for Meson Primary is 15.3 efd; anything is excess of this value is defense-in-depth. The minimum defense-in-depth is one foot.

Active Credited Engineering Controls

Active engineered controls are systems designed to reduce the risks from the MCI to an acceptable level. The active controls in place for Meson Primary are discussed below.

Radiation Safety Interlock System

The Meson Primary enclosure, M01, employs a Radiation Safety Interlock System (RSIS). This same system also protects enclosures F1, F2, and F3 in the Switchyard Fixed Target Beamlines segment; and enclosures M02, M03, M04, and M05 in the Meson Area. The characteristics of the system are described in Section I of the Fermilab SAD.

Access to M01 is via interlocked gates. The RSIS inhibits beam transport by controlling redundant critical devices, S:MLAM1 and S:V204, located in Enclosure C of the Switchyard Fixed Target Beamlines segment.

Meson Test

The Test Meson beamline begins at the upstream end of enclosure M02 and extends through enclosures M03 and M05. The Meson Test beamline delivers secondary beam – primary beam that has passed through a target -- to the MT6 enclosures, part of the Meson Switchyard 120 Experimental Areas.

Primary targets, that is, targets which receive primary beam, are located at the upstream end of the Meson Target Train, and in the MT3 section of the M03 enclosure.

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 in Meson Test. 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 element of the 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 enclosures are designed and constructed as permanent concrete and earth-covered radiation shielding that use a combination of permanent shielding, movable shielding, and penetration shielding to protect personnel from radiological exposure due to the MCI.

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. Finally, the required amount of shielding varies depending on the type of beam – primary or secondary. The secondary beam will have momentum and flux differing from the primary beam. No distinction is made as to particle type – protons are always assumed.

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).

Meson Test is assessed using the ISA spreadsheets. The relevant sections of the longitudinal and transverse sheets are shown below. "P" indicates primary beam; "S" indicates secondary beam.

Table 6: MTest Longitudinal Shielding

Beam Type	Longitudinal Range	Location	Fixed Shielding (efd)	Movable Shielding (efd)	Current Shielding (efd)	Category	Required (efd)	Difference (efd)
P	4340-4605	M02	19.3		19.3	3A	16.3	3.0
P	4605-4710	PIPE	25.3		25.3	3C	18.7	6.6
P	4710-4716	M02	18.2		18.2	3A	16.3	1.9
P	4716-4841	PIPE	23.5		23.5	3C	18.7	4.9
P	4841-4889	M03	15.5		15.5	3B	13.8	1.7
P	4889-4989	PIPE	17.7		17.7	3C	18.7	-0.9
P	4989-4995	M03	11.9		11.9	3B	13.8	-1.9
P	4995-5043	PIPE	17.4		17.4	3C	18.7	-1.3
P	5043-5164	M03	13.6		13.6	3A	16.3	-2.7
S	5164-5590	M03,4,5	11.9		11.9	3A	3.0	8.9
S	5590-5618	M05	6.9		6.9	3C	3.0	3.9

Table 7: MTest Transverse Shielding

Beam Type	Transverse Station (ft)	Location	Fixed Shielding (efd)	Movable Shielding (efd)	Current Shielding (efd)	Category	Required[1] (efd)	Difference (efd)
P	ME24375	M02	21.6		21.6	3A	16.3	5.3
P	MC24480	M02	22.3		22.3	3A	16.3	6.0
P	MC24540	M02	21.6		21.6	3A	16.3	5.3
P	MC24550	M02	17.4		17.4	3A	16.3	1.1
P	MC34775	M02	22.2		22.2	3C	18.7	3.6
P	MC34973	M03	18.1		18.1	3C	18.7	-0.5
P	MC34985	M03	13.1		13.1	3B	13.8	-0.6
P	ME35003	M03	19.8		19.8	3C	18.7	1.2
P	ME35005	M03	19.8		19.8	3C	18.7	1.2
P	MC35025	M03	17.3		17.3	3C	18.7	-1.3
P	MC35065	M03	13.6		13.6	3A	16.3	-2.7
S	MC45297	M04	12.7		12.7	3A	3.0	9.7

S	MC55520	M05	14.3		14.3	3A	3.0	11.3

Meson Test does not have adequate shielding to insure less than 100 mrem exposure outside the berm. An additional credited control is needed, which will be discussed in the "Fences" section.

Low Energy Pion Target Region

The Generic Shielding Criteria (ref. TM-2550) are used at Fermilab to determine shielding adequacy and to screen for situations that may require more detailed analysis. These criteria are encoded into spreadsheets for three common beam loss scenarios that are then scaled to various beam parameters using well-known scaling laws. For most areas, the criteria for a point-loss is used and then scaled by energy, intensity, and geometry to the relevant loss conditions.

The equation used is:
Dt = 3.38*log10[(1.6E14 protons/4.2E13 protons)*(1.33 s/55 s)*((3'/6.5')^2)]
Where 21', 1.6E14 protons, 1.33 s, and 3' are assumptions in the Generic Shielding Criteria. The result is -9.7 ft., that is, 9.7 ft. less than that required under the generic situation (23.7 ft.), or 14 ft.

At MT3, the generic shielding criteria indicate a requirement of 14 feet of soil-equivalent shielding to protect areas that may be occupied to less than 100 mrem/hour under MCI conditions. Since the minimum shielding between the beamline and the surface in this region is 13.5 feet, the deficit is reduced to 0.5 ft.

MT3 Cryo Penetration

The MT3 Cryo labyrinth is presently protected by a chipmunk. This is further discussed in the "Active Credited Engineering Controls" section.

Movable Shielding

Movable shielding is not listed in Meson Test.

Penetrations

The following penetrations are required to be filled/shielded.

Table 8: MTest Penetrations Requiring Fill

Location		**Removable Shielding**
Enclosure	**Z-Location**	
	(feet)	

M02	4350	Duct filled with 20 feet of sand
M02	4438 (MS2)	4.5 efd
M02	4467 (MS2)	4.5 efd
M02	4495 (MS2)	4.5 efd
M02	4550	Duct filled with 20 feet of sand

Fences

The existing radiation fencing surrounding the Meson Area berm will be credited (this includes the Meson Test area). The following analysis parallels that is Meson Primary.

At it's closest approach, the fencing is approximately 30 feet from the Meson Test beamline enclosure. This allows us to reduce the amount of credited shielding while taking credit for the fence.

Credited Shielding and Defense-in-Depth

As explained in "Fences", due to the distance between the credited fence and berm, one may reduce the required amount of shielding. There is a minimum of one foot of defense-in-depth. The following tables summarize the credited shielding, defense-in-depth, and exposure for an MCI of one hour duration.

Table 9: Meson Test Longitudinal Locations Showing Credited Shielding, Defense-in-Depth, and Exposure.

Location (Logitudinal)	credited shielding	defense-in-depth	exposure (one hour)
	[efd]	[efd]	[mrem]
4340-4605	14.5	4.8	11
4605-4710	14.5	10.8	57
4710-4716	14.5	3.7	11
4716-4841	14.5	9.0	57
4841-4889	14.5	1.0	2
4889-4989	14.5	3.2	57
4989-4995	9.9	2.0	47
4995-5043	15.0	2.4	41
5043-5164	11.6	2.0	17
5164-5590	3.0	8.9	3
5590-5618	3.0	3.9	3

Table 10: Meson Test Transverse Locations Showing Credited Shielding, Defense-in-Depth, and Exposure.

Location (Transverse)	credited shielding	defense-in-depth	exposure (one hour)
	[efd]	[efd]	[mrem]
ME24375	14.5	7.1	11
MC24480	14.5	7.8	11
MC24540	14.5	7.1	11
MC24550	14.5	2.9	11
MC34775	14.5	7.7	57
MC34973	14.5	3.6	57
MC34985	9.9	3.2	47
ME35003	15.0	4.8	41
ME35005	15.0	4.8	41
MC35025	15.0	2.3	41
MC35065	11.6	2.0	17
MC45297	3.0	9.7	3
MC55520	3.0	11.3	3

Active Credited Engineering Controls

Active engineered controls are systems designed to reduce the risks from the MCI to an acceptable level. The active controls in place for Meson Test are discussed below.

Radiation Safety Interlock System

The Meson Test enclosures, M02, M03, M04, and M05 employ a Radiation Safety Interlock System (RSIS). This same system also protects MT6 Section 1 and MT6 Section 2 in the Meson Area. The characteristics of the system are described in Section I of the Fermilab SAD.

Meson Test requires an interlocked radiation detector at the MT3 Cryo labyrinth, as discussed previously.

Access to M02, M03, M04, and M05 is via interlocked gates. The RSIS inhibits beam transport by controlling redundant critical devices, F:MW1W and MT3 Beam Stop. F:MW1W is located in M01; inhibiting this device prevents primary beam from traversing the Meson Target Train. The MT3 Beam Stop prevents beam transport beyond M03.

MT3 Cryo Penetration Chipmunk

The MT3 Cryo labyrinth is presently protected by a chipmunk. Two memoranda, (MTest Cryo Laby Low energy 2E14” and “MT-6 Z5115 Hard Component 2E14”” assess the locations at 1.67E12 protons per hour with a 60 second cycle time, and a single pulse of 2.5E13 protons. In both cases, 120 GeV protons are assumed. The analysis looks at a position 13' from the labyrinth exit, the location of the radiation fence. The results are summarized in Table 11:

Table 11: MT3 Cryo Labyrinth Analysis

Analysis (at fence)	Analyzed		MCI		
	[protons/cycle]	[mrem/cycle]	[protons/cycle]	[mrem/cycle]	[mrem/hr]
Low Energy	5.00E+13	0.17	4.20E+13	0.14	9.3
Hard Component	5.00E+13	0.75	4.20E+13	0.63	41

There is a ~50x reduction in dose from the labyrinth to the fence, which would result in 2515 mrem/hr (= 50 x (9.3+41) mrem/rh). This requires a credited radiation detector.

The "chipmunk trip calculator_7_21_15.xlxs" spreadsheet provided in Beams Document 4732-v8, "Chipmunk and TLM radiation detector trip calculators" is used to calculate the expected dose 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.

Setting the trip level is 95 mrem/hr would result in a 38 mrem exposure.

Table 12: MTest Chipmunk

Location	**Limit**	**Dose without chipmunk**		**Chipmunk trip setting**	**Dose with Chipmunk**
	[mrem]	[mrem]	[mrem/cycle]	[mrem/hr]	[mrem]
MT3 Cryo Penetration	100	2515	38	95	38

Primary Logic Chasis

The MTest Primary Logic Chassis in the MTest Critical Device Controller prevents unattenuated beam reaching the MT6-1 and MT6-2 enclosures by ensuring that secondary beamline is properly configured for one of the three possible modes. A target must be in place; a fixed-aperture collimator, if required, is in position; power supplies for key momentum-selection magnets will operate within the specified current range.

Meson Center

The Test Center beamline begins at the upstream end of enclosure M02 and extends through enclosures M03 and M05. The Meson Center beamline delivers secondary beam – primary beam that has passed through a target -- to the MC7 enclosure, part of the Meson Switchyard 120 Experimental Areas.

A primary target, that is, a target which receive primary beam, is located at the upstream end the MC6 enclosure.

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 in Meson Test. 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 element of the 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 enclosures are designed and constructed as permanent concrete and earth-covered radiation shielding that use a combination of permanent shielding, movable shielding, and penetration shielding to protect personnel from radiological exposure due to the MCI.

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. Finally, the required amount of shielding varies depending on the type of beam – primary or secondary. The secondary beam will have momentum and flux differing from the primary beam. No distinction is made as to particle type – protons are always assumed.

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

Meson Center is assessed using the ISA spreadsheets. The relevant sections of the longitudinal and transverse sheets are shown below. “P” indicates primary beam; “S” indicates secondary beam.

Table 13: Meson Center Longitudinal Shielding

Beam Type	Longitudinal Range	Location	Fixed Shielding (efd)	Movable Shielding (efd)	Current Shielding (efd)	Category	Required[1] (efd)	Difference (efd)
P	4340-4566	M02	18.6		18.6	3A	16.3	2.3
P	4566-4656	M02	18.9		18.9	3A	16.3	2.6
P	4656-4709	M02	21.5		21.5	3A	16.3	5.2
P	4709-4936	PIPE	24.3		24.3	3C	18.7	5.6
P	4936-4986	M03	17.5		17.5	3A	16.3	1.2
P	4986-5297	PIPE	19.1		19.1	3C	18.7	0.4
P	5297-5353	M04	15.1		15.1	3B	13.8	1.3
P	5353-5518	PIPE	18.9		18.9	3C	18.7	0.2
P	5518-5603	M05	15.5		15.5	3A	16.3	-0.8
P	5603-5662	MC6	15.0		15.0	4A	13.9	1.1
P	5662-5733	MC6		7.8	7.8	4A	13.9	-6.1
S	5733-5790	MC6		6.6	6.6	4A	3.0	3.6
S	5790-5793	MC6		3.3	3.3	4A	3.0	0.3
S	5793-5798	MC6		0.0	0.0	4A	3.0	-3.0

Table 14: Meson Center Transverse Shielding

Beam Type	Transverse Station (ft)	Location	Fixed Shielding (efd)	Movable Shielding (efd)	Current Shielding (efd)	Category	Required (efd)	Difference (efd)
P	MC24540	M02	21.7		21.7	3A	16.3	7.8
P	MC24550	M02	16.7		16.7	3A	16.3	2.8
P	MC34985	M03	19.7		19.7	3A	16.3	5.9
P	ME35003	M03	22.3		22.3	3A	16.3	8.4
P	ME35005	M03	22.3		22.3	3A	16.3	8.4
P	MC65655	MC6	16.9		16.9	4A	13.9	3.0
P	MC65662-E	MC6	28.0		28.0	4A	13.9	14.2
P	MC65662-W	MC6	39.1		39.1	4A	13.9	25.2
P	MC65664-E	MC6	22.2		22.2	4A	13.9	8.3
P	MC65670-W	MC6	29.7		29.7	4A	13.9	15.8
P	MC65673-W	MC6	48.2		48.2	4A	13.9	34.3
P	MC65679-W	MC6	26.4		26.4	4A	13.9	12.5
P	MC65682-W	MC6	16.5		16.5	4A	13.9	2.6
P	MC65685-W	MC6	13.2		13.2	4A	13.9	-0.7
P	MC65701-W	MC6	16.5		16.5	4A	13.9	2.6
P	MC65715-W	MC6	9.9		9.9	4A	13.9	-4.0
P	MC65719-W	MC6	13.2		13.2	4A	13.9	-0.7
P	MC65722-W	MC6	9.9		9.9	4A	13.9	-4.0
P	MC65728-W	MC6	9.9		9.9	4A	13.9	-4.0
S	MC65733-E	MC6	26.5		26.5	4A	3.0	23.5
S	MC65734-W	MC6	16.5		16.5	4A	3.0	13.5

S	MC65735-W	MC6	13.2		13.2	4A	3.0	10.2
S	MC65739-W	MC6	16.5		16.5	4A	3.0	13.5
S	MC65741-E	MC6	24.9		24.9	4A	3.0	21.9
S	MC65742-W	MC6	11.6		11.6	4A	3.0	8.6
S	MC65743-W	MC6	14.9		14.9	4A	3.0	11.9
S	MC65747-W	MC6	19.8		19.8	4A	3.0	16.8
S	MC65749-E	MC6	26.5		26.5	4A	3.0	23.5
S	MC65750-W	MC6	14.9		14.9	4A	3.0	11.9
S	MC65754-W	MC6	19.8		19.8	4A	3.0	16.8
S	MC65755-W	MC6	16.5		16.5	4A	3.0	13.5
S	MC65757-W	MC6	11.6		11.6	4A	3.0	8.6
S	MC65759-E	MC6	24.9		24.9	4A	3.0	21.9
S	MC65759-W	MC6	11.6		11.6	4A	3.0	8.6
S	MC65765-W	MC6	13.6		13.6	4A	3.0	10.6
S	MC65767-E	MC6	18.2		18.2	4A	3.0	15.2
S	MC65775-E	MC6	8.3		8.3	4A	3.0	5.3
S	MC65788-E	MC6	11.6		11.6	4A	3.0	8.6
S	MC65790-W	MC6	3.3		3.3	4A	3.0	0.3
S	MC65791-E	MC6	8.3		8.3	4A	3.0	5.3

Meson Center does not have adequate shielding to insure less than 100 mrem exposure outside the berm. An additional credited control is needed, which will be discussed in the "Fences" section.

The longitudinal table indicates two regions of insufficient shielding within the Meson Detector Building; this is also show in the transverse table. These regions will require interlocked detectors, discussed below.

Movable Shielding

The MC6 enclosure is constructed from movable shielding.

Penetrations

The following penetrations are required to be filled/shielded.

Table 15: Meson Center Penetrations Requiring Fill

Location		**Removable Shielding**
Enclosure	**Z-Location**	
	(feet)	**(efd)**
M02	4350	Duct filled with 16.5 feet of sand
M03	4985	MCenter sight riser filled with 16.5 feet of sand

M04	5300	MCenter sight riser filled with 13 feet of sand
M05	5510	MCenter sight riser filled with 15.5 feet of sand

Fences

The existing radiation fencing surrounding the Meson Area berm will be credited (this includes the Meson Center area). The following analysis parallels that is Meson Primary.

At it's closest approach, the fencing is approximately 86 feet from the Meson Center beamline enclosure. The minimum required shielding is 13.8 efd. Additionally, we "remove" an additional one foot of shielding for defense-in-depth, resulting in 12.8 efd. The distance from this edge to the fence is 73.2 ft., which is used to further scale the exposure by 1/r. Under this condition, the worst exposure would be 75 mrem for an MCI of one hour duration.

Credited Shielding and Defense-in-Depth

As explained in "Fences", due to the distance between the credited fence and berm, one may reduce the required amount of shielding. The credited shielding for Meson Center is 12.8 efd; anything is excess of this value is defense-in-depth. The minimum defense-in-depth is one foot.

Active Credited Engineering Controls

Active engineered controls are systems designed to reduce the risks from the MCI to an acceptable level. The active controls in place for Meson Test are discussed below.

Radiation Safety Interlock System

The Meson Center enclosures, M02, M03, M04, M05, and MC6 employ a Radiation Safety Interlock System (RSIS). This same system also protects MC7 and MB7, part of the Meson Switchyard 120 Experimental Areas. The characteristics of the system are described in Section I of the Fermilab SAD.

Access to M02, M03, M04, M05, and MC6 is via interlocked gates. The RSIS inhibits beam transport by controlling redundant critical devices, F:MC1D and MC2 Beam Stop. The F:MC1D magnet is located in M01; inhibiting this device prevents primary beam from traversing the Meson Target Train. The MC2 Beam Stop prevents beam transport beyond M02.

The current monitor on the MC6D magnet string is an input to the MCenter CDC. This magnet string is located immediately downstream of the primary target. The current is specified to prevent beam greater than 90 GeV from traversing the secondary beamline; the current must be less than 575 amps.

The ISA spreadsheets indicate insufficient shielding above the MC6 enclosure, located within the Meson Detector Building. The 5662-5733 region is referred to as the “MDB MC6” region. The 5793-5798 region is referred to the “MDB Catwalk”.

MDB MC6

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 dose 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.

MDB Catwalk

The approved MCenter shielding assessment assumes that an accident pulse of 120 GeV primary protons at 1E13/pulse and with a secondary yield of 4.7E-4 can be transported to this location. In this case, the accident dose rate is calculated using the Malensek method as 86 mrem/pulse. Since scaling by energy would not result in a meaningful difference, we will ignore it and scale this dose rate to:

D = (86 mrem/pulse) * (4.2E13/1E13) * (3600/55) = 2.36E4 mrem/hour

Summary

Four interlocked radiation monitors (“Chipmunks”) are required to provide sufficient coverage above MC6 – three spaced longitudinally above the enclosure and a fourth at the catwalk. The radiation monitor on the MC6 catwalk must be set to trip on a single pulse.

Table 16 summarizes the dose without and with a Chipmunk in place.

Table 16: Meson Center Dose with and Without a Chipmunk in place

Location	Present	Required	Limit	Dose without chipmunk		Chipmunk trip setting	Dose with Chipmunk
	[efd]	[efd]	[mrem]	[mrem]	[mrem/cycle]	[mrem/hr]	[mrem]
MDB MC6 US	13.2	13.9	500	806	12.3	440	114
MDB MC6 Mid	9.9	13.9	500	7628	117	440	146
MDB MC6 DS	9.9	13.9	500	7628	117	440	146
MC6 Catwalk	0	3.0	5000	23600	361	440	361

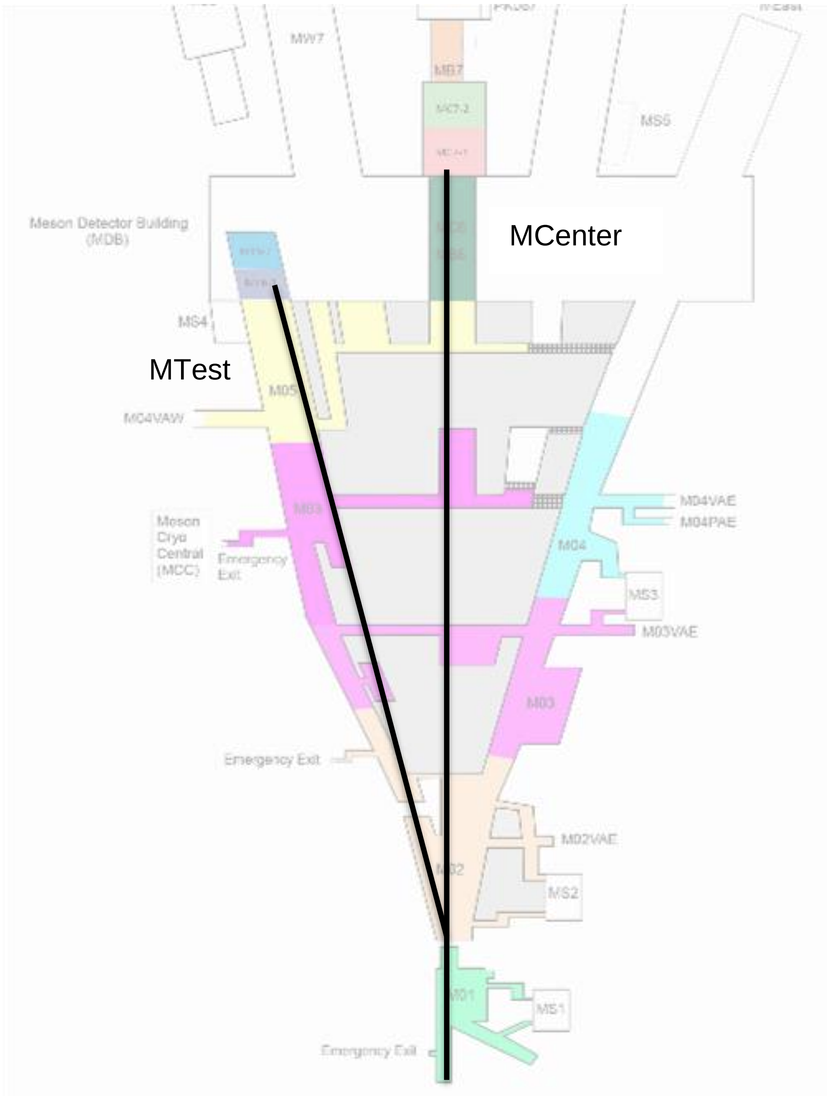
Conclusion

In the event of an MCI in the Meson Area 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 MC6 Catwalk, which is protected by an interlocked detector. This would result in a dose to an individual of approximately 361 mrem in one hour.

MT6 and MC7 Enclosures

This document describes the Maximum Credible Incident (MCI) for the MT6 and MT7 Enclosures.

The MT6 Enclosure receives secondary beam from the Meson Test beamline, which is part of the Meson Area. The MC7 Enclosure receives secondary beam from the Meson Center beamline, which is part of the Meson Area.



Beam Parameters

MT6

The MT6 Enclosures receive beam from the Meson Test beamline, which can operate in three different modes: “Diffracted Proton”, “High Energy Pion”, and “Low Energy Pion”. Details of these modes will not be addressed in this Note; they will be taken as underlying assumption.

Characteristics of the Meson Test beamline are shown in Table 1. This table assumes the MCI limit for the Meson area -- 2.75E15 protons per hour, 4.2E13 protons per cycle, 55 second cycle time, 120GeV beam energy.

Table 17: Comparison of the unprotected exposure in each of the listed modes assuming an MCI in the Meson Area.

Mode	**Energy**	**Intensity**	**Yield**	**Exposure**	
	[GeV]	[protons per cycle]	[]	[mrem/cycle]	[mrem/hr]
Meson Test - Diffracted Proton	120	4.2E+13	8.4E-06	128	8357
Meson Test - High Energy Pion	66	4.2E+13	2.0E-07	1.88	123
Meson Test - Low Energy Pion	30	4.2E+13	1.0E-05	50.1	3282

Enclosure MT6 will be evaluated assuming “Diffracted Proton” mode because this mode results in the greatest unprotected exposure.

MC7

The MC7 Enclosures receive beam from the Meson Center beamline, which delivers secondary protons up to 90 GeV. Details of the Meson Center beamline will not be addressed in this Note; they will be taken as underlying assumption. Characteristics of the Meson Test beamline are shown in Table 2. This table assumes the MCI limit for the Meson area -- 2.75E15 protons per hour, 4.2E13 protons per cycle, 55 second cycle time, 120GeV beam energy.

Table 18: Comparison of the unprotected exposure in each of the listed modes assuming an MCI in the Meson Area

Mode	**Energy**	**Intensity**	**Yield**	**Exposure**	
[]	[GeV]	[protons per cycle]	[]	[mrem/cycle]	[mrem/hr]
Meson Center Secondary	90	4.2E+13	4.7E-04	5.68E+03	3.71E+05

Credited Controls

MT6

The MT6 Enclosure begins upstream of the Meson Detector Building and extends into the Meson Detector Building. See Figure 1.

The “2003 Shielding Assessment for the Switchyard 120 Project” states:

> To calculate the one pulse accident dose, we use the maximum accelerated beam rate in the Main Injector of 3×10^{13} protons/pulse. The transmission of protons through the MTest target and collimator down to the MT6 user areas is calculated to be 1×10^{-5} in the proton mode. This means that if the maximum Main Injector intensity is delivered in one pulse to MT6, we receive 3×10^{8} protons. This is 300 times the intensity of the one pulse dose for 1x106 protons shown in Appendix GK-28. The maximum one pulse accident dose is thus 1.2 mrem, in region M. This is well below the acceptable value of 5 mrem. The interlocked integrating radiation detectors mentioned above limit the radiation flux from one pulse accidents to less than the limit appropriate to each area (the detectors are listed in Section 10.

As such, the maximum exposure is 1.2 mrem/3E8 protons at 120 GeV. Figure 1 shows the location and surrounding geography.

If, instead, we use the MCI intensity of 4.2E13 protons per cycle, and the updated yield of 8.4E-06, then the maximum intensity becomes 3.5E-08 protons per cycle. Scaling the exposure results in a 1.4 mrem exposure for a single MCI event.

Extrapolating this to one hour, and recalling that beam is delivered with at a 55 second cycle time, result a in 94 mrem exposure.

The greatest exposure outside the MT6 Enclosure, assuming a one-hour MCI in the Meson Test beamline, is 94 mrem. No interlocked detector is required.

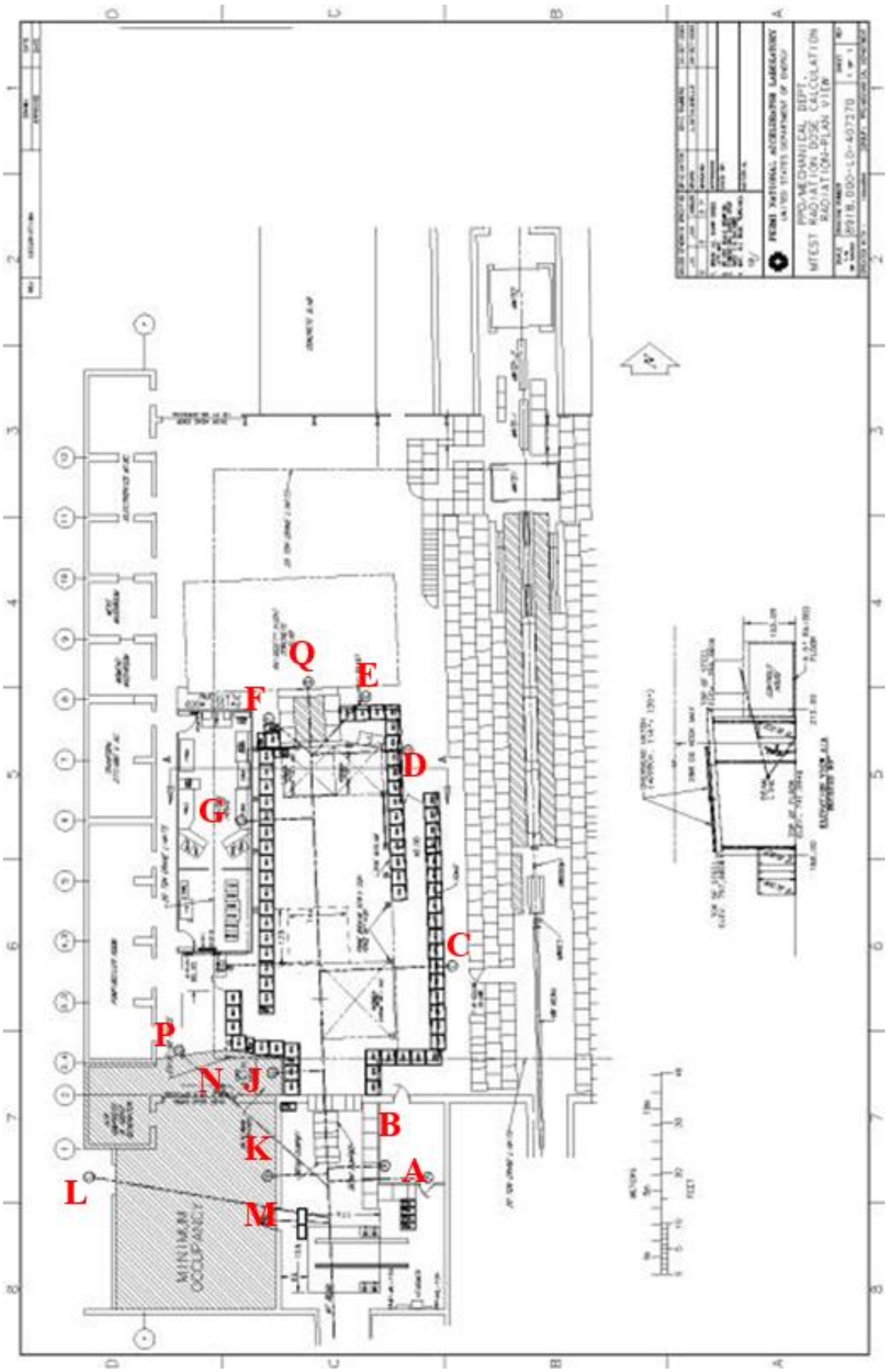


Figure 1: Location of MT6, the Meson Detector Building, and maximum exposure (M).

MC7

The MC7 Enclosure is located outside, and immediately North, of the Meson Detector Building, as indicated in Figure 2.

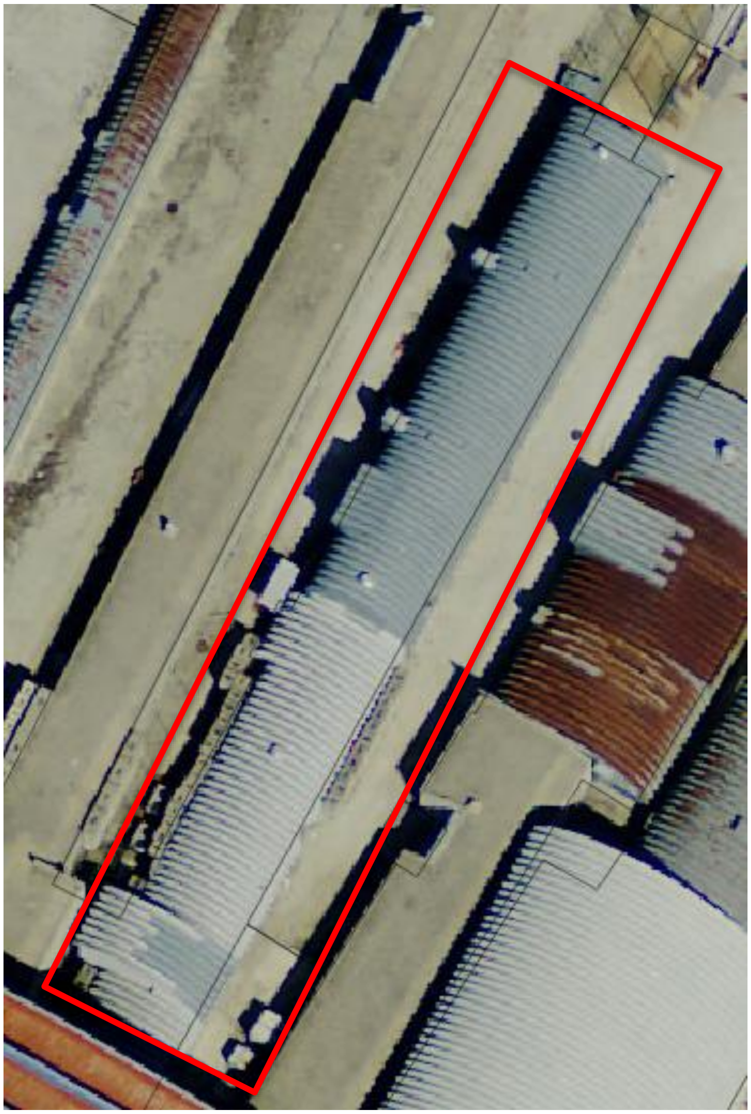


Figure 2: MC7 Enclosure.

Secondary beam enters MC7 from MC6. The beam strikes a “secondary target”, producing “tertiary beam”. The tertiary beam is used by experimenters.

The secondary beam is initially surrounded by shield blocks. The shield blocks provide a minimum of 3' of efd, which, as per the ISA spreadsheets, will reduce the dose from an MCI to between 100 mrem and 500 mrem.

The secondary beam them passes through an approximately three-foot gap. This gap is not shielded; it will be covered by an interlocked detector. The nearest exterior wall is 12' from the beam

Finally, the secondary beam strikes the secondary target. The target is housed in a monolithic assembly, consisting of shielding around the target; an aperture to allow tertiary particle to escape (the "tertiary beam"), and an absorber.

This assemble provides adequate shielding to reduce the dose to below 500 mrem in case of an MCI. The aperture, along with the yield, reduces the tertiary intensity by a factor of approximately 10^-3 (compared to the secondary beam intensity). The assembly must be locked in place before secondary beam is transported.

For clarity, the beam parameters are restated

- Primary beam: 4.2E13 protons per cycle, 55 second cycle time, 120 GeV
- Secondary yield: 4.7E-4 secondary particles (90 GeV) per primary proton
- Tertiary yield: 1.0E-3 tertiary particles per secondary particle
- Secondary beam: 1.97E10 protons per cycle, 55 second cycle time, 90 GeV
- Tertiary beam: 1.97E08 protons per cycle, 55 second cycle time, 90 GeV

Note the following: The methodology always assumes protons; the tertiary yield, for the radiological assessment is taken to be 10E-02 – a highly conservative value, ten-times greater that the calculated yield; the tertiary beam energy is assumed to be 90 GeV – a highly conservative value given the energy of the secondary beam and the production angle.

Using the Experimental Hall methodology, the anticipated dose on the MC7 roof – the point closest to the beam, yet not within the enclosure -- is 13.3E3 mrem in an hour, or 204 mrem per cycle, assuming MCI intensity. The anticipated dose from the tertiary beam is 130 mrem in an hour. One may conclude that an interlocked detector is required due to the secondary beam, and that the tertiary beam dose from the tertiary beam is acceptable.

A Chipmunk may be placed at the air gap, six feet below the secondary beam. The Experimental Hall methodology indicates an esposure of 13.1E3 mrem in an hour. Using this value in the

Chipmunk Trip Calculator, one finds that setting the trip level of 495 merm/hr would result in a 200 mrem exposure at the chipmunk. The chipmunk would trip on a single cycle. Table 2 lists exposure at various locations with and without a chipmunk. For other locations, the dose with a chipmunk is scaled by the dose without a chipmunk. Note that the proposed chipmunk is not accessible while running. Table 3 summarizes this information.

Table 19: Exposure with and without an interlocked radiation detector at various locations.

Location Description	**Distance From Loss**	**Dose**	
		without chipmunk	**with chipmunk**
	[ft]	**[mrem]**	**[mrem]**
One foot outside of MC7 Enclosure	12	3030	46
On contact with the lowest MC7 roof	5.71	13383	205
One foot above the lowest MC7 roof	6.71	9691	148
Proposed Chipmunk at air gap (not accessible while running)	6	13071	200

The greatest exposure outside the MC7 Enclosure, assuming a single MCI cycle, is 205 mrem.

Fences

The fencing north of the MC6 enclosure, spanning between the Meson Polarized and Meson West beamlines, is credited. This fencing is greater than 100 ft. from the loss point. Scaling by 1/r results in an exposure of less than 2 mrem.

Summary

In the event of MCI intensity beam being delivered to the Meson Test beamline, exposure outside the MT6 Enclosure would remain below 100 mrem for the one-hour MCI assumed duration. The shielding blocks, which define the MT6 enclosure, must be in place.

In the event of MCI intensity beam being delivered to the Meson Center beamline, exposure outside the MC7 Enclosure would exceed 100 mrem, necessitating an interlocked radiation monitor, credited fencing, and the target/collimator/absorber assembly in place. Configuring this detector to trip at 495 mrem/hr, the primary beam would be inhibited after a single cycle, resulting in an exposure of less than 2 mrem.

Critical Devices

Overview – MC1D & MC2BS

The critical devices MC1D and MC2BS allow beam to the MC7 enclosures. In the event either critical device actuates, this failure causes the upstream Critical Device Controller to inhibit the associated critical devices; in this case, beam would be inhibited from Meson Primary.
MC1D is a single dipole located immediately upstream of the Meson Target Train (MTT). When de-energized, beam is no longer directed toward the Meson Center beamline. Instead, the beam hits the downstream center absorber on the Meson Target Train, where it is absorbed. The MTT is approximately 75' long.

MC2BS is a 54" (1.37 m) long iron beam-stop located in enclosure M02, approximately 351 ft. downstream of the M01 target Meson Target Train. When MC2BS is closed, beam is absorbed, and loses energy, in the beam stop.

Horizontally, the MCenter beamline is straight; there are no horizontal bends. Vertically, the MCenter beamline has a "dogleg" at the downstream end of Enclsoure MC5, at where the beamline changes elevation; upon entering Enclosure MC6, the elevation has increased by approximately four feet.

Between MC3 and MC5, the beam passes through a 12" diameter berm pipe. There are intervening cross-overs and small "divots". MC5 is a 6'6" wide, 8' tall tunnel. MC6 is a larger enclosure. In this area, the (secondary) beamline is elevated atop concrete shield blocks, which occlude the MCenter primary beamline.

Exposure in Adjacent Enclosures -- Enclosure MC7

The exposure in MC7 is calculated in two steps. The exposure is calculated at the entrance to the MC6 enclosure using a "Labyrinth & Penetration" spreadsheet. This exposure is then attenuated by the intervening concrete blocks. Only the shielding blocks surrounding the fixed- and variable- collimators are accounted for (approximately 12 feet of concrete).

For the calculations, the MCI condition of 4.2E13 protons per cycle, 120 GeV, 55 second cycle time, and one-hour duration, are assumed. The tenth-layer value of concrete is 2.86 feet, thus, the 12 feet of concrete provides a reduction in exposure of 10^-(12/2.86) = 6.3E-05.

Case 1: MC1D

The spreadsheet, presented below, indicates an exposure of 11 mrem at the entrance of MC6. Next, we apply the reduction due to the concrete shielding, resulting in a final exposure of 7.1E-04 mrem.

Case 2: MC2BS

The spreadsheet, presented below, indicates an exposure of 1.71E+03 mrem at the entrance of MC6. Next, we apply the reduction due to the concrete shielding, resulting in a final exposure of 1.09E-01 mrem.

Conclusion

Assuming an MCI of 4.2E13 protons per cycle, 55 second cycle, 120 GeV protons, and one hour duration, employing either critical device, MC1D or MC2BS, would result in an exposure at MC7 of 7.1E-04 mrem or 1.09E-01 mrem, respectively.

Title:	MCI dose in MC7 for beam on Meson Target Train	MC1D- Target Train	
Description:	Beam incident upon Meson Target Train creates dose rate at nearest location in MC6 approximately 1320 feet downstream. Assume 10'x10' upstream tunnel cross-section; 12" berm pipe; 6'6"x8' downstream tunnel.		
Originated:		Reviewed:	

E_p =	120.0000	GeV
N_{ppp} =	4.20E+13	
Cycle Time =	55.00	seconds
R =	0.00	ft
S =	230.00	ft
T =	0.00	ft
Empirical Source =		mrem/pulse
Shielded Source =		mrem/pulse
Source Term =	1.24E+05	mrem/pulse
Number of Legs =	7	
Leg 1 Area =	80.000	ft²
Leg 2 Area =	0.785	ft²
Leg 3 Area =	80.000	ft²
Leg 4 Area =	0.785	ft²
Leg 5 Area =	52.000	ft²
Leg 6 Area =	0.785	ft²
Leg 7 Area =	80.000	ft²
Leg 1 Length =	145.00	ft
Leg 2 Length =	230.00	ft
Leg 3 Length =	54.00	ft
Leg 4 Length =	308.00	ft
Leg 5 Length =	52.00	ft
Leg 6 Length =	255.00	ft
Leg 7 Length =	55.00	ft
Leg 1 "Units" =	16.21	
Leg 2 "Units" =	259.53	
Leg 3 "Units" =	6.04	
Leg 4 "Units" =	347.54	
Leg 5 "Units" =	7.21	
Leg 6 "Units" =	287.74	
Leg 7 "Units" =	6.15	

Eff. Dose After Final Leg (mrem/pulse)	1.70E-01
Eff. Dose Rate After Final Leg (mrem/hour)	1.11E+01

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 =	230.00	ft
Θ_{source} =	0.00	degrees
Sullivan Correction Factor =	850.81	

α_1 = 0.00 degrees

Projections of Leg 1 Length		
$L1_R$ =	0.00	ft
$L1_S$ =	145.00	ft
$L1_T$ =	0.00	ft

Subsequent Leg Angles		
ϕ_2 =	0.00	degrees
ϕ_3 =	0.00	degrees
ϕ_4 =	0.00	degrees
ϕ_5 =	0.00	degrees
ϕ_6 =	0.00	degrees
ϕ_7 =	0.00	degrees

Loss-to-Wall Leg 2 Short Circuit Proj.		
SC_R =		ft
SC_S =		ft
SC_T =		ft

D_{sc} = ft

Leg 2 Short Cir. Contribution = mrem/pulse

Notes

	90° Attenuation	Attenuation Factors
Leg 1	6.32E-03	1.00E+00
Leg 2	1.00E+00	1.00E+00
Leg 3	1.00E+00	1.00E+00
Leg 4	1.00E+00	1.00E+00
Leg 5	1.00E+00	1.00E+00
Leg 6	1.00E+00	1.00E+00
Leg 7	1.37E-06	1.37E-06

Net Attenuation = 1.37E-06

	Effective Dose After Leg (mrem/pulse)	Effective Dose Rate After Leg (mrem/ hr)
Leg 1	1.24E+05	8.13E+06
Leg 2	1.24E+05	8.13E+06
Leg 3	1.24E+05	8.13E+06
Leg 4	1.24E+05	8.13E+06
Leg 5	1.24E+05	8.13E+06
Leg 6	1.24E+05	8.13E+06
Leg 7	1.70E-01	1.11E+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."

Title:	MCI dose in MC7 for beam on MC2BS	MC2BS	
Description:	Beam incident upon MC2BS creates dose rate at nearest location in MC6 approximately 967 feet downstream. Assume 10'x10' upstream tunnel cross-section; 12" berm pipe; 6'6"x8' downstream tunnel.		
Originated:		Reviewed:	

E_p =	120.0000	GeV
N_{ppp} =	4.20E+13	
Cycle Time =	55.00	seconds
R =	0.00	ft
S =	18.00	ft
T =	0.00	ft
Empirical Source =		mrem/pulse
Shielded Source =		mrem/pulse
Source Term =	2.03E+07	mrem/pulse
Number of Legs =	6	
Leg 1 Area =	0.785	ft²
Leg 2 Area =	80.000	ft²
Leg 3 Area =	0.785	ft²
Leg 4 Area =	52.000	ft²
Leg 5 Area =	0.785	ft²
Leg 6 Area =	80.000	ft²
Leg 1 Length =	230.00	ft
Leg 2 Length =	54.00	ft
Leg 3 Length =	308.00	ft
Leg 4 Length =	52.00	ft
Leg 5 Length =	255.00	ft
Leg 6 Length =	55.00	ft
Leg 1 "Units" =	259.53	
Leg 2 "Units" =	6.04	
Leg 3 "Units" =	347.54	
Leg 4 "Units" =	7.21	
Leg 5 "Units" =	287.74	
Leg 6 "Units" =	6.15	

Eff. Dose After Final Leg (mrem/pulse)	2.62E+01
Eff. Dose Rate After Final Leg (mrem/hour)	1.71E+03

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 =	18.00	ft
Θ_{source} =	0.00	degrees
Sullivan Correction Factor =	850.81	

α_1 = 0.00 degrees

Projections of Leg 1 Length		
$L1_R$=	0.00	ft
$L1_S$=	230.00	ft
$L1_T$=	0.00	ft

Subsequent Leg Angles		
ϕ_2 =	0.00	degrees
ϕ_3 =	0.00	degrees
ϕ_4 =	0.00	degrees
ϕ_5 =	0.00	degrees
ϕ_6 =	0.00	degrees

Loss-to-Wall Leg 2 Short Circuit Proj.		
SC_R=		ft
SC_S=		ft
SC_T=		ft

D_{sc} = ft

Leg 2 Short Cir. Contribution = mrem/pulse

	90° Attenuation
Leg 1	1.00E+00
Leg 2	1.00E+00
Leg 3	1.00E+00
Leg 4	1.00E+00
Leg 5	1.00E+00
Leg 6	1.29E-06

	Attenuation Factors
Leg 1	1.00E+00
Leg 2	1.00E+00
Leg 3	1.00E+00
Leg 4	1.00E+00
Leg 5	1.00E+00
Leg 6	1.29E-06

Net Attenuation = 1.29E-06

Notes

	Effective Dose After Leg (mrem/pulse)	Effective Dose Rate After Leg (mrem/ hr)
Leg 1	2.03E+07	1.33E+09
Leg 2	2.03E+07	1.33E+09
Leg 3	2.03E+07	1.33E+09
Leg 4	2.03E+07	1.33E+09
Leg 5	2.03E+07	1.33E+09
Leg 6	2.62E+01	1.71E+03

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 – MW1W & MT3BS

The critical devices MW1W and MT3BS allow beam to the MT6 enclosures. In the event either critical device actuates, this failure causes the upstream Critical Device Controller to inhibit the associated critical devices; in this case, beam would be inhibited from Meson Primary.

MW1W consists of six "three-way Lambertson" magnets wired in series; they are treated as dipoles. MW1W is located upstream of the MT1 target (used in "diffracted proton" and "high energy pion" modes). When MW1W is de-energized, the beam continues forward to the upstream absorber of the Meson Target Train, missing the primary target. No secondary particles are produced; beam is absorbed in the Meson Target Train.

MT3BS is a 54" (1.37 m) long iron beam-stop located in enclosure M03. MT3BS is located downstream of the M01 target (used in "diffracted proton" and "high energy pion" modes) and upstream of the MT3 target (used in "low energy pion" mode). When MT3BS is closed, beam is absorbed, and loses energy, in the beam stop.

Dose in Adjacent Enclosures -- Enclosure MT6

Case 1: MW1W

Enclosure MT6 is approximately 1332 ft. downstream of the of the Meson Target Train.

The dose in MT6 is calculated using the Lab. & Pen. Worksheet (below). The calculation assumes a continuous ten foot wide by eight foot tall tunnel, with no bends, from the Meson Target Train to the MT6 Enclosure. The resulting exposure is 16 mrem for a one-hour duration.

Case 2: MT3BS

Enclosure MT6 is approximately 579 ft. downstream of the of MT3 beam stop (MT3BS).

The dose in MT6 is calculated using the Lab. & Pen. Worksheet (below). The calculation assumes a continuous ten foot wide by eight foot tall tunnel, with no bends, from MT3BS to the MT6 Enclosure. The resulting exposure is 533 mrem for a one-hour duration.

Conclusion

Assuming an MCI of 4.2E13 protons per cycle, 55 second cycle, 120 GeV protons, and one hour duration, employing either critical device, MW1W or MT3BS, would result in an exposure at MT6 of 16 mrem or 533 mrem, respectively.

Title:	MCI dose in MT6-1 for beam on Meson Target Train	MW1W- Target Train
Description:	Beam incident upon Meson Target Train creates dose rate at nearest accessible location in MT6-1 approximately 1332 feet downstream. Tunnel segmented into 6 colinear legs to approximate as-built geometry.	
Originated:		Reviewed:

E_p =	120.0000	GeV
N_{ppp} =	4.20E+13	
Cycle Time =	55.00	seconds
R =	0.00	ft
S =	230.00	ft
T =	0.00	ft
Empirical Source =		mrem/pulse
Shielded Source =		mrem/pulse
Source Term =	1.24E+05	mrem/pulse
Number of Legs =	6	
Leg 1 Area =	0.785	ft²
Leg 2 Area =	52.000	ft²
Leg 3 Area =	0.785	ft²
Leg 4 Area =	52.000	ft²
Leg 5 Area =	120.000	ft²
Leg 6 Area =	52.000	ft²
Leg 1 Length =	280.00	ft
Leg 2 Length =	25.00	ft
Leg 3 Length =	190.00	ft
Leg 4 Length =	30.00	ft
Leg 5 Length =	250.00	ft
Leg 6 Length =	327.00	ft
Leg 1 "Units" =	316.03	
Leg 2 "Units" =	3.47	
Leg 3 "Units" =	214.45	
Leg 4 "Units" =	4.16	
Leg 5 "Units" =	22.82	
Leg 6 "Units" =	45.35	

Eff. Dose After Final Leg (mrem/pulse)	2.41E-01
Eff. Dose Rate After Final Leg (mrem/hour)	1.57E+01

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 =	230.00	ft
Θ_{source} =	0.00	degrees
Sullivan Correction Factor =	850.81	

α_1 =	0.00	degrees

Projections of Leg 1 Length		
$L1_R$ =	0.00	ft
$L1_S$ =	280.00	ft
$L1_T$ =	0.00	ft

Subsequent Leg Angles		
ϕ_2 =	0.00	degrees
ϕ_3 =	0.00	degrees
ϕ_4 =	0.00	degrees
ϕ_5 =	0.00	degrees
ϕ_6 =	0.00	degrees

Loss-to-Wall Leg 2 Short Circuit Proj.		
SC_R =		ft
SC_S =		ft
SC_T =		ft

D_{sc} =		ft
Leg 2 Short Cir. Contribution =		mrem/pulse

	90° Attenuation
Leg 1	1.00E+00
Leg 2	1.00E+00
Leg 3	1.00E+00
Leg 4	1.00E+00
Leg 5	1.00E+00
Leg 6	1.94E-06

	Attenuation Factors
Leg 1	1.00E+00
Leg 2	1.00E+00
Leg 3	1.00E+00
Leg 4	1.00E+00
Leg 5	1.00E+00
Leg 6	1.94E-06

Net Attenuation = 1.94E-06

Notes

	Effective Dose After Leg (mrem/pulse)		Effective Dose Rate After Leg (mrem/ hr)
Leg 1	1.24E+05	Leg 1	8.13E+06
Leg 2	1.24E+05	Leg 2	8.13E+06
Leg 3	1.24E+05	Leg 3	8.13E+06
Leg 4	1.24E+05	Leg 4	8.13E+06
Leg 5	1.24E+05	Leg 5	8.13E+06
Leg 6	2.41E-01	Leg 6	1.57E+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."

Title:	MCI dose in MT6-1 for beam on MTest critical device		MT3BS
Description:	Beam incident upon MT3BS creates dose rate at nearest accessible location in MT6-1 approximately 577 feet downstream. Tunnel approximated by single-leg labyrinth.		
Originated:		Reviewed:	

E_p =	120.0000	GeV
N_{ppp} =	4.20E+13	
Cycle Time =	55.00	seconds
R =	0.00	ft
S =	250.00	ft
T =	0.00	ft
Empirical Source =		mrem/pulse
Shielded Source =		mrem/pulse
Source Term =	1.05E+05	mrem/pulse
Number of Legs =	1	
Leg 1 Area =	52.000	ft²
Leg 1 Length =	327.00	ft
Leg 1 "Units" =	45.35	

Eff. Dose After Final Leg (mrem/pulse)	8.14E+00
Eff. Dose Rate After Final Leg (mrem/hour)	5.33E+02

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 =	250.00	ft
Θ_{source} =	0.00	degrees
Sullivan Correction Factor =	850.81	

Projections of Leg 1 Length

$L1_R$ =	0.00	ft
$L1_S$ =	327.00	ft
$L1_T$ =	0.00	ft

α_1 = 0.00 degrees

Subsequent Leg Angles

	90° Attenuation	Attenuation Factors
Leg 1	7.74E-05	7.74E-05

Net Attenuation = 7.74E-05

Notes

	Effective Dose After Leg (mrem/pulse)	Effective Dose Rate After Leg (mrem/ hr)
Leg 1	8.14E+00	5.33E+02

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