SWITCHYARD FIXED TARGET BEAMLINES

SECTION III CHAPTER 12 OF THE FERMILAB SAD

Revision 1 January 20, 2024

This Chapter of the Fermilab Safety Assessment Document (SAD) contains a summary of the results of the Safety Analysis for the Switchyard Fixed Target Beamlines 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 12 of the Fermi National Accelerator Laboratory (Fermilab) Safety Assessment Document (SAD), *Switchyard Fixed Target Beamlines*, 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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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	1	January 20, 2024	• Updated to align with updated SAD template • Included Risk Matrix tables and hazard discussion • Enclosure J listed as a separate enclosure. • Switchyard RSIS updated to include upstream Main Injector P150 Extraction RSIS usage for interlocked radiation detector input. See Change Request 272. • Updated to Include MCI Analysis and Credited Controls for MCI
John E. Anderson Jr. Craig Moore	0	October 15, 2013	Initial release of the Switchyard Fixed-Target Beam Lines 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-12. Switchyard 120 Fixed Target Beamlines

III-12.1. Introduction

This Section III, Chapter 12 of the Fermi National Accelerator Laboratory (Fermilab) Safety Assessment Document (SAD) covers the Switchyard Fixed Target beamlines.

III-12.1.1 Purpose/Function

The Switchyard fixed target beamlines transport beams of accelerated particles to target stations located along the Fermilab fixed-target beam lines. 120 Giga-electron Volt (GeV) protons are extracted from the Main Injector toward the Switchyard. The beam is split in the Switchyard and redirected to fixed-target beam lines, which have been historically designated the Meson, Neutrino, and Proton beam lines. At present, only the Meson and Neutrino beamlines are capable of receiving beam.

III-12.1.2 Current Status

The Switchyard fixed target beamlines are currently **Operational**.

The P150 Beamline (P1 Beamline) is currently **Operational**.

The A150 Beamline (A1 Beamline) is currently **Non-operational**.

The P2 Beamline is currently **Operational**.

The P3 Beamline is currently **Operational**.

The Switchyard Continental Beamline is currently **Operational**.

III-12.1.3 Description

The Switchyard fixed target beamlines start in the Tevatron F-Sector at E48 and continues to the upstream end of the Meson, Neutrino, and Proton enclosures M01, N01, and P01 respectively. The Switchyard fixed-target areas are comprised of the following enclosures:

- Tevatron F-Sector from E48 to F46
- Tevatron Transfer Hall from F47 to A24
- Switchyard Enclosure B
- Switchyard Enclosures C, D, & E
- Switchyard Enclosure J
- Meson Beam Line Enclosure F1-Manhole
- Meson Beam Line Enclosures F2-Manhole & F3-Manhole
- Neutrino Beam Line Enclosure G2

The Switchyard Fixed Target Beamlines may refer to the following beam lines:

- P150 Beamline (also known as P1 Beamline) in F-Sector
- A150 Beamline (also known as A1 Beamline) in F-Sector

- P2 Beamline in F-Sector
- P3 Beamline in F-Sector & Transfer Hall
- M1 Beamline in F-Sector
- Switchyard Continental in Transfer Hall, Enclosure B, Enclosure C, D, & E, Enclosure G2, F1-Manhole, F2-Manhole, and F3-Manhole.
- G1 Stub beamline in Enclosure C, D, & E

The Switchyard Fixed Target Beamlines include the following areas:

- The Switchyard Absorber

The following Service Buildings are included in the Switchyard Fixed Target Beamlines:

- F0
- F1
- F17
- F23
- F2
- F27
- F3
- F4
- A0
- Transfer Gallery
- A1
- Switchyard Service Building (SSB)
- G2

III-12.1.4 Location

The Switchyard Fixed Target area is located on the Fermilab site in Batavia, IL.

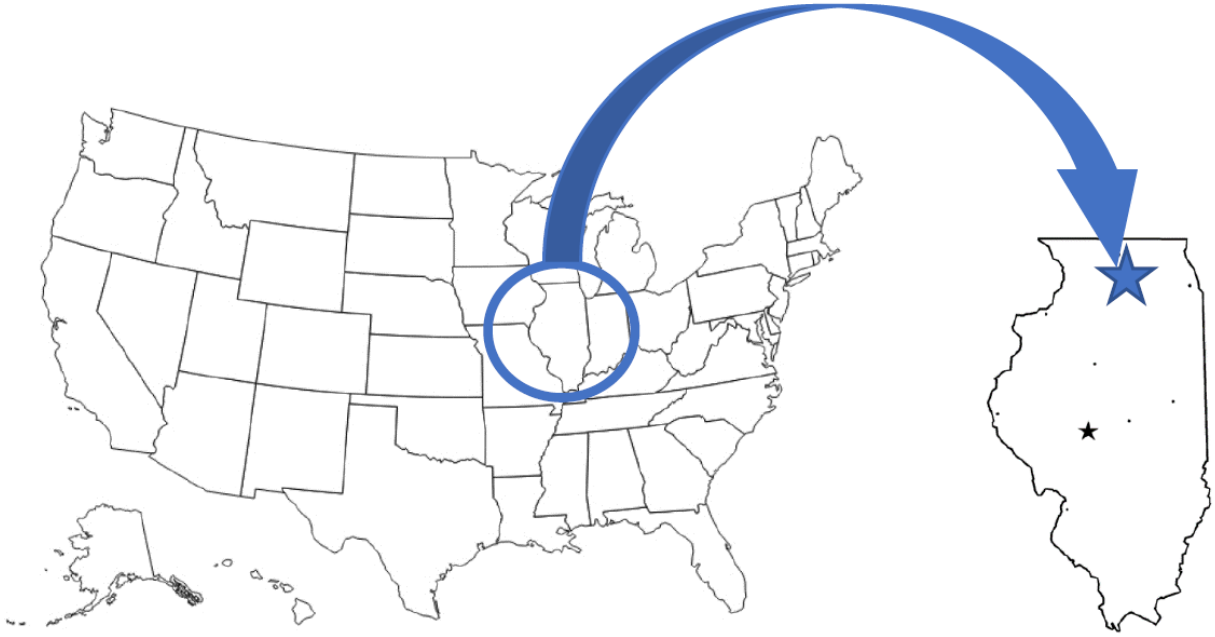

Figure 1. Regional view showing the location of the Fermilab site in Batavia, IL.

The Switchyard fixed target area is located to the east of Wilson Hall on the Fermilab site.

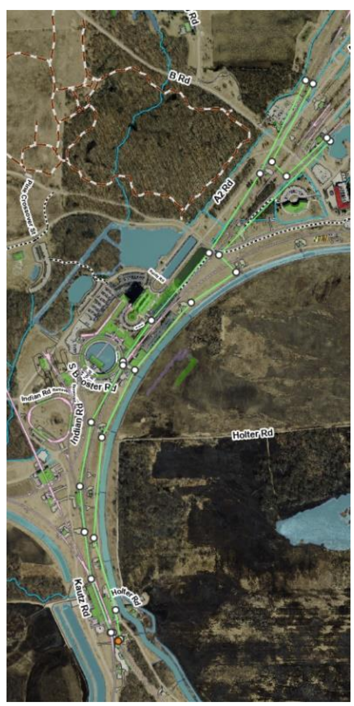

Figure 2. Aerial view of the Fermilab site, indicating the location of the Switchyard fixed target area.

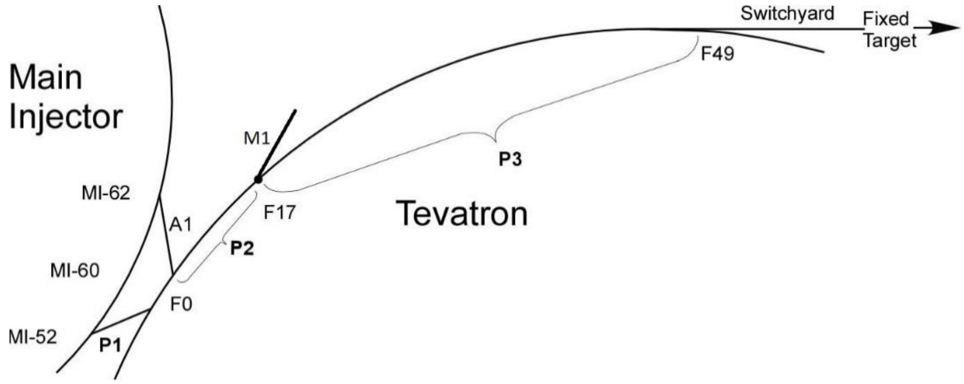

Figure 3: Beam Delivery Path for P1, P2 & P3 Beamlines (M1 Beamline begins at F17)

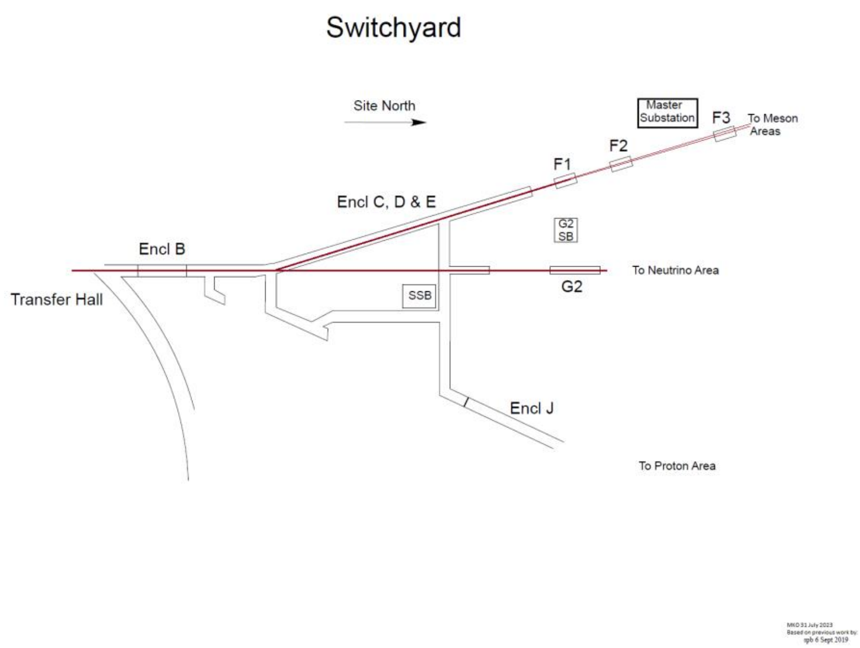

Figure 4: Beam delivery path for Switchyard continental. Operational area beam delivery in Red.

III-12.1.5 Management Organization

The Switchyard fixed target beamlines are managed by Accelerator Directorate, Beams Division, External Beam Delivery Department.

III-12.1.6 Operating Modes

The Switchyard fixed target beamlines transport a 120 GeV proton beam from the Main Injector, via the P150 Beamline (P1 Beamline), P2 Beamline, P3 Beamline, and Switchyard Continental beamline, to three possible destinations: the Switchyard Absorber, the Meson beamlines, and Neutrino beamline. The Switchyard absorber is used for commissioning and beam tune up. The Meson beam lines service two experimental areas, Meson Test (MTest) and Meson Center (MCenter), for use in the development for new detectors and detector technology. The Neutrino beam line services experiments installed in the NM4 experimental hall.

The A150 Beamline (A1 Beamline) previously operated as the anti-proton injection beamline from the Main Injector to the Tevatron. Following the abandonment of Tevatron operation in 2012, the injection and extraction devices for the A1 Beamline, kickers and Lambertson magnets T:ILAM and I:LAM62, were removed during the NOvA ANU shutdown from May 2012 to September 2013. While most of the A1 Beamline components still reside in the F-Sector enclosure, it is not possible to transport beam through this segment.

III-12.1.7 Inventory of Hazards

The following table lists all the identified hazards found in the Switchyard Fixed Target Beamline enclosures and support buildings. Section III-12.9 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-12.2 Safety Assessment. Prompt ionizing and Oxygen Deficiency Hazards due to cryogenic systems within accelerator enclosures 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 Switchyard Fixed Target Beamlines. Accelerator specific controls are identified as **purple/bold** throughout this chapter.

All other hazards present in the Switchyard Fixed Target Beamlines 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 considered to be Non-Accelerator-Specific Hazards (NASH), and their analysis will be summarized in this SAD Chapter.

Table 1. Hazard Inventory for the Switchyard Fixed Target Beamlines.

	Radiological		Toxic Materials
☒	**Prompt Ionizing Radiation**	☒	Lead
☒	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
☐	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

An additional hazard that was identified in the Switchyard area that is not included in the Hazard Identification table above is Working at Heights, which will be address in Section III-12.2.9.6.

III-12.2. Safety Assessment

All hazards for the Switchyard Fixed Target Beamlines are summarized in this section, with additional details of the analyses for accelerator specific hazards.

III-12.2.1 Radiological Hazards

The Switchyard Fixed Target Beamlines present radiological hazards in the form of prompt ionizing radiation, residual activation, groundwater activation, surface water activation, radioactive water systems, air activation, soil interactions, radioactive waste, contamination, ^{7}Be, and radioactive sources. Detailed shielding assessments[2][2][4] address 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 Switchyard Fixed Target Beamlines assess the areas described in Section III-12.1.3.

As shown in the risk analysis in Section III-12.10 Appendix – Risk Tables 20.1-20.3, the baseline risk level I has been reduced to a residual risk level of III or lower.

III-12.2.1.1 Prompt Ionizing Radiation

Prompt ionizing radiation is the principle radiological hazard that arises when beam is transported through the Switchyard beam lines. To protect workers and the 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-12.3. 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-12.4. The conclusion of these analyses is that the mitigated dose level associated with prompt ionizing radiation due to beam loss is acceptable.

III-12.2.1.2 Residual Activation

The Switchyard beam absorber will be highly activated, even when the Switchyard beam lines are not in operation or in a standby status. Access to beam absorber components is 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 an "as-low-as-reasonably-achievable" (ALARA) plan will be required for work on any highly activated equipment with a potential individual exposure greater than 200 mrem or potential job exposure greater than 1000 person-millirem (mrem). These tasks will be supervised by members of the ES&H Radiation Protection Group under the direction of the area Radiation Safety Officer (RSO).

Based on hazard analysis in Section III-12.10 Appendix – Risk Tables, Tables 20.1-20.3, the baseline risk level I has been reduced to a residual risk level of III or lower.

III-12.2.1.3 Groundwater Activation

Groundwater and surface water activation hazards are assessed in detailed shielding assessments. [2] [3] [4] Radioactivity is induced by the interaction of the high-energy particles with the soils that surrounds the beam line at the Switchyard beam absorber. Methodologies have been designed to provide conservative estimates of groundwater and surface water activation. The ground and surface water methodologies calculate the estimated annual concentration and then calculates the concentration buildup for continuous operations over a 10-year period. The release estimate for surface and groundwater after 10 years of operation at an integrated intensity of 2.98×10^{17} protons per year will produce combined ^{3}H (tritium) and ^{22}Na (sodium-22) concentrations that are 23.0% of the surface water limits and a negligible fraction of the groundwater limits respectively. The annual concentration estimates for ^{3}H and ^{22}Na surface water and groundwater from the Switchyard absorber are given in Table 2.

Table 2: Switchyard Absorber Surface Water & Groundwater Tritium & Sodium-22 Release Concentrations

Description	Annual Concentration Limits (picocurie per milliliter) [pCi/ml]		Annual Concentration Estimate (pCi/ml)	
	^{3}H	^{22}Na	^{3}H	^{22}Na
Switchyard Absorber Surface Water	1900	10	6.0×10^{0}	5.0×10^{-1}

Switchyard Absorber Groundwater	20	0.4	7.05×10^{-9}	6.27×10^{-10}

Groundwater is sampled as part of the Fermilab ES&H Environmental Monitoring System. Sump discharges and pond surface waters are sampled as part of the *Groundwater Protection Management Plan* as described in FESHM 8010.

Based on hazard analysis in Section III-12.10 Appendix – Risk Tables, Tables 20.1-20.3, the baseline risk level I has been reduced to a residual risk level of III or lower

III-12.2.1.4 Surface Water Activation

Surface water activation in the Switchyard fixed target beamlines is characterized in Section III Chapter 12.2.1.3.

III-12.2.1.5 Radioactive Water (RAW) Systems

The Switchyard Absorber is the only Radioactive Water (RAW) system for the Switchyard Fixed Target Beamlines in use. The absorber is a beam dump, contained in a reservoir of water. There is no water flow in this system during normal operation. Specifications and evaluation of hazards associated with the system are covered in *Review of Environmental Vulnerabilities Associated with the Switchyard* (March 17, 1999, updated June 9, 1999). Current Switchyard operation runs at lower energy, 120 GeV vs. 800 GeV, and less intensity than the 1999 Fixed Target run. Access to the Switchyard Absorber is controlled by ES&H and requires additional work planning controls before any access is made.

Based on hazard analysis in Section III-12.10 Appendix – Risk Tables, Tables 20.1-20.3, the baseline risk level I has been reduced to a residual risk level of III or lower.

III-12.2.1.6 Air Activation

In the P1 Beamline and P2 Beamline, the beam traverses a continuous vacuum. There is no activation from known loss points. [2]

In the P3 Beamline and Switchyard Continental, the beam destined for the Switchyard Absorber traverses a continuous vacuum until it reaches the downstream Switchyard Absorber intensity monitor. This air gap is the only known air activation point in Enclosure C, D, & E.

Beam destined for the Meson beamlines, traverses a continuous vacuum until it reaches the F1-Manhole enclosure intensity monitor. This air gap was found as an activation point for ^{7}Be. This was mitigated in 2022 by extending beam pipe from the vacuum windows to the intensity monitor on both ends, thereby containing the residual activation. This was the only known air activation point in the F1-Manhole enclosure.

Beam destined for the Neutrino Muon beamline traverses a continuous vacuum until it reaches the downstream G2 enclosure intensity monitor. This is the only known air activation point in the G2 enclosure.

Analysis is detailed in the shielding assessments. [2][3] Based on hazard analysis in Section III-12.10 Appendix – Risk Tables, Tables 20.1-20.3, the baseline risk level I has been reduced to a residual risk level of III.

III-12.2.1.7 Closed Loop Air Cooling

N/A.

III-12.2.1.8 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 Switchyard beam absorber. 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 (MeV)/centimeter (cm) and can only penetrate up to 200 meters (m) of earth equivalent shielding. The Switchyard beam absorber is 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 above grade. The soil surrounding the Switchyard area will be sampled during decommissioning to document activation levels as required by the Fermilab Environment, Safety, and Health (ES&H) Manual (FESHM).

Excessive beam loss coming from the transport of beam through buried pipe is also considered a source of soil interaction. These hazards are evaluated in detailed shielding assessments [2][3][4].

Based on hazard analysis in Section III-12.10 Appendix – Risk Tables, Tables 20.1-20.3, the baseline risk level I has been reduced to a residual risk level of IV.

III-12.2.1.9 Radioactive Waste

Radioactive waste produced during Switchyard 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 Switchyard, 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.

Based on hazard analysis in Section III-12.10 Appendix – Risk Tables, Tables 20.1-20.3, the baseline risk level I has been reduced to a residual risk level of IV.

III-12.2.1.10 Contamination

Contamination of components caused by beam interaction may exist in the Switchyard Fixed Target Beamlines. Based on hazard analysis in Section III-12.10 Appendix – Risk Tables, Tables 20.1-20.3, the baseline risk level I has been reduced to a residual risk level of IV.

III-12.2.1.11 Beryllium-7

^{7}Be is not hazardous in this pattern of use by the facility. Based on hazard analysis in Section III-12.10 Appendix – Risk Tables, Tables 20.1-20.3, the baseline risk level IV required no further preventative or mitigative controls.

III-12.2.1.12 Radioactive Sources

Radioactive Sources may be used in shutdown and maintenance activities. These sources, when used in the Switchyard Fixed Target Beamlines, are handled in accordance with FRCM. Based on hazard analysis in Section III-12.10 Appendix – Risk Tables, Tables 20.1-20.3, the baseline risk level I has been reduced to a residual risk level of IV.

III-12.2.1.13 Nuclear Material

N/A.

III-12.2.1.14 Radiation Generating Devices (RGDs)

N/A.

III-12.2.1.15 Non-Ionizing Radiation Hazards

N/A.

III-12.2.2 Toxic Materials

The Switchyard Fixed Target Beamlines present toxic material hazards identified in Table 1. All toxic material hazards present in the Switchyard Fixed Target Beamlines are in the form of Standard Industrial Hazards discussed in SAD Section I, Chapter 04.

III-12.2.2.1 Lead

This hazard exists in the form of lead solder from older electronics still in use and lead vacuum seals used in beamline vacuum equipment, original to the laboratory. 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-12.2.2.2 Beryllium

N/A.

III-12.2.2.3 Fluorinert & Its Byproducts

N/A.

III-12.2.2.4 Liquid Scintillator Oil

N/A.

III-12.2.2.5 Pseudocumene

N/A.

III-12.2.2.6 Ammonia

N/A.

III-12.2.2.7 Nanoparticle Exposures

N/A.

III-12.2.3 Flammables and Combustibles

III-12.2.3.1 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 Switchyard Fixed Target Beamlines involving this hazard implements the controls specified in the Common Risk Matrix Table. No unique controls are in use.

III-12.2.3.2 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 Switchyard Fixed Target Beamlines involving this hazard implements the controls specified in the Common Risk Matrix Table. No unique controls are in use.

III-12.2.4 Electrical Energy

III-12.2.4.1 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 Switchyard Fixed Target Beamlines involving this hazard implements the controls specified in the Common Risk Matrix Table. No unique controls are in use.

III-12.2.4.2 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 Switchyard Fixed Target Beamlines involving this hazard implements the controls specified in the Common Risk Matrix Table. No unique controls are in use.

III-12.2.4.3 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 Switchyard Fixed Target Beamlines involving this hazard implements the controls specified in the Common Risk Matrix Table. No unique controls are in use.

III-12.2.5 Thermal Energy

The Switchyard Fixed Target Beamlines present thermal energy hazards identified in Table 1. All thermal energy hazards present in the Switchyard Fixed Target Beamlines are in the form of Standard Industrial Hazards discussed in SAD Section I, Chapter 04.

III-12.2.5.1 Bakeouts

N/A.

III-12.2.5.2 Hot Work

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-12.2.5.3 Cryogenics

This hazard is not applicable to the Switchyard Fixed Target Beamlines.

Historically, the Tevatron F-Sector, Tevatron Transfer Hall, Enclosure B, and Enclosure C, D, & E were classified as Oxygen Deficient Hazard (ODH) Areas. Following the decommissioning of the Tevatron Cryogenic Systems and the Switchyard Cryogenic dipole magnets, known as the Left and Right Bends, the areas have been evaluated as ODH-0 areas on 3/6/2012 as per ADDP-CR-2314, *Tevatron Configuration for ODH-0 Classification*. By reclassifying the area to ODH-0, the in place ODH monitoring system was decommissioned as per the Division Head note dated 3/6/2012. Documentation is on file with the ES&H Division.

III-12.2.6 Kinetic Energy

The Switchyard Fixed Target Beamlines present kinetic energy hazards identified in Table 1. All kinetic energy hazards present in the Switchyard Fixed Target Beamlines are in the form of Standard Industrial Hazards discussed in SAD Section I Chapter 04.

III-12.2.6.1 Power Tools

Power tools are commonly used when working on components in the Switchyard Fixed Target Beamlines. 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-12.2.6.2 Pumps and Motors

Standard industrial pumps and motors are utilized throughout the Switchyard Fixed Target Beamlines 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 Switchyard Fixed Target Beamlines involving this hazard implements the controls specified in the Common Risk Matrix Table. No unique controls are in use.

III-12.2.6.3 Motion Tables

N/A.

III-12.2.6.4 Mobile Shielding

N/A.

III-12.2.7 Potential Energy

The Switchyard Fixed Target Beamlines present potential energy hazards identified in Table 1. All potential energy hazards present in the Switchyard Fixed Target Beamlines are in the form of Standard Industrial Hazards discussed in SAD Section I, Chapter 04.

III-12.2.7.1 Crane Operations

Trained technicians use various cranes to move, maintain, and install equipment in the Switchyard Fixed Target Beamlines. 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-12.2.7.2 Compressed Gasses

Compressed Air, Nitrogen, and $ArCO_2$, are present in the Switchyard Fixed Target Beamlines to facilitate machine operations. Compressed gas cylinders are used, stored, and moved throughout the Switchyard Fixed Target Beamlines 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 Switchyard Fixed Target Beamlines involving this hazard implements the controls specified in the Common Risk Matrix Table. No unique controls are in use.

III-12.2.7.3 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 Switchyard Fixed Target Beamlines involving this hazard implements the controls specified in the Common Risk Matrix Table. No unique controls are in use.

III-12.2.7.4 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 Switchyard Fixed Target Beamlines involving this hazard implements the controls specified in the Common Risk Matrix Table. No unique controls are in use.

III-12.2.7.5 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 Switchyard Fixed Target Beamlines involving this hazard implements the controls specified in the Common Risk Matrix Table. No unique controls are in use.

III-12.2.8 Magnetic Fields

The Switchyard Fixed Target Beamlines present magnetic field hazards identified in Table 1. All magnetic field hazards present in the Switchyard Fixed Target Beamlines are in the form of Standard Industrial Hazards discussed in SAD Section I, Chapter 04.

III-12.2.8.1 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 Switchyard Fixed Target Beamlines involving this hazard implements the controls specified in the Common Risk Matrix Table. No unique controls are in use.

III-12.2.9 Other Hazards

The Switchyard Fixed Target Beamlines present other hazards identified in Table 1. Unusual hazards are present in the form of Confined Spaces. After completion of the risk analysis in III-12.10 Appendix – Risk Tables, Tables 20.25-20.27, the baseline risk level I has been reduced to a residual risk level of III or lower.

All other hazards present in the Switchyard Fixed Target Beamlines are in the form of Standard Industrial Hazards discussed in SAD Section I, Chapter 04.

III-12.2.9.1 Confined Spaces

The Switchyard Fixed Target Beamlines contain areas defined as Confined Spaces. The F2-Manhole enclosure and F3-Manhole enclosure are confined spaces due to a single point of access and egress. Access to these enclosures follow Confined Space policy from FESHM 4230. After completion of the risk analysis in III-12.10 Appendix – Risk Tables, Tables 20.25-20.27, the baseline risk level I has been reduced to a residual risk level of III or lower.

All other confined spaces in the Switchyard Fixed Target Beamlines, 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 Switchyard Fixed Target Beamlines implements the controls specified in the Common Risk Matrix Table. No unique controls are in use.

III-12.2.9.2 Noise

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-12.2.9.3 Silica

N/A.

III-12.2.9.4 Ergonomics

This hazard has been evaluated within the Common Risk Matrix Table included in SAD Section I Chapter 04 Safety Analysis. Work in the Switchyard Fixed Target Beamlines involving this hazard implements the controls specified in the Common Risk Matrix Table. No unique controls are in use.

III-12.2.9.5 Asbestos

N/A.

III-12.2.9.6 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 Switchyard Fixed Target Beamlines involving this hazard implements the controls specified in the Common Risk Matrix Table. No unique controls are in use.

III-12.2.10 Access & Egress

III-12.2.10.1 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 Switchyard Fixed Target Beamlines involving this hazard implements the controls specified in the Common Risk Matrix Table. No unique controls are in use.

III-12.2.11 Environmental

III-12.2.11.1 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 Switchyard Fixed Target Beamlines involving this hazard implements the controls specified in the Common Risk Matrix Table. No unique controls are in use.

III-12.2.11.2 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 Switchyard Fixed Target Beamlines involving this hazard implements the controls specified in the Common Risk Matrix Table. No unique controls are in use.

III-12.2.11.3 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 Switchyard Fixed Target Beamlines involving this hazard implements the controls specified in the Common Risk Matrix Table. No unique controls are in use.

III-12.3. Maximum Credible Incident Scenario(s) for Accelerator Specific Hazards

This section evaluates the maximum credible incident (MCI) scenario that could happen in the Switchyard Fixed Target 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-12.3.1 Definition of a Maximum Credible Incident

The MCI for the Switchyard Fixed Target Beamlines is based on the analysis in Attachment 2. Due to geographic and programmatic designs, two (2) sub-segments of the Switchyard Fixed Target Beamlines must be evaluated separately.

The MCI scenario evaluated for the sub-segment of the P1 & P2 beamlines is 134.6 kW beam power delivered, 3.78E17 protons per hour, 7E12 protons per pulse, 15Hz repetition rate, 8GeV beam energy.

The MCI scenario evaluated for the sub-segments of the “P3 Beamline to Switchyard Absorber” and all areas downstream is 14.66kW beam power delivered, 2.75E15 protons per hour, 4.2E13 protons per event, at 120GeV, 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-12.4.

The accumulated dose outside of the shielding on the Switchyard berm is mitigated, by use of Credited Controls, in an MCI to less than 100 mrem on the public road, bike path and IERC parking lot, and 500 mrem in other areas.

III-12.4. Summary of Credited Controls

III-12.4.1 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 Switchyard Fixed Target Beamlines were designed with a concrete and earth covered radiation shield to protect personnel from radiological exposure during beam operations.

III-12.4.1.1 Shielding

III-12.4.1.1.1 Permanent Shielding

The Switchyard Fixed Target Beamlines 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 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 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.

For the P1 & P2 Beamlines:
The following longitudinal segments, their shielding category, and the credited amount of shielding are provided:

Table 3: P1 & P2 Beamline Longitudinal Credited Shielding

Z-Range (ft) or (cell)	Category	Credited Shielding (ft)
520-701	4C	20.3
702-708	4A	17.9
708-F0	4A	17.9
F0	4A	17.9

F0 – F13.5	4A	17.9
F13.5 – F15	4A	17.9
F15 Cryo Bldg	4A	17.9
F15 – F18	4A	17.9

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

Table 4: P1 & P2 Beamline Transverse Credited Shielding

Transverse Station (ft) or (cell)	Category	Credited Shielding (ft)
MI 8400	4C	20.3
MI 8450	4C	20.3
MI 8475	4C	20.3
MI 8569	4A	17.9
707 8650	4A	17.9
708 8725	4A	17.9
708 8740	4A	17.9
E48-4	4A	17.9
E48-7	4A	17.9
E49-7	4A	17.9
E49-9	4A	17.9
F00-5	4A	17.9
17270	4A	17.9
17450	4A	17.9
17657	4A	17.9
17683	4A	17.9
17707	4A	17.9
17910	4A	17.9
18100	4A	17.9

All labyrinths and penetrations conform to the requirements of limiting a dose to 5R in an hour within a service building.

All labyrinths and penetrations conform to the requirements of limiting a dose of 500mR in an hour, except for the following penetrations:

- Main Ring/Tevatron F15 Air Handler (outdoor)
    - An active control device will be required.

For the P3 Beamline to the Switchyard Absorber sub-segment:

The following longitudinal segments, their shielding category, and the credited amount of shielding are provided:

Table 5: P3 to Switchyard Absorber Longitudinal Credited Shielding

Z-Range (cell or ft)	Category	Credited Shielding (ft)
17880-18550	4A	13.9
18550-18600	4A	13.9
18600-19332	4A	13.9
19332-19345	4A	13.9
19345-19815	4A	13.9
19815-19867	4A	13.9
19867-20114	4A	13.9
20114-20128	4A	13.9
20128-20313	4A	13.9
20313-20370	4A	13.9
20370-20376	4A	13.9
20376-00130	4A	13.9
130-175	4A	13.9
175-215	4A	13.9
215-265	4A	13.9
265-360	4A	13.9
360-740	3C	18.7
740-750	3C	18.7
750-807	3C	18.7
807-920	3C	18.7
920-1250	3C	18.7
1250-1265	3C	18.7
1265-1290	3C	18.7
1290-1333	3C	18.7
1333-1495	3C	18.7
1495-1520	4C	16.3

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

Table 6: P3 to Switchyard Absorber Transverse Credited Shielding

Transverse Station	Shielding Category	Credited Shielding (ft)
17910	4A	13.9
18100	4A	13.9
18302	4A	13.9
18355	4A	13.9
18410	4A	13.9
18535	4A	13.9
18569	4A	13.9
18605	4A	13.9
18695	4A	13.9
18753	4A	13.9
18811	4A	13.9
19050	4A	13.9
19317	4A	13.9
19342	4A	13.9
19367	4A	13.9
19650	4A	13.9
19750	4A	13.9
19842	4A	13.9
19925	4A	13.9
20098	4A	13.9
20122	4A	13.9
20148	4A	13.9
20390	9A	5.5
0	4A	13.9
85	4A	13.9
124	9A	5.5
175	4A	13.9
184	4A	13.9
200	4A	13.9
236	4A	13.9
251	4A	13.9
260	4A	13.9
273	9A	5.5
300	4A	13.9
385	3C	18.7
400	3C	18.7

438	3C	18.7
500	3C	18.7
600	3C	18.7
700	3C	18.7
800	3C	18.7
814	3C	18.7
900	3C	18.7
948	3C	18.7
986	8C	10.2
1000	3C	18.7
1100	3C	18.7
1200	3C	18.7
1280	3C	18.7
1330	3C	18.7
1510	4C	16.3

Transverse station 20390’ (A0 Ramp) is deficient in shielding by 1.9 e.f.d. without a mitigation for a category 4A evaluation. A chipmunk (MUX ID#: 2-009 [A0 Ramp]) is credited as an active control for this station, therefore 5.5’ of shielding is credited.

Transverse station 124’ (TG Annex) is deficient in shielding by 1.2 e.f.d. without a mitigation for a category 4A evaluation. Two (2) chipmunks (MUX ID#: 2-010 [Transfer Gallery N. Addition #2] & MUX ID#: 2-011 [Transfer Gallery N. Addition #1]) are credited as an active control for this station, therefore 5.5’ of shielding is credited.

Transverse station FSCSz=273’ (WH-C-1 Manhole) is deficient in shielding by 0.4 e.f.d. for a category 4A evaluation. A TLM (MUX ID#: 2-015 [Switchyard Enclosure B TLM]) in the Transfer Hall enclosure and Enclosure B is credited as an active control for this station, therefore 5.5’ of shielding is credited.

Transverse station 986’ (P-64A Manhole), is deficient in shielding by 0.5 e.f.d. for a category 3C evaluation. A TLM (MUX ID#: 3-002 [Switchyard Enclosure C TLM]) in Enclosure C is credited as an active control for this station, therefore 10.2’ of shielding is credited.

All P3 Beamline to Switchyard Absorber Labyrinths conform to the requirements to limit a dose of 5R in a service building, 500 mrem in an hour, for areas the public is not invited, and 100 mrem in an hour, for areas where the public is invited.

The following P3 Beamline to Switchyard Absorber Penetrations do not conform to the requirements to limit a dose of 5R in an hour in a service building without an active control:

- F2 Refrigerator Building Cryogenic Penetration
    - A Chipmunk (MUX ID#: 2-246) is credited.
- F3 Refrigerator Building Cryogenic Penetration
    - A Chipmunk (MUX ID#: 2-250) is credited.
- F4 Refrigerator Building Cryogenic Penetration
    - A Chipmunk (MUX ID#: 2-252) is credited.
- The A0 Kicker Building Penetration “Short Cut”
    - Three (3) Chipmunks are credited.
        - A-0 Kicker Building South (MUX ID#: 2-006)
        - A-0 Kicker Building Middle (MUX ID#: 2-007)
        - A-0 Kicker Building North (MUX ID#: 2-008)

The following P3 Beamline to Switchyard Absorber Penetrations do not conform to the requirements to limit a dose of 500 mrem in an hour without an active control:

- Enclosure B Cryogenic Penetration (outdoor)
    - An active control device is required.

All other penetrations conform to the requirements as assessed.

For the upstream sub-segment of the Neutrino Muon beamline:

The following longitudinal segments, their shielding category, and the credited amount of shielding are provided:

Table 7: Neutrino Muon Longitudinal Credited Shielding

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

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

Table 8: Neutrino Muon Transverse Credited Shielding

Transverse Station	Category	Credited Shielding (ft)
NC11330	3C	18.7
NC11510	4C	16.3
NC11700	4C	16.3
NC11800	4C	16.3
NC11900	4C	16.3
NC12180	4A	13.9
NC12260	4A	13.9
NC12285	4A	13.9
NC12400	4A	13.9

NC12460	4C	16.3
NC12600	4C	16.3
NC12720	4C	16.3

All labyrinths in the upstream segment of the Neutrino Muon Beamline conform to the requirements to limit a dose of 500 mrem in an hour on the berm.

Two (2) penetrations do not conform to the requirements to limit a dose of 500 mrem in an hour without active control:

- G2 Cryogenic Penetration @ FSCSz=2333'
    - An active control device will be needed.
- G2 Cryogenic Penetration @ FSCSz=2337'
    - An active control device will be needed.

For the upstream segment of the Meson Primary Beamline:

The following longitudinal segments, their shielding category, and the credited amount of shielding are provided:

Table 9:Meson Primary Longitudinal Credited Shielding

Z-Range (cell or ft)	**Shielding Category**	**Credited Shielding (ft)**
1237-1335	3A	16.3
1335-1615	3C	18.7
1615-1635	4C	16.3
1635-2058	4C	16.3
2058-2130	4C	16.3
2130-2308	4C	16.3
2308-2350	4A	13.9
2350-2370	4C	16.3
2370-2413	4A	13.9
2413-2480	4C	16.3
2480-2850	4C	16.3
2850-2950	4C	16.3
2950-3005	4C	16.3
3005-3350	4C	15.5
3350-3475	4C	16.3
3475-3558	4C	16.3
3558-3950	4C	16.3
3950-3967	4C	16.3

FSCSz=3005' to 3350', 345' of buried beam pipe between the F2-Manhole and F3-Manhole enclosures, is evaluated at category 4C. The shielding is deficient by 0.8' in this region. The additional hazard for this area is that it is contained within the Master Substation yard, under the 345kV high voltage power lines and lightning arrestor system. This region is surrounded by an 8' tall fence along the perimeter of the substation. Access to the substation yard is controlled by the ISD High Voltage group and ISD Operations. In addition, an 8' tall Radiation Area Fence, which is made of a 5' tall chain-link fence and 3' tall "Jersey Barrier", a commonly used for highway barrier, prevents access to the beamline berm from the substation yard. Three access points from within the Master Substation yard are locked with Radiation Fence Area locks, to prevent unauthorized access. As per the direction of the ES&H Electrical Authority Having Jurisdiction, access to the region of the berm where the 345kV power lines are located is restricted to when the incoming 345kV power lines are de-energized. Because of this requirement, it is not feasible to add shielding material in this area until a scheduled outage for the Master Substation occurs. Furthermore, the proximity of the substation yard and grounding system to any active control device that would otherwise be deployed in other areas of the lab would result in a high likelihood of premature failure. Since de-energizing the Master Substation is a major task, which would impact accelerator operation, and the use of active control devices would be prone to abnormally high failure rates, it is not practical to apply the 500 mrem in an hour dose on the berm limit to this region due to the restrictions of accessing this area and the operational impact to access this region. The shielding is sufficient in this region for this category 5C (Dose Rate of 500 mrem in an hour to 1R in an hour). Further review of the shielding in this region found that the only downstream portion of the berm is the region deficient in shielding for the category 4C evaluation. Given the proximity of the Radiation Area Fence to this area, the closest approach is approximately 33'. Given this separation, a dose of 1R would not lead to a co-located worker receiving a dose of 500 mrem in an hour. All available shielding is credited for this sub-segment.

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

Table 10: Meson Primary Transverse Credited Shielding

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

M002600	4C	16.3
M002750	4C	16.3
M002950	4A	13.9
M003200	4C	15.05
ME13353	4C	16.3
ME13400	4C	16.3
ME13450	4C	16.3
ME13500	4C	16.3
ME13550	4C	16.3
ME13552	4C	16.3
ME13600	4C	16.3
ME13650	4C	16.3
ME13700	4C	16.3
ME13750	4C	16.3
ME13800	4C	16.3

Transverse station FSCSz=3200’ is deficient in shielding by 1.2 e.f.d. for a category 4C evaluation. For the reasons stated previously for the longitudinal segment z=3005’ to 3350’, the application of the 500 mrem in an hour dose on the berm limit is unreasonable. All available shielding is credited for this station.

All labyrinths and penetrations for the upstream segment of the Meson Primary Beamline conform to the shielding requirements to limit a dose of 500mrem in an hour.

III-12.4.1.1.2 Movable Shielding

The Switchyard area has moveable shielding placed in the equipment drop hatches adjacent to the SSB, at the downstream end of the G2 enclosure, and at the upstream end of the F1-Manhole enclosure. The shielding is administratively controlled by ES&H, using a procedure that outlines the conditions required to access the equipment drop hatch. The shielding is locked with two padlocks, one padlock cored to the enclosure entry key and one cored to configuration control series, utilized exclusively by members of ESH. The assigned RSO or designee will document the application and removal of the configuration control in a database established for this purpose.

III-12.4.1.1.3 Penetration Shielding

Refer to Section 3, Chapter 12.4.1.1.1 for penetration shielding analysis.

III-12.4.1.2 Fencing

The use of fences, gates, and locks in addition to the controls provide necessary and sufficient protection for those working in the Switchyard areas. The design, installation, use and maintenance of all signs and posting of areas where radiation may be present, search and secure procedures, controlled access procedures, and personnel training systems are in conformance with the requirements of the FRCM.

III-12.4.1.2.1 Radiation Area Fencing

The Radiation Area Fence surrounding the berm within the Master Substation is credited to prevent access to this area.

III-12.4.2 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 Switchyard Fixed Target Beamlines are discussed below.

III-12.4.2.1 Radiation Safety Interlock System

The Switchyard Fixed Target Beamlines employ a Radiation Safety Interlock System (RSIS). The characteristics of the system are described in Section I of the Fermilab SAD.

The Switchyard RSIS inhibits beam transport by controlling redundant critical devices, HP3US and HP3DS, which are dipole bend strings located in the Tevatron F-Sector beam line at the F3 Service Building and F4 Service Building. HP3US and HP3DS are a string of 104 twenty-foot magnets providing a bend angle of 450 milliradians and 360 milliradians respectively. Beam cannot traverse even the first two magnets in either 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 Main Injector P150 Extraction RSIS preventing beam extraction from the Main Injector. The Switchyard RSIS prevents personnel access to Tevatron Transfer Hall, Enclosure B, and Enclosure C, D, & E with beam enabled. Access is not allowed to these areas unless the critical devices are disabled.

The Main Injector P150 Extraction RSIS inhibits beam transport by controlling two sets of redundant critical devices, I:LAM52 & I:V701 and R:LAM52 & R:V703. I:LAM52 & I:V701 are the Main Injector Extraction Lambertsons and C-Magnets that direct 120 GeV beam to the P1 Beamline. R:LAM52 & R:V703 are the Recycler Extraction Lambertson and dipole magnet that direct 8 GeV beam to the P1 Beamline. Whereas Switchyard operation uses 120 GeV beam, the following discussion focuses on I:LAM52 and I:V701. The Lambertsons and C-magnets deflect the 120 GeV beam 24 milliradians upwards. Beam cannot be transported into the P1 Beamlines without both magnet strings being powered. In the event of a critical device failure, the system has a failure mode function that reaches back and disables the Main Injector RSIS, preventing beam from entering the Main Injector and Recycler.

The spill rate to the Switchyard beamlines is controlled by a Repetition Rate Monitor (RRM) interlocked to the Switchyard RSIS. This device inhibits beam extraction to the Switchyard enclosures if the monitored power supply is energized for more than seven seconds in any fifty-five second period. Beam cannot be transported to any of the experimental areas at a frequency rate greater that once every fifty-five second period.

Radiation detectors are placed around the Switchyard Fixed Target Beamlines. They are configured so that a beam loss producing a radiation flux that exceeds the allowable limit will inhibit the Main Injector P150 Extraction RSIS critical devices to provide radiation protection for those in the area. The trip levels of radiation detectors are interlocked to the Main Injector P150 Extraction RSIS. 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 appropriate to each Switchyard area. The justification for this implementation is documented in Change Request 272. 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 11: Credited Radiation Monitors for Switchyard

Device Type	Location	Credited Control Limit
Chipmunk	F15 Air Handler	440 mrem/hour
Chipmunk	A-0 Ramp	490 mrem/hour
Chipmunk	Transfer Gallery North Addition	24.5 mrem/hour
Chipmunk	Transfer Gallery North Addition	24.5 mrem/hour
TLM	Enclosure B	14641 nC/min
TLM	Enclosure C	74460 nC/min
Chipmunk	F2 Refrigerator Building	4810 mrem/hour
Chipmunk	F3 Refrigerator Building	4940 mrem/hour
Chipmunk	F4 Refrigerator Building	4940 mrem/hour
Chipmunk	A-0 Kicker Building (South)	4900 mrem/hour
Chipmunk	A-0 Kicker Building (Middle)	4900 mrem/hour
Chipmunk	A-0 Kicker Buiding (North)	4900 mrem/hour
Chipmunk	Enclosure B Cryo Penetration	95 mrem/hour
Chipmunk	G2 Cryo Penetration (z=2333')	495 mrem/hour
Chipmunk	G2 Cryo Penetration (z=2337')	490 mrem/hour

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-12.4.3 Administrative Credited Controls

All Switchyard 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, division, or department procedures. These procedures are the administrative controls that encompass the human interactions that define safe accelerator operations.

III-12.4.3.1 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 Switchyard Fixed Target Beamlines, the following enclosures must be secured:

- MI/TeV Crossover
- Tevatron F-Sector
- Tevatron Transfer Hall
- Muon Pre-Target Enclosure
- Switchyard Enclosure B
- Switchyard Enclosures C, D, & E

In addition, the Switchyard Repetition Rate Monitor (RRM) must be active, and all interlocked radiation detectors in place and active.

III-12.4.3.2 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-12.4.3.3 Accelerator Operating Parameters

To ensure operations within bounding conditions used in the MCI analysis, the following limits are applied to the two sub-segments defined in Section III, Chapter 12.3.1.

For the P1 & P2 Beamlines, beam shall not exceed 3.78E17 protons per hour at 8 GeV beam energy.

For the P3 Beamlines and all segments downstream, beam shall not exceed 2.75E15 protons per hour at 120 GeV.

III-12.5. Summary of Defense-in-Depth Controls

III-12.5.1 Defense-in-Depth Engineering Controls

III-12.5.1.1 Passive Defense-in-Depth Engineering Controls

III-12.5.1.1.1 Permanent Shielding

For the P1 & P2 Beamlines:

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

Table 12: P1 & P2 Longitudinal Defense in Depth Shielding

Z-Range (ft)	Defense in Depth (ft)
520-701	4.3
702-708	6.5
708-F0	8.8
F0	8.4
F0 - F13.5	10.3
F13.5 - F15	2.7
F15 Cryo Bldg	0.8
F15 - F18	2.7

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

Table 13: P1 & P2 Transverse Defense in Depth Shielding

Transverse Station	Defense in Depth (ft)
MI 8400	4.2
MI 8450	4.2
MI 8475	4.2
MI 8569	6.6
707 8650	7.3
708 8725	7.3
708 8740	15.3
E48-4	7.2
E48-7	9.7
E49-7	7.2
E49-9	12.1
F00-5	7.8
17270	6.5
17450	6.5
17657	1.1
17683	0.1
17707	1.1

17910	1.1
18100	1.1

For the P3 to Switchyard Absorber Segment:

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

Table 14: P3 to Switchyard Absorber Longitudinal Defense in Depth Shielding

Z-Range (cell or ft)	**Defense In Depth (ft)**
17880-18550	6.7
18550-18600	3.8
18600-19332	6.7
19332-19345	1.3
19345-19815	6.7
19815-19867	6.2
19867-20114	6.7
20114-20128	4.0
20128-20313	6.7
20313-20370	3.7
20370-20376	1.6
20376-00130	3.6
130-175	2.7
175-215	3.6
215-265	2.8
265-360	7.1
360-740	2.0
740-750	3.5
750-807	3.7
807-920	4.4
920-1250	1.9
1250-1265	1.1
1265-1290	1.1
1290-1333	0.1
1333-1495	2.8
1495-1520	6.8

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

Table 15: P3 to Switchyard Absorber Transverse Defense in Depth Shielding

Transverse	**Defense**

Station	In Depth (ft)
17910	6.1
18100	8.1
18302	8.1
18355	1.4
18410	6.1
18535	5.0
18569	4.6
18605	5.4
18695	5.9
18753	1.4
18811	7.1
19050	6.9
19317	4.7
19342	4.7
19367	4.7
19650	5.9
19750	3.7
19842	4.1
19925	4.6
20098	7.1
20122	1.5
20148	7.1
20390	6.5
0	3.9
85	6.9
124	7.2
175	44.1
184	32.4
200	5.1
236	2.6
251	43.8
260	20.8
273	8.0
300	6.2
385	5.3
400	3.7
438	13.2
500	3.7
600	3.3
700	3.3

800	3.3
814	19.6
900	4.8
948	9.6
986	8.0
1000	3.3
1100	3.3
1200	3.3
1280	1.8
1330	3.5
1510	9.3

For the upstream segment of the Neutrino Muon Beamline:

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

Table 16: Neutrino Muon Longitudinal Defense in Depth Shielding

Z-Range (cell or ft)	Defense In Depth (ft)
1520-1536	2.2
1536-1633	3.2
1633-1708	6.4
1708-1752	2.7
1752-2070	4.7
2070-2224	3.8
2224-2285	4.5
2285-2390	2.6
2390-2417	3.5
2417-2420	3.1
2420-2430	4.7
2430-2690	10.7
2690-2763	7.7
2763-3090	12.7
3090-3110	5.6
3110-3146	13.7
3146-3179	8.1

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

Table 17: Neutrino Muon Transverse Defense in Depth Shielding

Transverse	Defense

Station	In Depth (ft)
NC11330	2.5
NC11510	0.6
NC11700	0.9
NC11800	4.5
NC11900	4.5
NC12180	5.3
NC12260	4.7
NC12285	5.0
NC12400	3.5
NC12460	8.7
NC12600	9.0
NC12720	7.5

For the upstream Meson Primary Beamline segment:

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

Table 18: Meson Primary Longitudinal Defense in Depth Shielding

Z-Range	Defense
(cell or ft)	In Depth (ft)
1237-1335	2.5
1335-1615	3.4
1615-1635	3.7
1635-2058	4.7
2058-2130	4.7
2130-2308	5.3
2308-2350	5.4
2350-2370	2.9
2370-2413	6.0
2413-2480	4.7
2480-2850	5.1
2850-2950	4.4
2950-3005	1.8
3005-3350	0.0
3350-3475	1.8
3475-3558	2.4
3558-3950	1.4
3950-3967	2.4

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

Table 19: Meson Primary Transverse Defense in Depth Shielding

Transverse Station	Defense In Depth (ft)
M001280	2.2
M001330	3.7
M001500	6.6
M001600	6.5
M001620	6.6
M001640	6.2
M002050	7.1
M002100	6.9
M002200	6.2
M002340	6.4
M002360	6.1
M002400	4.4
M002600	5.5
M002750	6.0
M002950	4.4
M003200	0.0
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

III-12.5.1.2 Active Defense-in-Depth Engineering Controls

III-12.5.1.2.1 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 beam lines and the Switchyard Beam Absorber on an hourly basis.

III-12.5.1.3 Defense-in-Depth Administrative Controls

III-12.5.1.3.1 Fencing and Posting

Fences are used and posted to designate potential Radiation Areas during machine operations. The Switchyard area has posted and locked radiological fences to prohibit access to outside berm areas. These include the fences at the South Booster Road, Gate A0PSA1, Gate inside ring at Transfer Hall, Gate A0PAA1, Gate B/CPA1, Fenced penetrations at Road D, Gate SSBVA1, Gate SSBVA2, Gate FNCLCPA1, F1-Manhole enclosure equipment hatch F1MPA1, F2-Manhole personnel hatch F2MPA1, Gate M01PAW, Gate G2PA1, Gate G2PA2, Gate G2VA1, Gate G2PA3, Gate M01 PAE, and Gate M01PAW.

III-12.5.1.3.2 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-12.6. Decommissioning

DOE Field Element Manager approval shall be obtained prior to the start of any decommissioning activities for the Switchyard Fixed Target Beamlines.

III-12.7. Summary and Conclusion

Specific hazards associated with the operation of the Switchyard area enclosures are identified and assessed in this chapter of the Fermilab SAD. The designs, controls, and procedures to mitigate Switchyard specific hazards are identified and described. The Switchyard 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 Switchyard 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-12.8. References

[1] Fermilab Radiological Control Manual
[2] P1 and P2 Beamline Incremental Shielding Assessment
[3] P3 to SY Absorber Incremental Shielding Assessment 09-20-17
[4] 2003 Shielding Assessment for the Switchyard 120 Project
[5] Review of Environmental Vulnerabilities Associated with the Switchyard (March 17, 1999, updated June 9, 1999)
[6] Change Request 272
[7] Frank T. Cole (Fermilab)(ed.), Edwin L. Goldwasser (Fermilab)(ed.), Robert Rathbun Wilson (Fermilab)(ed.) National Accelerator Laboratory Design Report, January 1968

III-12.9. 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-12.4 of this Chapter as well as SAD Chapter VII-A.1 *Accelerator Safety Envelope – Fermi Main Accelerator*.