MESON AREA

SECTION III CHAPTER 13 OF THE FERMILAB SAD

Revision 2 March 14, 2024

This Chapter of the Fermilab Safety Assessment Document (SAD) contains a summary of the results of the Safety Analysis for the Meson Area of the Fermilab Main Accelerator that are pertinent to understanding the risks to the workers, the public, and the environment due to its operation.

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SAD Chapter Review

This Section III Chapter 13 of the Fermi National Accelerator Laboratory (Fermilab) Safety Assessment Document (SAD), *Meson Area*, was prepared and reviewed by the staff of the Accelerator Directorate, Beams Division, External Beam Delivery Department in conjunction with the Environment, Safety, & Health Division (ES&H) Accelerator Safety Department.

Signatures below indicate review of this Chapter and recommendation that it be approved and incorporated into the Fermilab SAD.

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Revision History

Printed versions of this Chapter of the Fermilab Safety Assessment Document (SAD) may not be the currently approved revision. The current revision of this Chapter can be found on ES&H DocDB #1066 along with all other current revisions of all Chapters of the Fermilab SAD.

Author	Rev. No.	Date	Description of Change
Michael K. Olander	2	March 14, 2024	• Updated to align with new SAD Layout • Incorporated Risk Matrix & hazard discussion • Updated to include MCI Analysis & Credited Controls.
Wayne Schmitt Thomas R. Kobilarcik	1	January 18, 2019	• Updated MCenter beamline area description • Updated operating intensity limits, where applicable
John E. Anderson Jr. Craig Moore	0	April 29, 2014	Initial release of the Meson Area Chapter for the Fermi National Accelerator Laboratory Safety Assessment Document (SAD).

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Acronyms and Abbreviations

ACGIH	American Conference of Governmental Industrial Hygienists
ACNET	Accelerator Control Network System
AD	Accelerator Directorate
AHJ	Authority Having Jurisdiction
ALARA	As Low As Reasonably Achievable
ANSI	American National Standards Institute
APS-TD	Applied Physics and Superconducting Technology Directorate
ARA	Airborne Radioactivity Area
ASE	Accelerator Safety Envelope
ASHRAE	American Society of Heating, Refrigerating and Air Conditioning Engineers
ASME	American Society of Mechanical Engineers
ASO	Accelerator Safety Order, referring to DOE O 420.2D *Safety of Accelerators*
^{7}Be	Beryllium-7
BLM	Beam Loss Monitor
BNB	Booster Neutrino Beam
BPM	Beam Position Monitor
BY	Boneyard
CA	Controlled Area
CA	Contamination Area
CAS	Contractor Assurance System
CC	Credited Control
CCL	Coupled Cavity Linac
CDC	Critical Device Controller
CERN	European Organization for Nuclear Research
CFM	Cubic Feet per Minute
CFR	Code of Federal Regulations (United States)
Ci	Curie
CLW	Co-Located Worker (the worker in the vicinity of the work but not actively participating)
cm	centimeter
CPB	Cryogenics Plant Building
CSO	Chief Safety Officer
CUB	Central Utility Building
CW	Continuous Wave
CX	Categorically Excluded
D&D	Decontamination and Decommissioning
DA	Diagnostic Absorber
DAE	Department of Atomic Energy India

DCS	Derived Concentration Standard
DocDB	Document Database
DOE	Department of Energy
DOT	Department of Transportation
DR	Delivery Ring
DSO	Division Safety Officer
DSS	Division Safety Specialist
DTL	Drift Tube Linac
DUNE	Deep Underground Neutrino Experiment
EA	Environmental Assessment
EA	Exclusion Area
EAV	Exhaust Air Vent
EENF	Environmental Evaluation Notification Form
EMS	Environmental Management System
EOC	Emergency Operations Center
EPA	Environmental Protection Agency
ES&H	Environment, Safety and Health
Fermilab	Fermi National Accelerator Laboratory, see also FNAL
FESHCom	Fermilab ES&H Committee
FESHM	Fermilab Environment, Safety and Health Manual
FHS	Fire Hazard Subcommittee
FIRUS	Fire Incident Reporting Utility System
FNAL	Fermi National Accelerator Laboratory, see also Fermilab
FODO	Focus-Defocus
FONSI	Finding of No Significant Impact
FQAM	Fermilab Quality Assurance Manual
FRA	Fermi Research Alliance
FRCM	Fermilab Radiological Control Manual
FSO	Fermilab Site Office
FW	Facility Worker (the worker actively performing the work)
GERT	General Employee Radiation Training
GeV	Giga-electron Volt
^{3}H	Tritium
HA	Hazard Analysis
HAR	Hazard Analysis Report
HCA	High Contamination Area
HCTT	Hazard Control Technology Team
HEP	High Energy Physics
HFD	Hold for Decay

HLCF	High Level Calibration Facility
HPR	Highly Protected Risk
Hr	Hour
HRA	High Radiation Area
HSSD	High Sensitivity Air Sampling Detection
HVAC	Heating, Ventilation, and Air Conditioning
HWSF	Hazardous Waste Storage Facility
Hz	Hertz
IB	Industrial Building
IBC	International Building Code
ICW	Industrial Cooling Water
IEPA	Illinois Environmental Protection Agency
IEEE	Institute of Electrical and Electronics Engineers
INFN	Istituto Nazionale di Fisica Nucleare
IMPACT	Integrated Management Planning and Control Tool
IPCB	Illinois Pollution Control Board
IQA	Integrated Quality Assurance
ISD	Infrastructure Services Division
ISM	Integrated Safety Management
ITNA	Individual Training Needs Assessment
KeV	kilo-electron volt
kg	kilo-grams
kW	kilo-watt
LBNF	Long Baseline Neutrino Facility
LCW	Low Conductivity Water
LHC	Large Hadron Collider
LLCF	Low Level Calibration Facility
LLWCP	Low Level Waste Certification Program
LLWHF	Low Level Waste Handling Facility
LOTO	Lockout/Tagout
LPM	Laser Profile Monitor
LSND	Liquid Scintillator Neutrino Detector
LSO	Laser Safety Officer
m	meter
mA	milli-amp
MABAS	Mutual Aid Box Alarm System
MARS	Monte Carlo Shielding Computer Code
MC	Meson Center
MC&A	Materials Control and Accountability

MCR	Main Control Room
MEBT	Medium Energy Beam Transport
MEI	Maximally Exposed Individual
MeV	Mega-electron volt
MI	Main Injector
MINOS	Main Injector Neutrino Oscillation Search
MMR	Material Move Request
MOI	Maximally-Exposed Offsite Individual *(Note: due to the Fermilab Batavia Site being open to the public, the location of the MOI is taken to be the location closest to the accelerator that is accessible to members of the public.)*
MP	Meson Polarized
mrad	milli-radian
mrem	milli-rem
mrem/hr	milli-rem per hour
MT	Meson Test
MTA	400 MeV Test Area
MTF	Magnet Test Facility
^{22}Na	Sodium-22
NC	Neutrino Center
NE	Neutrino East
NEC	National Electrical Code
NEPA	National Environmental Policy Act
NESHAPS	National Emissions Standards for Hazardous Air Pollutants
NFPA	National Fire Protection Association
NM	Neutrino Muon
NMR	Nuclear Material Representative
NOvA	Neutrino Off-axis Electron Neutrino (ve) Appearance
NPH	Natural Phenomena Hazard
NRTL	Nationally Recognized Testing Laboratory
NIF	Neutron Irradiation Facility
NTSB	Neutrino Target Service Building, see also TSB
NuMI	Neutrinos at the Main Injector
NW	Neutrino West
ODH	Oxygen Deficiency Hazard
ORC	Operational Readiness Clearance
OSHA	Occupational Safety and Health Administration
pCi	pico-Curie
pCi/mL	pico-Curie per milliliter
PE	Professional Engineer

PIN	Personal Identification Number
PIP	Proton Improvement Plan
PIP-II	Proton Improvement Plan - II
PHAR	Preliminary Hazards Analysis Report
PPD	Particle Physics Directorate
PPE	Personnel Protective Equipment
QA	Quality Assurance
QAM	Quality Assurance Manual
RA	Radiation Area
RAF	Radionuclide Analysis Facility
RAW	Radioactive Water
RCT	Radiological Control Technician
RF	Radio-Frequency
RFQ	Radio-Frequency Quadrupole
RIL	RFQ Injector Line
RMA	Radioactive Material Area
RMS	Root Mean Square
RPCF	Radiation Physics Calibration Facility
RPE	Radiation Physics Engineering Department
RPO	Radiation Physics Operations Department
RRM	Repetition Rate Monitor
RSI	Reviewed Safety Issue
RSIS	Radiation Safety Interlock System
RSO	Radiation Safety Officer
RWP	Radiological Work Permit
SA	Shielding Assessment
SAA	Satellite Accumulation Areas
SAD	Safety Assessment Document
SCF	Standard Cubic Feet
SCFH	Standard Cubic Feet per Hour
SEWS	Site-Wide Emergency Warning System
SNS	Spallation Neutron Source
SR	Survey Riser
SRF	Superconducting Radio-Frequency
SRSO	Senior Radiation Safety Officer
SSB	Switchyard Service Building
SSP	Site Security Plan
SWIC	Segmented Wire Ionization Chambers
TLM	Total Loss Monitor

TLVs	Threshold Limit Values
TPC	Time Projection Chamber
TPES	Target Pile Evaporator Stack
TPL	Tagged Photon Lab
TSB	Target Service Building, see also NTSB
TSCA	Toxic Substances Control Act
TSW	Technical Scope of Work
T&I	Test and Instrumentation
UPB	Utility Plant Building
UPS	Uninterruptible Power Supply
USI	Unreviewed Safety Issue
VCTF	Vertical Cavity Test Facility
VHRA	Very High Radiation Area
VMS	Village Machine Shop
VMTF	Vertical Magnet Test Facility
VTS	Vertical Test Stand
WSHP	Worker Safety and Health Program
µs	micro-second

III-13. Meson Area

III-13.1. Introduction

This Section III Chapter 13 of the Fermi National Accelerator Laboratory (Fermilab) Safety Assessment Document (SAD) covers the Meson Area. For completeness, this chapter covers beam-related radiological hazards in the MT6 and MC7 enclosures, which are part of the Meson Switchyard 120 Experimental Areas.

III-13.1.1 Purpose/Function

The purpose of the Meson Area is to deliver primary proton beam to separate targets and convey secondary particles produced from the target collisions to two independent experimental areas, Meson Test and Meson Center, located in the Meson Switchyard 120 Experimental Areas, for use in test beam research and development.

III-13.1.2 Current Status

The Meson Primary (MPrimary) segment of the Meson Area is currently: **Operational**

The Meson Test (MTest) segment of the Meson Area is currently: **Operational**

The Meson Center (MCenter) segment of the Meson Area is currently: **Operational**

The Meson East (MEast) segment of the Meson Area is currently: **Non-operational**

The Meson Polarized (MPolarized) segment of the Meson Area is currently: **Non-operational**

The Meson Bottom (MBottom) segment of the Meson Area is currently: **Non-operational**

III-13.1.3 Description

The MPrimary beamline starts at the upstream end of the M01 enclosure and continues to the downstream end of the Meson Target Train. The MTest beamline begins at the downstream end of the Meson Target Train and continues the downstream end of M05. The MCenter beamline begins at the downstream end of the Meson Target Train and continues to the downstream end of MC6. Associated beamline infrastructure is located at the service buildings.

The Meson Area beamlines comprise the following enclosures:

- M01
- M02
- M03
- M05
- M05
- MC6

The Meson Area beamlines comprise of the following service buildings:

- MS1
- MS2
- MS3
- MS4
- MS5

The Meson Area may refer to the following beamlines:

- Meson East (MEast)
- Meson Polarized (MPolarized)
- Meson Center (MCenter)
- Meson West (MWest)
- Meson Test (MTest)

The Meson Area beamlines includes the following areas:

- The Meson Target Train located between the M01 Enclosure and M02 Enclosure.

The MT6 Sections 1 and 2 enclosures, and the MC6 enclosure, are housed in the Meson Detector Building. The Meson Detector Building also houses additional experimental facilities not addressed in this assessment.

Figure 3 shows the MPrimary, MTest, and MCenter beamlines are in black, and the Meson Switchyard 120 Experimental Area enclosures MT6 and MC7 in red.

III-13.1.4 Location

The Meson Area is located on the Fermilab site in Batavia, IL.

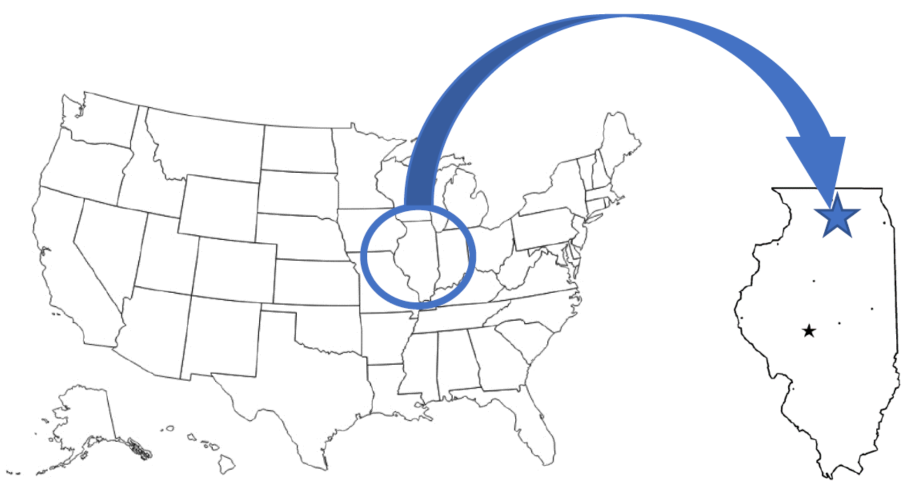

Figure 1. Regional view showing the location of the Fermilab site in Batavia, IL.

The Meson Area is located to the north of Wilson Hall on the Fermilab site.

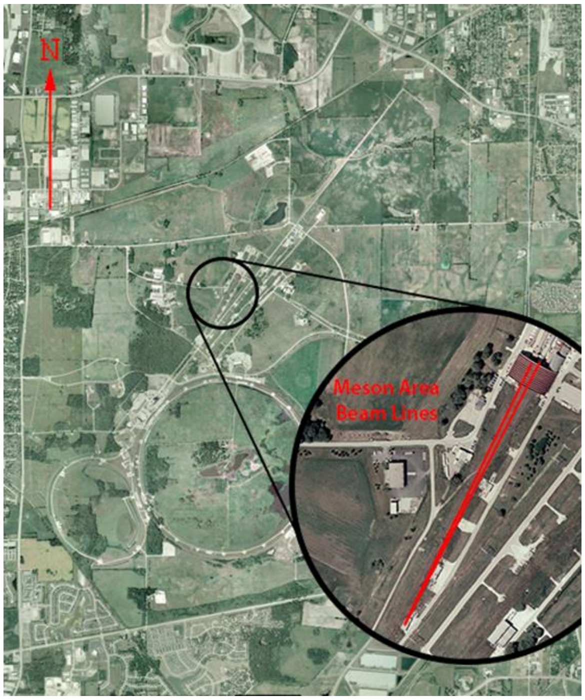

Figure 2. Aerial view of the Fermilab site, indicating the location of the Meson Area.

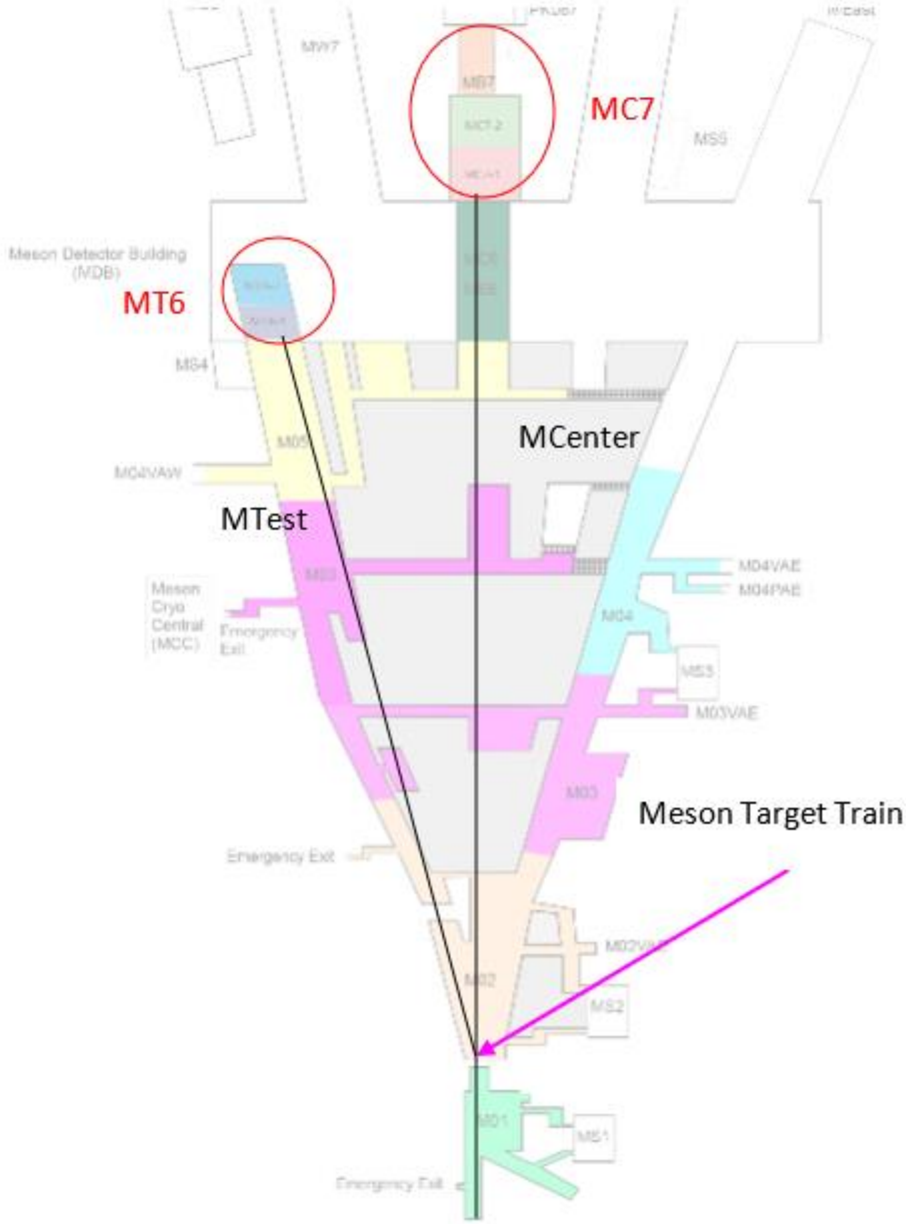

Figure 3: Meson Enclosures & Service Buildings

III-13.1.5 Management Organization

The Meson Area is Managed by Accelerator Directorate, Beams Division, External Beam Delivery Department. The experimental areas, Fermilab Test Beam Facility (FTBF) is managed by Particle Physics Directorate, Engineering Division, Detector Development & Testing Department, Test Beam Facilities Group.

III-13.1.6 Operating Modes

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 segment.

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 Meson Target Train is located between enclosures M01 and M02. Primary beam for MTest or MCenter may be temporarily disabled and absorbed on the target train.

The MTest beamline has three modes of operation. The requirements for a particular running mode are monitored by the MTest Primary Critical Device Controller Primary Logic Chassis (Primary Logic Chassis). The Primary Logic Chassis ensures the secondary beam is correctly configured. The operating modes are:

- Diffracted Proton Mode
- High Energy Pion Mode
- Low Energy Pion Mode

The MCenter beamline has one mode of operation. The CDC ensures the secondary beamline is correctly configured. The operating mode is:

- Pion Mode

The Meson Area houses several non-operational beamlines, which are not capable of delivering beam. These areas are Meson East (MEast), Meson Polarized (MPolarized), Meson Bottom (MBottom), and Meson West (MWest).

III-13.1.7 Inventory of Hazards

The following table lists all the identified hazards found in the Meson Area enclosures and support buildings. Section III-13.9 *Appendix – Risk Matrices* describes the baseline risk (i.e., unmitigated risk), any preventative controls and/or mitigative controls in place to reduce the risk, and residual risk (i.e., mitigated risk) for a facility worker, co-located worker, and maximally exposed offsite individual (MOI) (i.e., members of the public). A summary of these controls is described within Section III-13.2 *Safety Assessment.*

Prompt ionizing, oxygen deficiency hazards due to cryogenic systems within accelerator enclosures, and fluorinert byproducts due to use of fluorinert that is subject to particle beam have been identified as accelerator specific hazards, and as such their controls are identified as Credited Controls. The analysis of these hazards and their Credited Controls will be discussed within this SAD Chapter, and their Credited

Controls summarized in the Accelerator Safety Envelope for the Meson Area. Accelerator-specific controls are identified as **purple/bold** throughout this chapter.

All other hazards present in the Meson Area are safely managed by other DOE-approved applicable safety and health programs and/or processes, and their analyses have been performed according to applicable DOE requirements as flowed down through the Fermilab Environment, Safety and Health Manual (FESHM). These hazards are non-accelerator specific hazards (NASH), and their analysis will be summarized in this SAD Chapter.

Table 1. Hazard Inventory for the Meson Area.

	Radiological		**Toxic Materials**
☒	**Prompt Ionizing Radiation**	☒	Lead Shielding
☒	Residual Activation	☒	Beryllium
☒	Groundwater Activation	☐	Fluorinert & Its Byproducts
☒	Surface Water Activation	☐	Liquid Scintillator Oil
☒	Radioactive Water (RAW) Systems	☐	Pseudocumene
☒	Air Activation	☐	Ammonia
☐	Closed Loop Air Cooling	☐	Nanoparticle Exposures
☒	Soil Interactions		**Flammables and Combustibles**
☒	Radioactive Waste	☒	Combustible Materials (e.g., cables, wood cribbing, etc.)
☒	Contamination	☐	Flammable Materials (e.g., flammable gas, cleaning materials, etc.)
☒	Beryllium-7		**Electrical Energy**
☒	Radioactive Sources	☒	Stored Energy Exposure
☐	Nuclear Material	☒	High Voltage Exposure
☐	Radiation Generating Devices (RGDs)	☒	Low Voltage, High Current Exposure
☐	Non-Ionizing Radiation Hazards		**Kinetic Energy**
	Thermal Energy	☒	Power Tools
☐	Magnet Bakeouts	☒	Pumps and Motors
☒	Hot Work	☒	Motion Tables
☒	**Cryogenics**	☐	Mobile Shielding
	Potential Energy		**Magnetic Fields**
☒	Crane Operations	☒	Fringe Fields
☒	Compressed Gasses		**Other Hazards**
☒	Vacuum/Pressure Vessels/Piping	☒	Confined Spaces
☒	Vacuum Pumps	☒	Noise
☐	Material Handling	☐	Silica
	Access & Egress	☒	Ergonomics
☒	Life Safety Egress	☐	Asbestos

III-13.2. Safety Assessment

All hazards for the Meson Area are summarized in this section, with additional details of the analyses for accelerator specific hazards.

III-13.2.1 Radiological Hazards

The Meson Area presents radiological hazards in the form of prompt ionizing radiation, residual activation, groundwater activation, surface water activation, radioactive water (RAW) systems, air activation, soil interactions, radioactive waste, contamination, beryllium-7, and radioactive sources. A detailed shielding assessment [2][3][4][5] addresses these hazards and provide a detailed analysis of the facility demonstrating the required shielding, controls, and interlocks to comply with the Fermilab Radiological Control Manual (FRCM)[1].

The shielding assessments for the Meson Area assess the areas described in Section III Chapter 13.1.3.

As shown in the risk analysis in Section III-13.10 *Appendix – Risk Tables* 13.1-13.3, the baseline risk level I has been reduced to a residual risk level of III or lower.

III-13.2.1.1 Prompt Ionizing Radiation

Prompt ionizing radiation is the principle radiological hazard that arises when beam is transported through the Meson Area beam lines. To protect workers and the general public, the enclosures and beam pipes are surrounded either by sufficient amounts of shielding (soil, concrete, or iron), and/or networks of interlocked detectors to keep any prompt radiation exposure within acceptable levels. Operation of the area conforms to the FRCM to maintain exposures for operating personnel as low as reasonably achievable (ALARA).

This hazard has been evaluated via a Maximum Credible Incident (MCI) analysis that is described in Section III-13.3.1.1. This analysis specifies that Fermilab uses Credited Controls that flow down to the Accelerator Safety Envelope (ASE) to mitigate the consequences of the MCI to at or below the acceptable dose levels described in SAD Section I Chapter 4. A detailed description of each of the Credited Controls and their function is provided in Section III-13.4. The conclusion of these analyses is that the mitigated dose level associated with prompt ionizing radiation due to beam loss is acceptable.

III-13.2.1.2 Residual Activation

The Meson Target Train, MTest M03 Pinhole Collimator, MTest MT4 Low Energy Pion Target, MTest MT4 Palmer Collimators, MCenter MC2 Pinhole Collimator, MCenter MC3 Palmer Collimators, MCenter MC6 Target, and MCenter MC6 Momentum Collimator may be highly activated even when the Meson beamlines are in a non-operational or standby condition. Access to these components will be tightly controlled with the control dependent on the level of residual radiation. The control measures include training and training verification, centralized access authorization, and key entry. Controls required for different levels of residual radiation are specified in the FRCM and are detailed in the Radiological Work Permit (RWP) for the work to be performed.

In most situations, general RWPs for accesses will suffice. A job-specific RWP and/or an ALARA ("as-low-as-reasonably-achievable") plan will be required for work on any highly activated equipment with a potential individual exposure greater than 200 millirem (mrem) or potential exposure for all persons on the job greater than 1000 mrem. These tasks will be supervised by members of the Radiological Control Organization under the direction of the assigned Radiation Safety Officer (RSO).

As shown in the risk analysis in Section III-13.10 *Appendix – Risk Tables* 13.1-13.3, the baseline risk level I has been reduced to a residual risk level of III or lower.

III-13.2.1.3 Groundwater Activation

The release estimate for surface and groundwater after 10 years of operation to the Meson Target Train in M01 at an integrated intensity of 7.94x10^{17} protons per year will produce combined ^{3}H (tritium) and ^{22}Na (sodium-22) concentrations that are 22% of the surface water limits and a negligible fraction of the groundwater limits respectively.

The release estimate for surface and groundwater after 10 years of operation to the M03 Pinhole Collimator at an integrated intensity of 1.74x10^{17} protons per year will produce combined ^{3}H and ^{22}Na concentrations that are 32% of the surface water limits and a negligible fraction of the groundwater limits respectively.

The release estimate for surface and groundwater after 10 years of operation to the M03 Low Energy Pion Mode target at an integrated intensity of 1.2x10^{17} protons per year will produce combined ^{3}H and ^{22}Na concentrations that are 65% of the surface water limits and a negligible fraction of the groundwater limits respectively.[1]

The release estimate for surface and groundwater after 10 years of operation to the MCenter Target Pile in MC6 at an integrated intensity of 5.26x10^{16} protons per year will produce combined ^{3}H and ^{22}Na concentrations that are 0.6% of the surface water limits and a negligible fraction of the groundwater limits respectively[1]. The annual concentration estimates for ^{3}H and ^{22}Na in surface water and groundwater from these absorbers are given in Table 2.

Table 2: Meson Area Surface Water & Groundwater ^{3}H & ^{22}Na Release Concentrations

Description	**Annual Concentration Limits In picocuries per milliliter (pCi/ml)**		**Annual Concentration Estimate In picocuries per milliliter (pCi/ml)**	
	^{3}H	**^{22}Na**	**^{3}H**	**^{22}Na**
Target Train Surface Water	1900	10	2.4x10^{1}	2.1x10^{0}
Target Train Groundwater	20	0.4	2.2x10^{-7}	1.0x10^{-8}
M03 Pinhole Collimator Surface Water	1900	10	3.4x10^{1}	3.0x10^{0}
M03 Pinhole Collimator Groundwater	20	0.4	3.2x10^{-7}	1.5x10^{-8}
MT3 Low Energy Pion Target Surface Water	1900	10	1.7x10^{1}	1.5x10^{0}
MT3 Low Energy Pion Target Groundwater	20	0.4	1.6x10^{-7}	7.0x10^{-9}
MCenter Target Pile Surface Water	1900	10	6.5x10^{-1}	5.8x10^{-2}
MCenter Target Pile Groundwater	20	0.4	1.3x10^{-8}	2.6x10^{-13}
^{3}H Regulatory Limit from 40 CFR 141 *Federal Drinking Water Standards*. ^{22}Na Regulatory Limits from the Department of Energy STD-1196-2011 *Derived Concentration Standards.*				

The ^3H and ^{22}Na surface and groundwater concentration estimates are all within the FRCM limits. Groundwater and surface water is sampled as part of the Fermilab Environment, Safety, Health, and Quality Section Environmental Monitoring Program.

As shown in the risk analysis in Section III-13.10 *Appendix – Risk Tables* 13.1-13.3, the baseline risk level I has been reduced to a residual risk level of III or lower.

III-13.2.1.4 Surface Water Activation

Surface water activation in the Meson Area is characterized in Section III Chapter 13.2.1.3.

III-13.2.1.5 Radioactive Water (RAW) Systems

The Meson Area uses a Radioactive Water (RAW) System in the M01 enclosure. This system is used to cool the Meson Target Train. The system is a closed-loop system. As shown in the risk analysis in Section III-13.10 *Appendix – Risk Tables* 13.1-13.3, the baseline risk level I has been reduced to a residual risk level of III or lower.

III-13.2.1.6 Air Activation

Air activation measurements were taken during the 1999 Fixed Target run and documented in the shielding assessment [2]. 0 Ci of measured air release was observed under similar beam operating conditions to the present day. [2] Therefore, the consequence of air activation in the Meson Area is negligible. As shown in the risk analysis in Section III-13.10 *Appendix – Risk Tables* 13.1-13.3, the baseline risk level IV requires no further preventative of mitigative controls are required.

III-13.2.1.7 Closed Loop Air Cooling

N/A

III-13.2.1.8 Soil Interactions

A forward cone, with angles on the order of 5 milliradians (mrad) of energetic penetrating muons is created whenever a 120-GeV proton beam is absorbed in the Meson Area beam absorbers. There is no significant flux of pions and kaons produced at energies above 100 GeV and hence no significant flux of muons produced at energies above 80 GeV. The 80-GeV muons have a specific ionization energy loss of 4 mega-electronvolts per centimeter (MeV/cm) and can only penetrate up to 200 meters of earth equivalent shielding.

The Meson Target Train and MTest M03 Pinhole Collimator are followed by steel and earth shielding. There is shielding well over 200 m earth equivalent in thickness in the forward direction for production angles of less than 5 mrad. This amount of shielding is sufficient to stop the muon plumes that arise from penetrating beyond M05. For MCenter operations, the MC6 Target Pile has the potential to produce muon dose rates downstream of the target. MARS Monte Carlo code simulations of the target pile indicate muon dose rates in all potentially occupied areas are less than 0.05 mrem/hr.

The soil surrounding the Meson Area will be sampled during decommissioning to document activation levels as required by the FESHM.

As shown in the risk analysis in Section III-13.10 *Appendix – Risk Tables* 13.1-13.3, the baseline risk level I has been reduced to a residual risk level of IV.

III-13.2.1.9 Radioactive Waste

Radioactive waste produced in the course of Meson Area operations will be managed within the established Radiological Protection Program (RPP) and as prescribed in the Fermilab Radiological Control Manual (FRCM). It is a standard radiological hazard. Waste minimization is an objective of the equipment design and operational procedures. Although production of radioactive material is not an operational function of the Meson Area, beam loss and, in the case of some beam diagnostics devices, intentional interception of the beam will result in activation of beam line elements. Reuse of activated items will be carried out when feasible. Activated items that cannot be reused will be disposed of as radioactive waste in accordance with the FRCM requirements.

As shown in the risk analysis in Section III-13.10 *Appendix – Risk Tables* 13.1-13.3, the baseline risk level I has been reduced to a residual risk level of IV.

III-13.2.1.10 Contamination

Contamination of components caused by beam interaction may exist in the Meson Area. As shown in the risk analysis in Section III-13.10 *Appendix – Risk Tables* 13.1-13.3, the baseline risk level I has been reduced to a residual risk level of IV.

III-13.2.1.11 Beryllium-7

^{7}Be is not hazardous in this pattern of use by the facility. As shown in the risk analysis in Section III-13.10 *Appendix – Risk Tables* 13.1-13.3, the baseline risk level IV requires no further preventative or mitigative controls.

III-13.2.1.12 Radioactive Sources

Radioactive sources may be used in shutdown and maintenance activities. These sources, when used in the Meson Area, are handled in accordance with FRCM. As shown in the risk analysis in Section III-13.10 *Appendix – Risk Tables* 13.1-13.3, the baseline risk level I has been reduced to a residual risk level of IV.

III-13.2.1.13 Nuclear Material

N/A

III-13.2.1.14 Radiation Generating Devices (RGDs)

N/A

III-13.2.1.15 Non-Ionizing Radiation Hazards

N/A

III-13.2.2 Toxic Materials

The Meson Area presents toxic material hazards in the form of a list of checked off hazards shown in Table 1 of the Meson Area SAD. All toxic material hazards present in the Meson Area are in the form of Non-Accelerator Specific hazards discussed in SAD Section I Chapter 04.

III-13.2.2.1 Lead

Lead is present in the form of unpainted bricks and lead wool in the M02 enclosure. In addition, lead vacuum seals from equipment originally installed during the construction of the Meson Area in the 1970s and lead solder from electronics currently in use may be present. This hazard has been evaluated within the common risk matrix table included in SAD Section I Chapter 04 *Safety Analysis*. Work in the Meson Area involving this hazard implements the controls specified in the common risk matrix table. No unique controls are in use. For a facility worker, the baseline risk for this hazard was R II and, after control measures were evaluated, the residual risk level was R IV; for a co-located worker and an MOI, the baseline risk for this hazard was R III and, after control measures were evaluated, the residual risk level was R IV.

III-13.2.2.2 Beryllium

Beryllium is present in the MTest MT4 Low Energy Pion Target cage, located in the M03 enclosure. Access to the target cage is controlled by ES&H and requires additional work planning and controls. This target is sealed in Kapton to prevent exposure to the atmosphere and to prevent beryllium dust contamination. This target is not used operationally and is physically located such that beam cannot interact with this target. This hazard has been evaluated within the common risk matrix table included in SAD Section I Chapter 04 *Safety Analysis*. Work in the Meson Area involving this hazard implements the controls specified in the common risk matrix table. No unique controls are in use. For a facility worker, the baseline risk for this hazard was R II and, after control measures were evaluated, the residual risk level was R IV; for a co-located worker and an MOI, the baseline risk for this hazard was R II and, after control measures were evaluated, the residual risk level was R III.

III-13.2.2.3 Fluorinert & Its Byproducts

N/A

III-13.2.2.4 Liquid Scintillator Oil

N/A

III-13.2.2.5 Pseudocumene

N/A

III-13.2.2.6 Ammonia

N/A

III-13.2.2.7 Nanoparticle Exposures

N/A

III-13.2.3 Flammables and Combustibles

III-13.2.3.1 Combustible Materials

This hazard has been evaluated within the common risk matrix table included in SAD Section I Chapter 04 *Safety Analysis*. Work in the Meson Area involving this hazard implements the controls specified in the common risk matrix table. No unique controls are in use. For a facility worker, the baseline risk for this hazard was R I and, after control measures were evaluated, the residual risk level was R IV; for a co-located worker, the baseline risk for this hazard was R II and, after control measures were evaluated, the residual risk level was R IV; for an MOI, the baseline risk for this hazard was R III and, after control measures were evaluated, the residual risk level was R IV.

III-13.2.3.2 Flammable Materials

This hazard has been evaluated within the common risk matrix table included in SAD Section I Chapter 04 *Safety Analysis*. Work in the Meson Area involving this hazard implements the controls specified in the common risk matrix table. No unique controls are in use. For a facility worker, the baseline risk for this hazard was R I and, after control measures were evaluated, the residual risk level was R IV; for a co-located worker, the baseline risk for this hazard was R II and, after control measures were evaluated, the residual risk level was R IV; for an MOI, the baseline risk for this hazard was R III and, after control measures were evaluated, the residual risk level was R IV.

III-13.2.4 Electrical Energy

III-13.2.4.1 Stored Energy Exposure

This hazard has been evaluated within the common risk matrix table included in SAD Section I Chapter 04 *Safety Analysis*. Work in the Meson Area involving this hazard implements the controls specified in the common risk matrix table. No unique controls are in use. The baseline risk for this hazard was R I and, after control measures were evaluated, the residual risk level was R IV.

III-13.2.4.2 High Voltage Exposure

This hazard has been evaluated within the common risk matrix table included in SAD Section I Chapter 04 *Safety Analysis*. Work in the Meson Area involving this hazard implements the controls specified in the common risk matrix table. No unique controls are in use. The baseline risk for this hazard was R I and, after control measures were evaluated, the residual risk level was R IV.

III-13.2.4.3 Low Voltage, High Current Exposure

This hazard has been evaluated within the common risk matrix table included in SAD Section I Chapter 04 *Safety Analysis*. Work in the Meson Area involving this hazard implements the controls specified in the common risk matrix table. No unique controls are in use. For an on-site worker, the baseline risk for this hazard was R I and, after control measures were evaluated, the residual risk level was R IV; for an MOI, this hazard is non-applicable.

III-13.2.5 Thermal Energy

The Meson Area presents thermal energy hazards identified in Table 1. All thermal energy hazards present in the Meson Area are in the form of standard industrial hazards discussed in SAD Section I Chapter 04.

III-13.2.5.1 Bakeouts

N/A

III-13.2.5.2 Hot Work

Hot work may include brazing and welding activities during maintenance periods. This hazard has been evaluated within the common risk matrix table included in SAD Section I Chapter 04 *Safety Analysis*. Work in the Meson Area involving this hazard implements the controls specified in the common risk matrix table. No unique controls are in use. For an on-site worker, the baseline risk for this hazard was R I and, after control measures were evaluated, the residual risk level was R IV; for an MOI, the baseline risk for this hazard was R III and, after control measures were evaluated, the residual risk level was R IV.

III-13.2.5.3 Cryogenics

The Meson Area beamlines do not use cryogenics operationally, however test stands located in the Meson Detector Building (MDB) use cryogenic helium for various experiments. The liquification plant is located at the Meson Cryo Central building. The cryogenics then use existing piping through enclosures M03 and M04 to reach the test stands. All credible failure scenarios leading to release of inert gas into the area are analyzed in the ODH assessment. The scenarios include leaks of the cryogenic transfer line, rupture of low- and high-pressure helium header, rupture of the nitrogen header, failure of helium and nitrogen suction and transfer line flanges, and improper installation of the Kautzky valve. Due to the active use of the cryogenic test stands in the MDB, the Meson enclosures M02, M03, M04, and M05 are classified as ODH-1 areas. The Meson Area ODH assessment is on file with APS/TD Cryogenics. The hazards associated with cryogenics include ODH conditions and burns. Table 3 summarizes the ODH assessment for the Meson Area.

Table 3. ODH Requirements of Analysis for Meson

Building Space	M02	M03	M04	M05
Minimum O2 (%)	0[1]			
ODH Class	1			
Oxygen sensors	0[2]	2 high, 2 low	2 high, 2 low	0[2]
Ventilation	No credit is taken for forced ventilation calculation for tunnel ODH classification. Only natural ventilation is considered for ODH analysis of Tunnel area and divided into two zones. Zone A: 40.4 scfm natural ventilation capacity. Zone B: 112.3 scfm natural ventilation capacity.			
Exceptions to FESHM 4240 control measures	No exceptions: Personal oxygen monitor and a self-rescue supplied atmosphere respirator is required for entry into the enclosures.			
Training	Oxygen deficiency hazard training and medical approval for oxygen deficiency hazard work is required.			

[1] Improper installation of nitrogen Kautzky valve.
[2] All releases to M02 and M05 pass through oxygen sensors in M03 and M04.

These hazards have been evaluated within the common risk matrix table included in SAD Section I Chapter 04 *Safety Analysis*. Work in the Meson Area involving these hazards implements the controls specified in the common risk matrix table. No unique controls are in use. For an on-site worker, the baseline risk for this hazard was R I and, after control measures were evaluated, the residual risk level was R IV; for an MOI, the baseline risk for this hazard was R III and, after control measures were evaluated, the residual risk level was R IV.

III-13.2.6 Kinetic Energy

The Meson Area presents kinetic energy hazards identified in Table 1. All kinetic energy hazards present in the Meson Area are in the form of standard industrial hazards discussed in SAD Section I Chapter 04.

III-13.2.6.1 Power Tools

Power tools may be used in repair and maintenance activities during maintenance periods. This hazard has been evaluated within the common risk matrix table included in SAD Section I Chapter 04 *Safety Analysis*. Work in the Meson Area involving this hazard implements the controls specified in the common risk matrix table. No unique controls are in use. For an on-site worker, the baseline risk for this hazard was R I and, after control measures were evaluated, the residual risk level was R IV; for an MOI, this risk is non-applicable.

III-13.2.6.2 Pumps and Motors

Standard industrial pumps and motors are utilized throughout the Meson Area for water cooling and vacuum systems. This hazard has been evaluated within the common risk matrix table included in SAD Section I Chapter 04 *Safety Analysis*. Work in the Meson Area involving this hazard implements the controls specified in the common risk matrix table. No unique controls are in use. For a facility worker, the baseline risk for this hazard was R I and, after control measures were evaluated, the residual risk level was R III; for a co-located worker, the baseline risk for this hazard was R I and, after control measures were evaluated, the residual risk level was R IV; for an MOI, this risk is non-applicable.

III-13.2.6.3 Motion Tables

The MTest M01 Target, MTest M03 High-rate Tracking Area experiment motion table, and the MTest MT4 Low Energy Pion Mode Target use motion tables to control the position of the targets and detectors, if an experiment is installed in the M03 High-rate Tracking Area. This hazard has been evaluated within the common risk matrix table included in SAD Section I Chapter 04 *Safety Analysis*. Work in the Meson Area involving this hazard implements the controls specified in the common risk matrix table. No unique controls are in use. For an on-site worker, the baseline risk for this hazard was R I and, after control measures were evaluated, the residual risk level was R III; for an MOI, this risk is non-applicable.

III-13.2.6.4 Mobile Shielding

N/A

III-13.2.7 Potential Energy

III-13.2.7.1 Crane Operations

Trained technicians use various cranes to move, maintain, and install equipment in the Meson Area. This hazard has been evaluated within the common risk matrix table included in SAD Section I Chapter 04 *Safety Analysis*. Work in the Meson Area involving this hazard implements the controls specified in the common risk matrix table. No unique controls are in use. For an on-site worker, the baseline risk for this hazard was R I and, after control measures were evaluated, the residual risk level was R IV; for an MOI, this risk is non-applicable.

III-13.2.7.2 Compressed Gasses

Compressed air, Nitrogen, and $ArCO_2$ are present in the Meson Area to facilitate machine operations. Compressed gas cylinders are used, stored, and moved throughout the Meson Area Service Buildings. This hazard has been evaluated within the common risk matrix table included in SAD Section I Chapter 04 *Safety Analysis*. Work in the Meson Area involving this hazard implements the controls specified in the common risk matrix table. No unique controls are in use. For a facility worker, the baseline risk for this hazard was R I and, after control measures were evaluated, the residual risk level was R IV; for a co-located worker and an MOI, the baseline risk for this hazard was R I and, after control measures were evaluated, the residual risk level was R III.

III-13.2.7.3 Vacuum/Pressure Vessels/Piping

This hazard has been evaluated within the common risk matrix table included in SAD Section I Chapter 04 *Safety Analysis*. Work in the Meson Area involving this hazard implements the controls specified in the common risk matrix table. No unique controls are in use. Baseline risk for this hazard was R I and, after control measures were evaluated, the residual risk level was R III.

III-13.2.7.4 Vacuum Pumps

This hazard has been evaluated within the common risk matrix table included in SAD Section I Chapter 04 *Safety Analysis*. Work in the Meson Area involving this hazard implements the controls specified in the common risk matrix table. No unique controls are in use. For an on-site worker, the baseline risk for this hazard was R I and, after control measures were evaluated, the residual risk level was R III; for an MOI, this risk is non-applicable.

III-13.2.7.5 Material Handling

This hazard has been evaluated within the common risk matrix table included in SAD Section I Chapter 04 *Safety Analysis*. Work in the Meson Area involving this hazard implements the controls specified in the common risk matrix table. No unique controls are in use. For a facility worker, the baseline risk for this hazard was R I and, after control measures were evaluated, the residual risk level was R IV; for a co-located worker, the baseline risk for this hazard was R I and, after control measures were evaluated, the residual risk level was R III; for an MOI, this risk is non-applicable.

III-13.2.8 Magnetic Fields

The Meson Area presents magnetic field hazards identified in Table 1. All magnetic field hazards present in the Meson Area are in the form of standard industrial hazards discussed in SAD Section I Chapter 04.

III-13.2.8.1 Fringe Fields

This hazard has been evaluated within the common risk matrix table included in SAD Section I Chapter 04 *Safety Analysis*. Work in the Meson Area involving this hazard implements the controls specified in the common risk matrix table. No unique controls are in use. Baseline risk for this hazard was R I (III) for workers with (without) ferromagnetic or electronic medical devices and, after control measures were evaluated, the residual risk level was R III (IV).

III-13.2.9 Other Hazards

The Meson Area presents other hazards identified in Table 1. Unusual hazards are present in the form of Confined Spaces. After completion of the risk analysis in III-13.10 *Appendix – Risk Tables*, Tables 13.25-13.27, the baseline risk level I has been reduced to a residual risk level of III or lower.

All other hazards present in the Meson Area are in the form of standard industrial hazards discussed in SAD Section I Chapter 04.

III-13.2.9.1 Confined Spaces

The Meson Area has several areas considered confined spaces. In the M02, M03, and MC6 enclosures, there are areas that exist below grade and have only one point of entry and egress. Access to these areas follows Confined Space policy from FESHM 4230. Based on the risk analysis in III-13.10 *Appendix – Risk Tables*, Tables 13.25-13.27, the baseline risk level I has been reduced to a residual risk level of III.

All other confined spaces in the Meson Area, e.g., sump pits, have been evaluated within the Common Risk Matrix, included in SAD Section I Chapter 04 *Safety Analysis*. Work involving Confined Spaces in the

Meson Area implements the controls specified in the common risk matrix table. No unique controls are in use. For a facility worker, the baseline risk for this hazard was R I and, after control measures were evaluated, the residual risk level was R IV; for a co-located worker and an MOI, the baseline risk for this hazard was R III and, after control measures were evaluated, the residual risk level was R III.

III-13.2.9.2 Noise

The upstream area of the M02 enclosure is marked as a noise hazard when the MS2 LCW System is running. This hazard has been evaluated within the common risk matrix table included in SAD Section I Chapter 04 *Safety Analysis*. Work in the Meson Area involving this hazard implements the controls specified in the common risk matrix table. No unique controls are in use. For an on-site worker, the baseline risk for this hazard was R III and, after control measures were evaluated, the residual risk level was R IV; for an MOI, the baseline risk for this hazard was R IV and, after control measures were evaluated, the residual risk level was R IV.

III-13.2.9.3 Silica

N/A

III-13.2.9.4 Ergonomics

This hazard has been evaluated within the common risk matrix table included in SAD Section I Chapter 04 *Safety Analysis*. Work in the Meson Area involving this hazard implements the controls specified in the common risk matrix table. No unique controls are in use. For a facility worker, the baseline risk for this hazard was R I and, after control measures were evaluated, the residual risk level was R IV; for a co-located worker and MOI, this risk is non-applicable.

III-13.2.9.5 Asbestos

N/A

III-13.2.9.6 Working at Heights

This hazard has been evaluated within the common risk matrix table included in SAD Section I Chapter 04 *Safety Analysis*. Work in the Meson Area involving this hazard implements the controls specified in the common risk matrix table. No unique controls are in use. Baseline risk for this hazard was R I and, after control measures were evaluated, the residual risk level was R III.

III-13.2.10 Access & Egress

III-13.2.10.1 Life Safety Egress

This hazard has been evaluated within the common risk matrix table included in SAD Section I Chapter 04 *Safety Analysis*. Work in the Meson Area involving this hazard implements the controls specified in the common risk matrix table. No unique controls are in use. For a facility worker, the baseline risk for this hazard was R I and, after control measures were evaluated, the residual risk level was R IV; for a co-located worker, the baseline risk for this hazard was R II and, after control measures were evaluated, the residual risk level was R IV; for an MOI, this risk is non-applicable.

III-13.2.11 Environmental

III-13.2.11.1 Hazard to Air

This hazard has been evaluated within the common risk matrix table included in SAD Section I Chapter 04 *Safety Analysis*. Work in the Meson Area involving this hazard implements the controls specified in the common risk matrix table. No unique controls are in use. Baseline risk for this hazard was R IV and, after control measures were evaluated, the residual risk level was R IV.

III-13.2.11.2 Hazard to Water

Glycol is used in the low conductivity water cooling system. There exists the potential for this system to leak. This hazard has been evaluated within the common risk matrix table included in SAD Section I Chapter 04 *Safety Analysis*. Work in the Meson Area involving this hazard implements the controls specified in the common risk matrix table. No unique controls are in use. Baseline risk for this hazard was R I and, after control measures were evaluated, the residual risk level was R IV.

III-13.2.11.3 Hazard to Soil

This hazard has been evaluated within the common risk matrix table included in SAD Section I Chapter 04 *Safety Analysis*. Work in the Meson Area involving this hazard implements the controls specified in the common risk matrix table. No unique controls are in use. Baseline risk for this hazard was R IV and, after control measures were evaluated, the residual risk level was R IV.

III-13.3. Maximum Credible Incident Scenario for Accelerator Specific Hazards

This section evaluates the maximum credible incident (MCI) scenario that could happen in the Meson Area. Consideration and analysis of this MCI is focused on an onsite facility worker, onsite co-located worker, and a maximally exposed off-site individual (MOI).

III-13.3.1 Definition of a Maximum Credible Incident

The MCI scenario evaluated for the Meson Area is 7E12 protons per cycle, 55 second cycle time, 120 GeV energy, resulting in 2.75E15 protons per hour.

The MCI Analysis for the Meson Area assumes this MCI for the Meson Primary, Meson Test, and Meson Center beamlines individually.

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

- Less than 500 mrem in one hour in all laboratory areas to which the public is assumed to be excluded
- Less than 100 mrem in one hour at Fermilab’s site boundary and/or in any areas onsite in which the public is authorized (which includes Batavia Road, Prairie Path, parking lots open to the public, and general access areas including Wilson Hall, Ramsey Auditorium)
- Less than 5 rem in one hour in any area accessible by facility workers or co-located workers

These Credited Controls are discussed in Section III-13.4.

The accumulated dose outside of the shielding on the Meson berm is mitigated, by use of Credited Controls, to less than 500 mrem in an MCI. The closest possible location of a member of the public to the Meson berm is the public road and bike path. This location is more than five feet away from the berm, which would result in dose of less than 100 mrem applying a conservative dose reduction of 1/r.

A change in the MCI for upstream segments will be evaluated for its effect on the Meson Area through the USI process.

III-13.4. Summary of Credited Controls

This section summarizes the Credited Controls for the Meson Area, and the radiologically associated Credited Controls for the Meson Switchyard 120 Experimental Areas (SAD Section IV Chapter 3). The chapter numbering for the Meson Area follows the conventional numbering system, that is, “III-13.4.x.”, etc.; the chapter numbering for the Meson Switchyard 120 Experimental Area has the letter ‘B’ inserted, that is, “III-13.4.B.x”, etc. Additionally, the transition between these sections is called out in bold font.

III-13.4.1 Passive Credited Controls

Passive controls are accelerator elements that are part of the physical design of the facility that require no action to function properly. These passive controls are fixed elements of the beam line that take direct human intervention to remove. The Meson Area was designed with a concrete- and earth-covered radiation shield to protect personnel from radiological exposure during beam operations.

III-13.4.1.1 Shielding

III-13.4.1.1.1 Permanent Shielding Including Labyrinths

The required amount of shielding in the Meson Area is determined using the Incremental Shielding Assessment (ISA) spreadsheets. Credited levels of shielding are based on the Maximum Credible Incident (MCI) analysis, which utilized ES&H shielding assessment group shielding categories from the *Incremental Shielding Assessment Methodology*. 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 amount of shielding is specified in terms of equivalent feet of dirt (efd).

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

The existing radiation fencing surrounding the Meson Area berm is credited. The fencing north of the MC6 enclosure, spanning between the Meson Polarized and Meson West beamlines, is also credited. This reduces the amount of required shielding determined by the ISA spreadsheet.

The amount of credited permanent shielding, and minimum defense-in-depth, is given by beamline:

- Meson Primary: 15.3 efd credited, one efd minimum defense-in-depth.
- Meson Center: 12.8 efd credited, one efd minimum defense-in-depth.

- Meson Test: (refer to Tables 9 and 10)

Table 4: Meson Test Longitudinal Locations Showing Credited Shielding, Defense-in-Depth..

Location (Logitudinal)	credited shielding	defense-in-depth
	[efd]	[efd]
4340-4605	14.5	4.8
4605-4710	14.5	10.8
4710-4716	14.5	3.7
4716-4841	14.5	9.0
4841-4889	14.5	1.0
4889-4989	14.5	3.2
4989-4995	9.9	2.0
4995-5043	15.0	2.4
5043-5164	11.6	2.0
5164-5590	3.0	8.9
5590-5618	3.0	3.9

Table 5: Meson Test Transverse Locations Showing Credited Shielding, Defense-in-Depth..

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

The upstream portion of the MT6 enclosure is shares a common wall with the MS4 service building. The downstream portion of MT6 is constructed from 3'x3'x6.5' concrete shielding blocks.

The MCI analysis concludes that the greatest exposure outside the MT6 enclosures is located at the concrete wall common to MT6 and MS4. Assuming a one-hour MCI in the Meson Test beamline would result in a 94 mrem exposure at the location of the common wall.

The MCI analysis for MC7 assumes a nominal thickness of 0.0328 feet (0.393 inches) of steel for the enclosure. This results in an inconsequential 3% decrease in exposure; the primary purpose of this wall is to prevent one from approaching closer than 12 feet from the beam.

The MCI analysis concludes that the exposure adjacent to the MC7 enclosure would result in a 3.0E03 exposure at this location, and a 13E03 exposure on top of the roof. One concludes that an interlocked radiation detector is required for MC7.

III-13.4.1.1.2 Movable Shielding

The Meson Area has moveable shielding placed in the tunnel vehicle access entrances at M01, M02, M03, and M04. These movable shield blocks are either posted to prohibit moving of these blocks without ES&H approval or are additionally chained and locked with a Radiation Safety lock and an applicable padlock where deemed necessary.

The MC6 enclosure is constructed from movable shielding. The existing and required shielding are tabulated below. Regions with inadequate shielding, highlighted in red, require an active engineered Credited Control.

Table 6: Meson Center Longitudinal Shielding

Longitudinal Range	Location	Current Shielding (efd)	Required (efd)	Difference (efd)
5603-5662	MC6	15.0	13.9	1.1
5662-5733	MC6	7.8	13.9	-6.1
5733-5790	MC6	6.6	3.0	3.6
5790-5793	MC6	3.3	3.0	0.3
5793-5798	MC6	0.0	3.0	-3.0

Table 7: Meson Center Transverse Shielding (continued on next page)

Transverse Station (ft)	Current Shielding (efd)	Required (efd)	Difference (efd)
MC65655	16.9	13.9	3.0
MC65662-E	28.0	13.9	14.2
MC65662-W	39.1	13.9	25.2
MC65664-E	22.2	13.9	8.3
MC65670-W	29.7	13.9	15.8
MC65673-W	48.2	13.9	34.3
MC65679-W	26.4	13.9	12.5
MC65682-W	16.5	13.9	2.6
MC65685-W	13.2	13.9	-0.7
MC65701-W	16.5	13.9	2.6
MC65715-W	9.9	13.9	-4.0
MC65719-W	13.2	13.9	-0.7
MC65722-W	9.9	13.9	-4.0
MC65728-W	9.9	13.9	-4.0
MC65733-E	26.5	3.0	23.5
MC65734-W	16.5	3.0	13.5
MC65735-W	13.2	3.0	10.2
MC65739-W	16.5	3.0	13.5
MC65741-E	24.9	3.0	21.9
MC65742-W	11.6	3.0	8.6
MC65743-W	14.9	3.0	11.9
MC65747-W	19.8	3.0	16.8
MC65749-E	26.5	3.0	23.5
MC65750-W	14.9	3.0	11.9
MC65754-W	19.8	3.0	16.8

MC65755-W	16.5	3.0	13.5
MC65757-W	11.6	3.0	8.6
MC65759-E	24.9	3.0	21.9
MC65759-W	11.6	3.0	8.6
MC65765-W	13.6	3.0	10.6
MC65767-E	18.2	3.0	15.2
MC65775-E	8.3	3.0	5.3
MC65788-E	11.6	3.0	8.6
MC65790-W	3.3	3.0	0.3
MC65791-E	8.3	3.0	5.3

The following credited shielding resides in the Meson Switchyard 120 Experimental Areas.

The downstream portion of the MT6 enclosure is assembled from large shielding blocks. These movable shield blocks are either posted to prohibit moving of these blocks without ES&H approval or are additionally chained and locked with a Radiation Safety lock and an applicable padlock where deemed necessary.

As analyzed in the MCI analysis for MC7, 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 assembly must be locked in place before beam is run.

III-13.4.1.1.3 Penetration Shielding

Table 10 summarizes the penetrations that require shielding ("fill" – shielding material inside the penetration).

Table 8: Meson Area Penetrations Requiring Fill. Locations and required fill.

Location		**Fill**
Enclosure	**Z-Location**	
	(feet)	**(efd)**
M01	4128 (MS1)	2.65
M01	4144 (MS1)	2.65
M01	4158 (MS1)	2.65
M02	4350	Duct filled with 19.5 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
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

There are no penetrations to the MT6 enclosure; routing is over the shielding blocks.

There are no penetration failures for the MC7 enclosure.

III-13.4.1.2 Fences

The existing radiation fencing surrounding the Meson Area berm is credited. The fencing north of the MC6 enclosure, spanning between the Meson Polarized and Meson West beamlines, is also credited.

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.

III-13.4.2 Active Engineered Credited Controls

Active engineered controls are systems designed to reduce the risks from the MCI to acceptable levels. These automatic systems limit operations, shut down operations, or provide warning alarms when operating parameters are exceeded. The active controls in place for the Meson Area are discussed below.

III-13.4.2.1 Radiation Safety Interlock System

The Meson Area beamlines employ three Radiation Safety Interlock Systems (RSIS). The characteristics of the systems are described in Section I of the Fermilab SAD. The first system allows beam into the Meson Target Train enclosures; the other two systems allow beam into the two experimental areas MTest and MCenter.

Radiation detectors are placed around the MTest and MCenter experimental areas. The alarm levels of radiation detectors are interlocked to either the MTest or MCenter RSIS to ensure compliance with FRCM requirements. Such detectors are capable and set to disable beam within one second of exceeding a predetermined level.

The RSIS inhibits beam transport by controlling redundant critical devices. Beam cannot be transported to downstream areas without both critical devices enabled. In the event of a critical device failure, the system has a failure moved function that reaches back and disables the upstream RSIS, preventing beam from reaching the failed device.

The Meson Area protected enclosures, along with the CDC name, critical devices, and location of critical devices, are listed in Table 4. For completeness, Meson Switchyard 120 Experimental Area enclosures protected by Meson Area devices are also listed.

Table 9: Protected Enclosures and Associated CDC. For completeness, Meson Switchyard 120 Experimental Area enclosures are also listed; these enclosures are indicated with an (*)

Protected Enclosure(s)	Critical Device Controller		
	Name	Devices	Location
M01, M02, M03, M04, and M05	Meson	S:MLAM1, S:V204	Switchyard EncC
MC6, MC7*	M-Center	F:MC1D, MC2 Beam Stop	M01, M02
MT6*	M-Test	F:MW1W, MT3 Beam Stop	M01, M03

Radiation detectors are placed around the Meson Area beamlines. They are configured so that a beam loss producing a radiation flux that exceeds the allowable limit will inhibit the associated RSIS critical devices to provide radiation protection for those in the area. Such detectors can disable beam within one second of exceeding a predetermined level. The radiation detectors limit the radiation flux from one-pulse accidents to less than the limit. The table below lists the radiation detectors in use that are required for the MCI, the detector type, and the Credited Control trip limit. Operationally, to satisfy 10 CFR Part 835 occupation requirements, additional radiation detectors are used with the credited radiation detectors at settings lower than that required for the MCI by the SAD. These settings are made at the discretion of the Radiation Physics Operation Department (RPO).

Table 10: Credited Radiation Monitors for the Meson Area. Note that the "MC7 Air Gap" chipmunk resides in a Meson Switchyard 120 Experimental Area, and is addressed further in that section.

Device Type	**Location**	**Credited Control Limit (mrem/hour)**
Chipmunk	MT3 Cryo Penetration	95
Chipmunk	MDB MC6 US	19.7
Chipmunk	MDB MC6 Mid	28.2
Chipmunk	MDB MC6 DS	28.2
Chipmunk	MC6 Catwalk	440
Chipmunk	MC7 Air Gap	485

The MTest RSIS includes a "Primary Logic Chassis" that monitors several beamline elements to determine if the criteria for one of three modes of operation are met. The beamline is not capable of transporting beam unless the specific target positions, collimator positions, and magnet currents are within the allowed values for a particular mode.

The MCenter RSIS includes a current interlock on the F:MC6D power supply, which powers the energy selection dipole magnet string in the MC6 Enclosure. This interlock is set to 575A, which is the current required to transport 90GeV secondary particles.

Personnel from the Accelerator Directorate, Beams Division, Operations Department are required to Search & Secure the enclosures to establish the interlocks for the Exclusion Areas. Search & Secure ensures no personnel remain within the Exclusion Areas during operation.

The RSIS, including requirements for hardware and system testing, inventory of interlock keys, Search & Secure procedures for the beamline, controlled access procedures, personnel training requirements, and procedures for maintenance of interlock systems are maintained in conformance with the requirements stated in the FRCM.

III-13.4.2.2 ODH Safety System

During personnel access into Meson (M02, M03, M04, M05), the following components of the oxygen deficiency hazard (ODH) safety system shall be in place, with no known loss of safety function, during personnel access into applicable areas:

- Four (4) area/fixed oxygen monitors, two (2) high and two (2) low, in M03
- Four (4) area/fixed oxygen monitors, two (2) high and two (2) low, in M04
- One (1) horn and one (1) strobe in M03
- One (1) horn and one (1) strobe in M04

III-13.4.3 Administrative Credited Controls

All Meson Area operations with the potential to affect the safety of employees, researchers, or the public or to adversely affect the environment are performed using approved laboratory, directorate, division, or department procedures. These procedures are the administrative controls that encompass the human interactions that define safe accelerator operations.

III-13.4.3.1 Operation Authorization Document

Beam will not be transported to the Meson Area without an approved Beam Permit and Run Condition. The Beam Permit specifies beam power limits as determined and approved by the Head of the Accelerator Directorate, in consultation with the Head of ES&H, assigned area RSO, Accelerator Directorate, Beams Division, Operations Department Head, and Beams Division External Beam Delivery Department Head. The Run Conditions list the operating modes and safety envelope for the Meson Area. Run Conditions are issued by ES&H, and are signed by the Accelerator Directorate, Beams Division, Operations Department Head, assigned area RSO, and the Head of Accelerator Directorate.

- To run beam in the Meson Primary beamline area to the Meson Target Train, the F-Manholes, and enclosures M01 through M05 must be secure.
- To run beam in the MTest areas, the MT6 Section 1 and MT6 Section 2 enclosures must be secure.
- To run beam in the MCenter areas, the MC6, MC7 Section 1, MC7 Section 2, and MB7 enclosures must be secure.

III-13.4.3.2 Staffing

The following staffing shall be in place during applicable beam operation:

- At least one member of the AD Operations Department who has achieved the rank of Operator II or higher shall be on duty and on site.
- At least one member of the AD Operations Department shall be present in the Main Control Room (MCR).
- A single person could satisfy both of these conditions.

III-13.4.3.3 Accelerator Operating Parameters

To ensure operations within the bounding conditions of the MCI analysis, the following limits are applied to the Meson Area:

- Primary proton beam delivery shall not exceed 2.75E15 protons per hour at 120 GeV.

III-13.5. Summary of Defense-in-Depth Controls

III-13.5.1 Defense-in-Depth Engineering Controls

III-13.5.1.1 Passive Defense-in-Depth Engineering Controls

III-13.5.1.1.1 Permanent Shielding

The amount of credited permanent shielding, and minimum defense-in-depth, is given by beamline:

- Meson Primary: 15.3 efd credited, one efd minimum defense-in-depth.
- Meson Center: 12.8 efd credited, one efd minimum defense-in-depth.
- Meson Test: (refer to Tables 9 and 10).

III-13.5.1.2 Active Defense-in-Depth Engineering Controls

III-13.5.1.2.1 Machine Protection Controls

Beam Loss Monitors routinely determine when beam is being lost at unacceptable regions and/or rates. Beam position monitors and segmented wire ionization chambers determine the trajectories of the beam so that the Main Control Room may control losses. The beam budget monitor continually monitors the integrated beam delivered to the beamlines on an hourly basis.

III-13.5.1.3 Defense-in-Depth Administrative Controls

III-13.5.1.3.1 Fencing and Posting

Fences are used and posted to designate potential Radiation Areas during machine operations.

III-13.5.1.3.2 Training

All personnel engaged in the commissioning, operation, and emergency management of the Meson Area shall have at a minimum, Fermilab's Radiation Worker training current. Furthermore, personnel approved for access into the interlocked enclosure shall have Fermilab's Controlled Access training current as well.

III-13.6. Decommissioning

DOE Field Element Manager approval shall be obtained prior to the start of any decommissioning activities for the Meson Area.

III-13.7. Summary and Conclusion

Specific hazards associated with the operation of the Meson Area enclosures are identified and assessed in this chapter of the Fermilab SAD. The designs, controls, and procedures to mitigate Meson Area-specific hazards are identified and described. The Meson Area is subject to the safety requirements, controls, and procedures outlined in Section I of the Fermilab SAD.

The preceding discussion of the hazards presented by Meson Area operations and the Credited Controls established to mitigate those hazards demonstrate that the area can be operated in a manner that will produce minimal hazards to the health and safety of Fermilab workers, researchers, members of the public, as well as to the environment.

III-13.8. References

[1] *Fermilab Radiological Control Manual*

[2] *2003 Shielding Assessment for the Switchyard 120 Project*

[3] *Addendum to the SY 120 Shielding Assessment to Add the MCenter Branch to the Beam Line (2004)*

[4] *"Post Assessment Document" to the 2003 SY120 Shielding Assessment to Enable a Low Energy Pion Mode of Operation in the MTest Beamline (2007)*

[5] *Addendum to the SY 120 Shielding Assessment for Continued Operation of the Meson Center Beam Line (2013)*

III-13.9. Appendix – Risk Matrices

Risk assessment methodology was developed based on the methodology described in DOE-HDBK-1163-2020. Hazards and their potential events are evaluated for likelihood and potential consequence assuming no controls in place, which results in a baseline risk. A baseline risk (i.e., an unmitigated risk) value of III and IV does not require further controls based on the Handbook. Events with a baseline risk value of I or II do require prevention and/or mitigation measures to be established in order to reduce the risk value to an acceptable level of III or IV. Generally, preventive controls are applied prior to a loss event, reflecting a likelihood reduction, and mitigative controls are applied after a loss event, reflecting a consequence reduction. For each control put in place, likelihood or consequence can have a single "bin drop," resulting in a new residual risk (i.e., a mitigated risk). This risk assessment process is repeated for each hazard for facility workers, co-located workers, and maximally-exposed offsite individuals (MOI). At the conclusion of the risk assessments, controls that are in place for the identified accelerator-specific hazards are identified as Credited Controls and further summarized in Section III-13.4 of this Chapter as well as SAD Chapter VII-A.1 *Accelerator Safety Envelope – Fermi Main Accelerator*.