MESON AREA

SECTION III CHAPTER 13 OF THE FERMILAB SAD

Revision 2 January 21, 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 Fermi Main Accelerator that are pertinent to understanding the risks to the workers, the public, and the environment due to its operation.

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 (ESH) 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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Accelerator Safety Department Head

☐ ______________________________________
SAD Review Subcommittee Chair

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 ESH 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	January 21,2024	• 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.

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 (MTest) and Meson Center (MCenter), for use in test beam research and development.

III-13.1.2 Current Status

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 Meson Area beamlines start at the upstream end of the M01 enclosure and continue to the downstream end of MT6 Section 2 for the MTest beamline and the downstream end of MC7 Section 2 for the MCenter beamline. Associated beamline infrastructure is located at the service buildings.

The Meson area beamlines comprise the following enclosures:

- M01
- M02
- M03
- M05
- M05
- MC6
- MT6 Section 1 (MT6-1)
- MT6 Section 2 (MT6-2)
- MC7 Section 1 (MC7-1)
- MC7 Section 2 (MC7-2)
- MB7

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.

III-13.1.4 Location

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

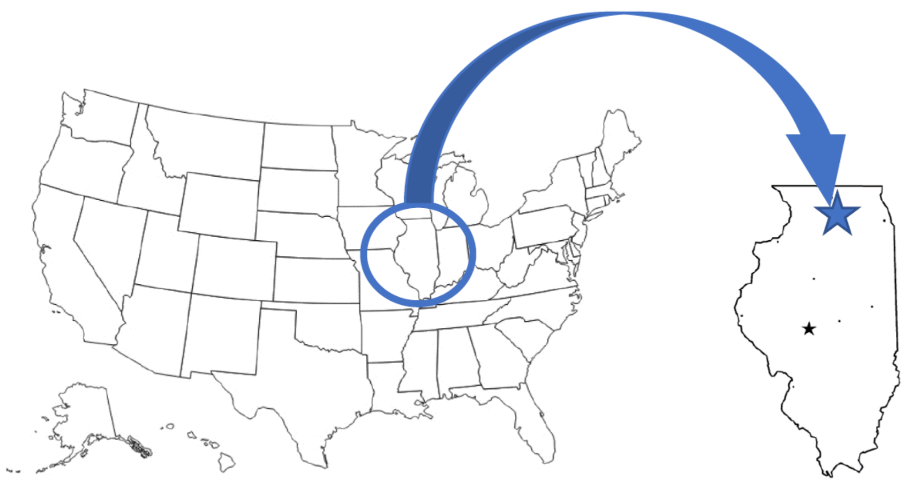

Figure 1. Regional view showing the location of the Fermilab site in Batavia, IL.

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

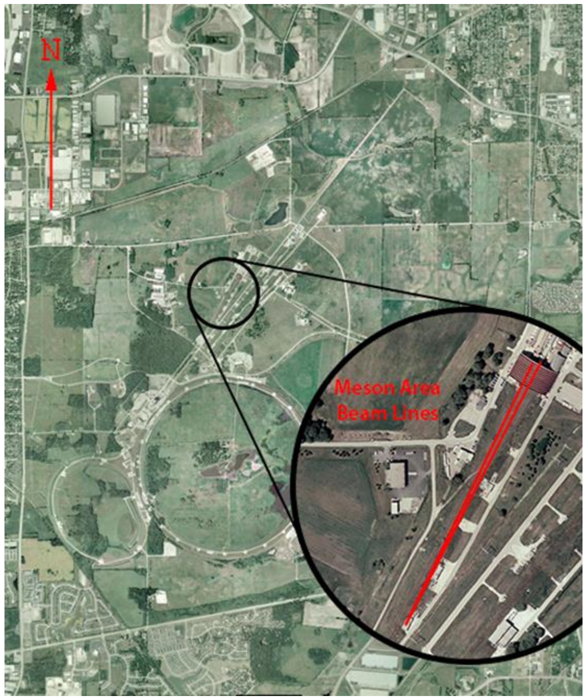

Figure 2. Aerial view of the Fermilab site, indicating the location of the Meson Area.

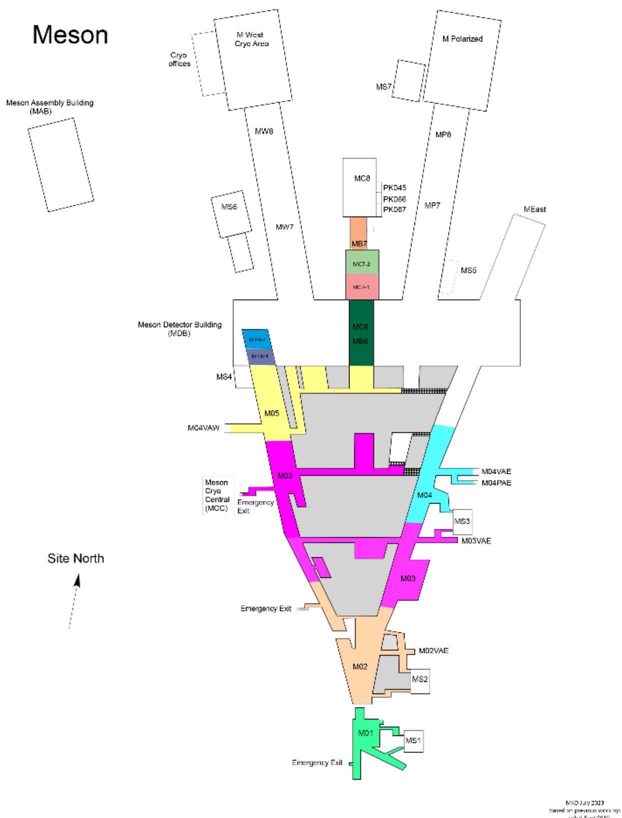

Figure 3: Meson Enclosures & Service Buildings

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 upstream Meson Area, the M01 enclosure, receives 120 giga-electron volt (GeV) beam from the Switchyard Fixed Target beamlines and delivers to the Meson experimental facilities. For each facility, 120 GeV protons strike a target. The secondary particles produced from these targets are transported via a system of electromagnets to the test beam facilities. The production targets and transport systems are separate and independent of each other. Changes in the running conditions at one of the experimental areas do not affect operations in the other experimental area. Beam can be provided to any one experiment or both experiments simultaneously without special beam line configuration changes.

The Meson Target Train is located between enclosures M01 and M02. For operational purposes, such as tuning or temporarily inhibiting beam, primary beam for MTest or MCenter may be temporarily disabled and absorbed on the target train. The MTest and MCenter secondary beam targets do not reside in the Meson Target Train. The name is historical.

The MTest facility modes of operation are described in detailed shielding assessments. The modes of operation are based on the shielding assessments, which consider beamline configuration of targets, collimators, and magnet power supply settings. These requirements for a particular running mode are monitored by the "MTest Primary Critical Device Controller Primary Logic Chassis", which is a credited control device. The Primary Logic Chassis prevents the MTest CDC from being enabled unless all requirements of the desired operating mode are met. The modes of operation of the MTest facility are:

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

There is no provision for neutral particles. Individual species cannot be selected – the experiment is responsible for particle type identification.

The MCenter facility modes of operation are described in detailed shielding assessments. The modes of operation are based on the shielding assessments, which consider beamline configuration of targets, collimators, and magnet power supply settings. The modes of operation for the MCenter facility are:

- Pion Mode

There is no provision for neutral particles. Individual species cannot be selected – the experiment is responsible for particle type identification.

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 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**Error! Reference source not found.** 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 7.94×10^{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 1.74×10^{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 1.2×10^{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 5.26×10^{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.[Error! Bookmark not defined.] 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	2.4×10^{1}	2.1×10^{0}
Target Train Groundwater	20	0.4	2.2×10^{-7}	1.0×10^{-8}
M03 Pinhole Collimator Surface Water	1900	10	3.4×10^{1}	3.0×10^{0}
M03 Pinhole Collimator Groundwater	20	0.4	3.2×10^{-7}	1.5×10^{-8}
MT3 Low Energy Pion Target Surface Water	1900	10	1.7×10^{1}	1.5×10^{0}
MT3 Low Energy Pion Target Groundwater	20	0.4	1.6×10^{-7}	7.0×10^{-9}
MCenter Target Pile Surface Water	1900	10	6.5×10^{-1}	5.8×10^{-2}
MCenter Target Pile Groundwater	20	0.4	1.3×10^{-8}	2.6×10^{-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 ^{3}H 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-electron volt 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 Fermilab Environment, Safety, and Health (ES&H) Manual (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). Radioactive waste is a standard radiological hazard that is managed within the established Radiological Protection Program (RPP) and as prescribed in the Fermilab Radiological Control Manual (FRCM). 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 are required.

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 Standard Industrial 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.

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 Switchyard Fixed Target Beamlines involving this hazard implements the controls specified in the Common Risk Matrix Table. No unique controls are in use.

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.

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.

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.

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.

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.

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.

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 Meson Detector Building, 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 in to 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.

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.

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.

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.

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.

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.

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.

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.

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.

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.

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.

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.

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.

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.

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.

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.

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.

III-13.2.11.2 Hazard to Water

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.

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.

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 for the Meson Area is based on the MCI analysis presented in SAD Section III Chapter 12.3 for the Switchyard Fixed Target Beamlines. In the Meson Area, the MCI scenario must be evaluated for both the Meson Test (MTest) segment and Meson Center (MCenter) segment.

The MCI scenario evaluated for the Meson Area is 14.66 kW beam power delivered, 2.75E15 protons per hour, 4.2E13 protons per event, at 120 GeV, once every fifty-five (55) seconds.

For the MTest segment, the MCI scenario evaluated assumes that the primary beam reaches the "MT4 Low Energy Pion Mode" Target, in the M03 Enclosure at FSCSz=5164'. This is chosen because this is the furthest that unattenuated beam can travel in the MTest beamline. The secondary beam MCI for the MTest beamline segment is 4.2E8 secondaries per cycle, 30 GeV, once every fifty-five (55) seconds.

For the MCenter segment, the MCI scenario evaluated assumes that the primary beam reaches the MC6 Target, in the MC6 Enclosure at FSCSz=5728'. The secondary beam MCI for the MCenter beamline segment is 1.97E10 secondaries per cycle, 90GeV, once every fifty-five (55) seconds.

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.

III-13.4. Summary of Credited Controls

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

The Meson Area beam lines shielding analyses indicate the mitigations necessary to comply with the FRCM requirements. Interlocked radiation detectors are installed along the MTest and MCenter beam lines as prescribed by the shielding assessments to mitigate this concern.

III-13.4.1.1.1 Permanent Shielding Including Labyrinths

The Meson Area Shielding Assessments contain transverse, longitudinal, and labyrinth shielding summaries. Credited levels of shielding are based on the use of the ES&H Shielding Assessment Group Shielding Categories from the *Incremental Shielding Assessment Methodology*. For the analysis of the MCI, areas where the public is invited are evaluated at categories 3A, 3B, or 3C, representing shielding for a dose of 100 mrem in an hour on the berm for a loss on a magnet, beam pipe in an enclosure, or buried pipe, respectively. Areas where the public are not invited are evaluated at categories 4A, 4B, and 4C, representing a dose of 500mrem in an hour on the berm for a loss on a magnet, beam pipe in an enclosure, or buried pipe, respectively.

In the event a region does not have sufficient shielding for the aforementioned shielding categories, an active control device, such as a chipmunk, scarecrow, or TLM is required. Once the active control device is in place, the shielding category changes to categories 8A, 8B, or 8C for a dose of 100 mrem in an hour on a magnet, beam pipe in an enclosure, or buried pipe, respectively, or 9A, 9B, or 9C for a dose of 500 mrem in an hour on a magnet, beam pipe in an enclosure, or buried pipe, respectively.

The shielding analysis for the MTest and MCenter beamlines is provided. While some stations and z-ranges will appear to be duplicated, the MTest beamline is angled 3.7mrad to the West from the MCenter beamline, and therefore requires both segments be evaluated.

The following Longitudinal ranges of the MTest beamline, their evaluated category and credited shielding are as follows:

Table 4: MTest Longitudinal Credited Shielding

Z-Range (cell or ft)	Category	Credited Shielding (ft)
3967-4003	4A	13.9
4003-4062	4A	13.9
4062-4160	4A	13.9
4160-4300	4A	13.9
4300-4340	4C	16.3
4340-4605	4A	13.9
4605-4710	4C	16.3
4710-4716	4A	13.9
4716-4841	4C	16.3
4841-4889	4B	11.4
4889-4989	4C	16.3
4989-4995	4B	11.4
4995-5043	4C	16.3
5043-5164	4C	11.6
5164-5590	4A	3.0
5590-5618	4C	3.0

From FSCSz=5164’ onward, the beam is a secondary beam, attenuated by 1E-5 secondary particles per proton due to the interaction with the target. The shielding requirements for FSCSz=5164’ to 5618’ are based on the secondary beam intensity and energy selected in the MCI.

The following Transverse Stations of the MTest beamline, their evaluated category and credited shielding are as follows:

Table 5: MTest Transverse Credited Shielding

Transverse Station	Shielding Category	Credited Shielding (ft)
ME13850	4C	16.3
ME13900	4C	16.3
ME13950	4C	16.3
ME13975	4A	13.9
ME14000	4A	13.9
MC14035	4A	13.9
ME14050	4A	13.9
ME24250	4A	13.9
ME13353	4C	16.3

ME13400	4C	16.3
ME13450	4C	16.3
ME13500	4C	16.3
ME13550	4C	16.3
ME13552	4C	16.3
ME13600	4C	16.3
ME13650	4C	16.3
ME13700	4C	16.3
ME13750	4C	16.3
ME13800	4C	16.3
ME24375	4A	13.9
MC24480	4A	13.9
MC24540	4A	13.9
MC24550	4A	13.9
MC34775	4C	16.3
MC34973	4C	16.3
MC34985	4B	11.4
ME35003	4C	16.3
ME35005	4C	16.3
MC35025	4C	16.3
MC35065	4C	11.6
MC45297	4A	3.0
MC55520	4A	3.0

All Labyrinths and Penetrations for the MTest beamline segment conform to the requirements to prevent a dose of 500mrem in an hour on the berm.

For the MTest Experimental Enclosures, MT6-1 and MT6-2, following the methodology of the *2003 Shielding Assessment for the Switchyard 120 Project* (Reference GK-28) to evaluate the dose in the MTest experimental areas, no unshielded dose higher than 197 mrem in an hour exists. Therefore, no shielding is credited for the MT6-1 or MT6-2 enclosures from FSCSz=5618' to the MT6-2 Beam Absorber for the MCI. These areas are within the Meson Detector Building (MDB) and the MS4 Service Building and conform to the requirement to prevent a dose of 5R.

The following Longitudinal ranges of the MCenter beamline, their evaluated category and credited shielding are as follows:

Table 6: MCenter Longitudinal Credited Shielding

Z-Range (cell or ft)	**Category**	**Credited Shielding (ft)**
3967-4003	4A	13.9

4003-4062	4A	13.9
4062-4160	4A	13.9
4160-4300	4A	13.9
4300-4340	4A	13.9
4340-4566	4A	13.9
4566-4656	4A	13.9
4656-4709	4A	13.9
4709-4936	4C	16.3
4936-4986	4A	13.9
4986-5297	4C	16.3
5297-5353	4B	11.4
5353-5518	4C	16.3
5518-5603	4A	13.9
5603-5662	4A	13.9
5662-5733	9A	5.5
5733-5790	4A	3.0
5790-5793	4A	3.0
5793-5798	4A	0.0

Longitudinal range from FSCSz=5733' to 5798' are downstream of the MC6 target. The MC6 target attenuates the beam by a factor of 4.7E-4 secondaries per hadron. Therefore, the most intensity the secondary beam can be is 1.97E10 secondary particles per spill. The shielding required for is based on this secondary beam intensity.

Longitudinal range z=5662' to 5733 is deficient in shielding by 6.1' for a category 4A evaluation. A set of three (3) chipmunks (MUX ID #0-052 [MDB MC6 US], MUX ID #0-053 [MDB MC6 Mid], and MUX ID #0-054 [MDB MC6 DS]) are credited for this segment, therefore the shielding category changes to 9A and 5.5' of shielding is credited.

Longitudinal range z=5793' to 5798' is the last 5' of the MC6 enclosure near the North wall of the Meson Detector Building. Specifically, the area encompasses the MC6 Catwalk, where the Meson Detector Building crane electronics are located. This area is locked behind a radiation fence. No fixed shielding exists for this range due to the limitations of the area that the MDB crane can reach safely. From *Experimental Halls Methodology* summarized in a memo by Malensek (1991), the dose rate transverse to a beam of hadrons incident upon a 15 cm diameter by 90 cm long iron cylinder is estimated by the following equation:

$$D = I * Y * 1x10^{-3} * 1x10^{-2} * \left(\frac{E}{1000}\right)^{0.8} * \left(\frac{0.5}{d}\right)^{2} * 10^{-\frac{t}{T}}$$

Where D is the dose rate in mrem per pulse, I the incident primary proton intensity (4.2E13 protons per pulse), Y the secondary hadron yield (4.7e-4 secondaries per hadron), E the incident hadron energy in GeV

(120 GeV), d the distance from the center of the beamline to the point of interest in feet (5'), t the thickness of the shielding (0'), and T the Tenth Value Thickness of the shielding material (2.6 e.f.d for concrete). The calculation yields a dose of 362 mrem/cycle (23.7 R in an hour) for this segment. A chipmunk (MUX ID#: 0-058 [MC6 Catwalk]) is credited in this location to limit the dose on the MC6 catwalk in the Meson Detector Building to a dose of 5R in an hour.

The following Transverse Stations for the MCenter beamline segment, their evaluated category and credited shielding are as follows:

Table 7: MCenter Transverse Credited Shielding

Z-Range (cell or ft)	Shielding Category	Credited Shielding (ft)
ME13975	4A	13.9
ME14000	4A	13.9
MC14035	4A	13.9
ME14050	4A	13.9
ME24250	4A	13.9
MC24540	4A	13.9
MC24550	4A	13.9
MC34985	4A	13.9
ME35003	4A	13.9
ME35005	4A	13.9
MC65655	4A	13.9
MC65662-E	4A	13.9
MC65662-W	4A	13.9
MC65664-E	4A	13.9
MC65670-W	4A	13.9
MC65673-W	4A	13.9
MC65679-W	4A	13.9
MC65682-W	4A	13.9
MC65685-W	4A	13.2
MC65701-W	4A	13.9
MC65715-W	9A	5.5
MC65719-W	4A	13.2
MC65722-W	9A	5.5
MC65728-W	4A	3.0
MC65733-E	4A	3.0
MC65734-W	4A	3.0
MC65735-W	4A	3.0
MC65739-W	4A	3.0
MC65741-E	4A	3.0

MC65742-W	4A	3.0
MC65743-W	4A	3.0
MC65747-W	4A	3.0
MC65749-E	4A	3.0
MC65750-W	4A	3.0
MC65754-W	4A	3.0
MC65755-W	4A	3.0
MC65757-W	4A	3.0
MC65759-E	4A	3.0
MC65759-W	4A	3.0
MC65765-W	4A	3.0
MC65767-E	4A	3.0
MC65775-E	4A	3.0
MC65788-E	4A	3.0
MC65790-W	4A	3.0
MC65791-E	4A	3.0

The MCenter shielding, beginning at FSCSz=5655', are stacked concrete shielding blocks. Transverse Stations MC6 5685-W and MC6 5719-W credit the amount of stacked shielding at those stations.

Transverse station MC6 5685W, is deficient in shielding by 0.7 e.f.d. for a category 4A evaluation, however the dose rate is under 5R in an hour for this station, located in the Meson Detector Building (MDB). Therefore 13.2' of shielding is credited.

Transverse station MC6 5715W, is deficient in shielding by 4.0 e.f.d. for a category 4A evaluation. A chipmunk (MUX ID#: 0-053 [MDB MC6 Mid]) is credited as an active control. Therefore, the shielding category changes to 9A. 5.5' of shielding is credited.

Transverse station MC6 5719W is deficient in shielding by 0.7 e.f.d. for a category 4A evaluation, however the dose rate is under 5R in an hour for this station, located in the Meson Detector Building (MDB). Therefore 13.2' of shielding is credited.

Transverse station MC6 5722W is deficient in shielding by 4.0 e.f.d. for a category 4A evaluation. A chipmunk (MUX ID#: 0-054 [MDB MC6 DS]) is credited as an active control. Therefore, the shielding category changes to 9A. 5.5' of shielding is credited.

All Labyrinths and Penetrations for the MCenter beamline segment conforms to the requirements of 5R in an hour in a service building and 500 mrem in an hour on the berm.

The MC7 Enclosure has no shielding to credit. Based on analysis of the MC7 enclosure, two (2) active control devices will be required to protect against a dose of 500 mrem in an hour on the outside of the enclosure.

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, at the M04 and M05 crossovers, and along the sides and in between the MC7 and MC8 enclosures. The MC6 and MT6 enclosures are assembled from large concrete movable shielding blocks. These movable shield blocks are either posted to prohibit moving of these blocks without ESH approval or are additionally chained and locked with a Radiation Safety lock and an applicable padlock, where deemed necessary.

III-13.4.1.1.3 Penetration Shielding

Refer to Section III Chapter 13.4.1.1.1.

III-13.4.2 Active Engineered Credited Controls

Active engineered controls are systems designed to reduce the risks from accelerator operations 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 include beam loss controls and a Radiation Safety Interlock System (RSIS).

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.

The Meson Primary RSIS inhibits beam transport to the F Line Manholes and enclosures M01-M05 by controlling redundant critical devices, MLAM1 and V204, which are a string of Lambertson magnets and dipole bend string respectively, located in the Switchyard Enclosure C. MLAM1 bends the beam to the west by 8.0 mrad. With MLAM1 off, the beam goes straight ahead to the Switchyard absorber. V204 bends the beam up by 11.9 mrad into the Meson beamline. Beam cannot traverse beyond the first magnet in the V204 string when off. In the event of a critical device failure, the system has a failure mode function that will reach back and disable the upstream Switchyard RSIS, preventing beam from entering the Switchyard. The Meson Primary RSIS inhibits beam when personnel access the F1, F2, or F3-Manholes, M01, M02, M03, M04, or M05 enclosures. Access is not allowed to these areas unless the critical devices are disabled.

The MTest RSIS inhibits beam transport to the MTest experimental areas MT6 Section 1 and MT6 Section 2 by controlling redundant critical devices, MW1W and MT3BS, which are a string of Lambertson magnets and a beam stop, located in the Meson M01 and M03 enclosures respectively. MW1W bends the beam to the west by 3.7 mrad into the MTest beamline. With MW1W off, the beam travels straight and is absorbed in the Meson Target Train collimators. With MT3BS closed, the beam is absorbed in the beam stop. In the event of a critical device failure, the system has a failure mode function that will reach back and disable the upstream Meson Primary RSIS preventing beam from entering the MTest beamline. The

MTest RSIS inhibits beam when personnel access the MT6 Section 1 and MT6 Section 2 enclosures. Access is not allowed to these areas unless the critical devices are disabled.

The MTest RSIS includes a "Primary Logic Chassis" which monitors several beamline elements to determine if the criteria for one of three modes of operation are met. The beamline will not be 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 inhibits beam transport to the MCenter experimental areas MC6, MC7 Section 1, MC7 Section 2, and MB7 by controlling redundant critical devices. These devices are MC1D and MC2BS, which are a dipole magnet and a beam stop located in the Meson M01 and M02 enclosures, respectively. MC1D bends the beam down by 1.5 mrad into the MCenter beamline. With MC1D off, the beam travels straight and is absorbed in the Meson Target Train collimators. With MC2BS closed, the beam is absorbed in the beam stop. In the event of a critical device failure, the system has a failure mode function that will reach back and disable the upstream Meson Primary RSIS preventing beam from entering the MCenter beamline. The MCenter RSIS inhibits beam when personnel access the MC6, MC7 Sections 1 and 2, or MB7 enclosures. Access is not allowed to these areas unless the critical devices are disabled.

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.

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 following devices are the active credited controls for the Meson Area:

- Meson Primary RSIS
- MTest RSIS
  - Including the MTest Primary Logic Chassis
- MCenter RSIS

The following interlocked radiation detectors, their location, and trip point are credited:

Table 8: Meson Area Active Credited Controls

Device Type	**Location**	**Credited Control Limit (mrem/hour)**
Chipmunk	MDB MC6 US	19.7
Chipmunk	MDB MC6 Mid	28.2
Chipmunk	MDB MC6 DS	28.2
Chipmunk	MC6 Catwalk	4870
Chipmunk	One ft outside MC7	480

Chipmunk	On Lowest MC7 Roof	440

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 and secure procedures for the beam line, 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:

- One (1) area/fixed oxygen monitor of four (4) available,
- One (1) horn and one (1) strobe for each enclosure.

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 Switchyard Fixed Target Beamlines 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 Switchyard Fixed Target Beamlines. 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

For the MTest Beamline Segment:

The following longitudinal ranges and their shielding defense-in-depth are noted:

Table 9: MTest Longitudinal Shielding Defense-in-Depth

Z-Range (ft)	***Defense in Depth (ft)***
3967-4003	1.9
4003-4062	2.6
4062-4160	6.5
4160-4300	2.6
4300-4340	9.7
4340-4605	5.4
4605-4710	9.0
4710-4716	4.3
4716-4841	7.3
4841-4889	4.1
4889-4989	1.5
4989-4995	0.5
4995-5043	1.1

5043-5164	0.3
5164-5590	8.9
5590-5618	3.9

The following transverse stations and their shielding defense-in-depth are noted:

Table 10: MTest Transverse Shielding Defense-in-Depth

Transverse Station (ft)	***Defense in Depth (ft)***
ME13850	1.0
ME13900	2.1
ME13950	1.3
ME13975	2.0
ME14000	1.8
MC14035	6.8
ME14050	7.4
ME24250	5.2
ME13353	1.5
ME13400	0.8
ME13450	1.9
ME13500	2.0
ME13550	1.1
ME13552	1.1
ME13600	1.4
ME13650	2.0
ME13700	2.7
ME13750	1.1
ME13800	1.8
ME13850	1.0
ME13900	2.1
ME13950	1.3
ME13975	2.0
ME14000	1.8
MC14035	6.8
ME14050	7.4
ME24250	5.2
ME24375	7.7
MC24480	8.4
MC24540	7.7

MC24550	3.5
MC34775	6.0
MC34973	1.9
MC34985	1.8
ME35003	3.6
ME35005	3.6
MC35025	1.1
MC35065	2.0
MC45297	9.7
MC55520	11.3

For the MCenter beamline:

The following longitudinal ranges and their shielding defense-in-depth are noted:

Table 11: MCenter Longitudinal Defense-in-Depth Shielding

Z-Range (ft)	***Defense in Depth (ft)***
3347-3475	1.8
3475-3558	2.4
3558-3950	1.4
3950-3967	2.3
3967-4003	1.8
4003-4062	2.6
4062-4160	6.5
4160-4300	2.5
4300-4340	11.9
4340-4566	4.7
4566-4656	5.0
4656-4709	7.6
4709-4936	8.0
4936-4986	3.6
4986-5297	2.8
5297-5353	3.7
5353-5518	2.6
5518-5603	1.6
5603-5662	1.1
5662-5733	2.3
5733-5790	3.6
5790-5793	0.3

5793-5798	0.0

The following transverse stations and their shielding defense-in-depth are noted:

Table 12: MCenter Transverse Defense-in-Depth Shielding

Transverse Station (ft)	***Defense in Depth (ft)***
ME13353	1.5
ME13400	0.8
ME13450	1.9
ME13500	2.0
ME13550	1.1
ME13552	1.1
ME13600	1.4
ME13650	2.0
ME13700	2.7
ME13750	1.1
ME13800	1.8
ME13850	1.0
ME13900	2.1
ME13950	1.3
ME13975	2.0
ME14000	1.8
MC14035	6.8
ME14050	7.4
ME24250	5.2
MC24540	7.8
MC24550	2.8
MC34985	5.9
ME35003	8.4
ME35005	8.4
MC65655	3.0
MC65662-E	14.2
MC65662-W	25.2
MC65664-E	8.3
MC65670-W	15.8
MC65673-W	34.3
MC65679-W	12.5
MC65682-W	2.6

MC65685-W	0.0
MC65701-W	2.6
MC65715-W	4.4
MC65719-W	0.0
MC65722-W	4.4
MC65728-W	6.9
MC65733-E	23.5
MC65734-W	13.5
MC65735-W	10.2
MC65739-W	13.5
MC65741-E	21.9
MC65742-W	8.6
MC65743-W	11.9
MC65747-W	16.8
MC65749-E	23.5
MC65750-W	11.9
MC65754-W	16.8
MC65755-W	13.5
MC65757-W	8.6
MC65759-E	21.9
MC65759-W	8.6
MC65765-W	10.6
MC65767-E	15.2
MC65775-E	5.3
MC65788-E	8.6
MC65790-W	0.3
MC65791-E	5.3

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 Meson Areas on an hourly basis.

III-13.5.1.3 Defense-in-Depth Administrative Controls

III-13.5.1.3.1 Fencing and Posting

The Meson Area has posted and locked radiological fences to prohibit access to outside berm areas. These include the fences at the M01 enclosure including Gates M01PAE and M01PAW, at the M03 enclosure including Gates M03PAE1, M03PAE2 and M03VAE, at the M04 enclosure including gates M04PAE, M04PAW, M04VAE, and M04VAW, and at the MC6-MC8 enclosures that provides a barrier to limit personnel access near the MCenter beamlines.

III-13.5.1.3.2 Training

All personnel engaged in the commissioning, operation, and emergency management of the Switchyard Fixed Target Beamlines 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 (FW), Co-Located Workers (CLW), and Maximally-Exposed Offsite Individual (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*.