SWITCHYARD FIXED TARGET BEAMLINES

SECTION III CHAPTER 12 OF THE FERMILAB SAD

Revision 1 March 14, 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 Fermilab Main Accelerator that are pertinent to understanding the risks to the workers, the public, and the environment due to its operation.

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SAD Chapter Review

This Section III Chapter 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 (ES&H) Accelerator Safety Department.

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

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Accelerator Safety Department Head

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SAD Review Subcommittee Chair

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Revision History

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

Author	Rev. No.	Date	Description of Change
Michael K. Olander	1	March 14, 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 120 Giga-electron Volt (GeV) protons from the P2 beamline.. The beam is split in the Switchyard and redirected to the Meson Area and Neutrino Area.

III-12.1.2 Current Status

The Switchyard Fixed Target Beamlines are currently **Operational**.

III-12.1.3 Description

The Switchyard Fixed Target Beamlines start in the Tevatron F-Sector at F17 and continue 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 F17 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 beamlines:

- The P3 beamline, from the downstream end of the F17B3 magnet to the downstream end of the MLAM1 magnet.
- The Meson Primary beamline, from the downstream end of the MLAM1 magnet to the upstream wall of Enclosure M01 in the Meson Area segment.
- The Switchyard Dump beamline, from the downstream end of the MLAM1 magnet to the Switchyard Dump.
- The Neutrino Muon beamline, from the downstream end of the V100 magnet to the upstream wall of Enclosure NM1 in the Neutrino Area segment.

The Switchyard Fixed Target Beamlines include the following areas:

- The Switchyard Absorber

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

- 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.

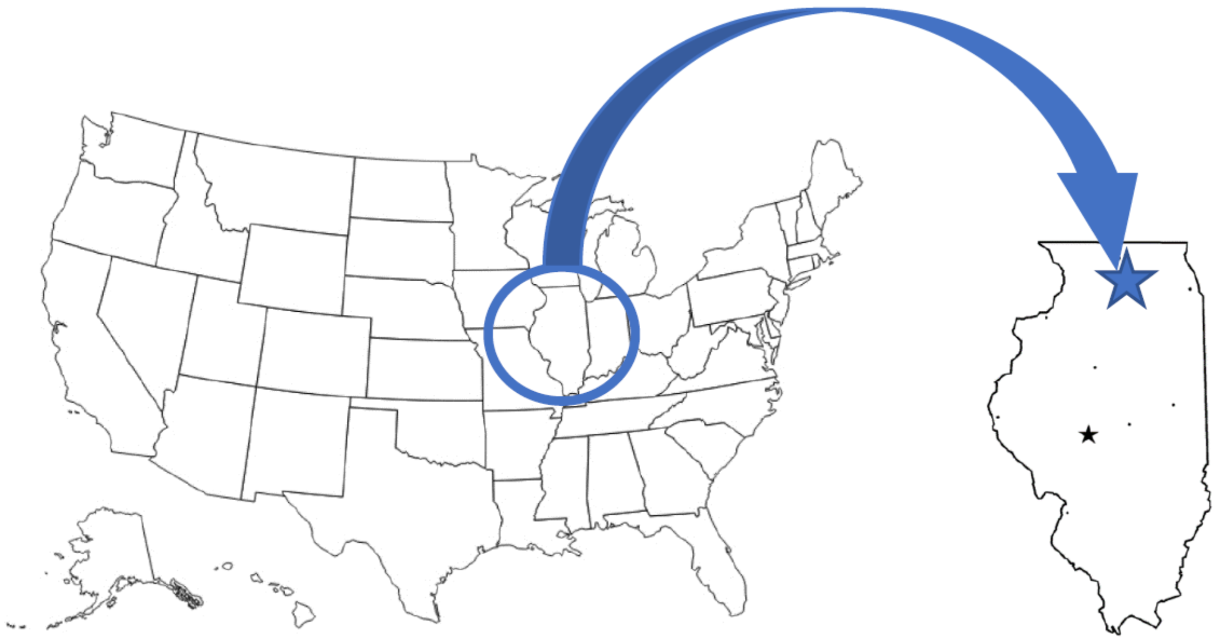

Figure 1. Regional view showing the location of the Fermilab site in Batavia, IL.

The Switchyard fixed target area is located to the east of Wilson Hall on the Fermilab site. This area is located beyond Obvious Indicators, as shown in Figure 2 below.

Figure 2: Obvious Indicators

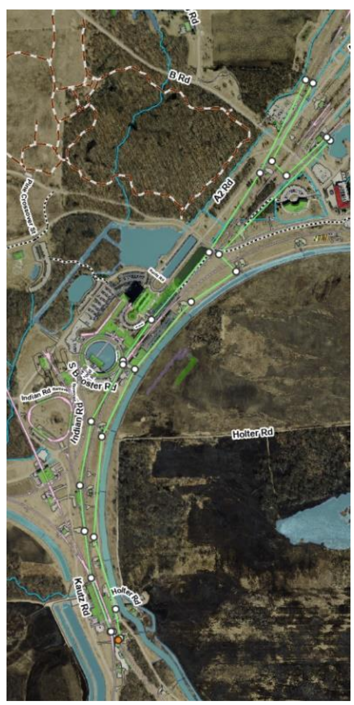

Figure 3. Aerial view of the Fermilab site, indicating the location of the Switchyard fixed target area.

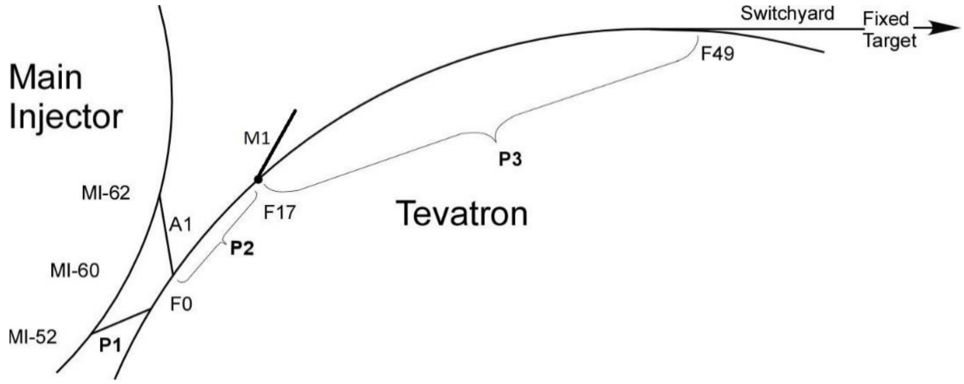

Figure 4: Beam Delivery Path for P1, P2 & P3 Beamlines (M1 Beamline begins at F17)

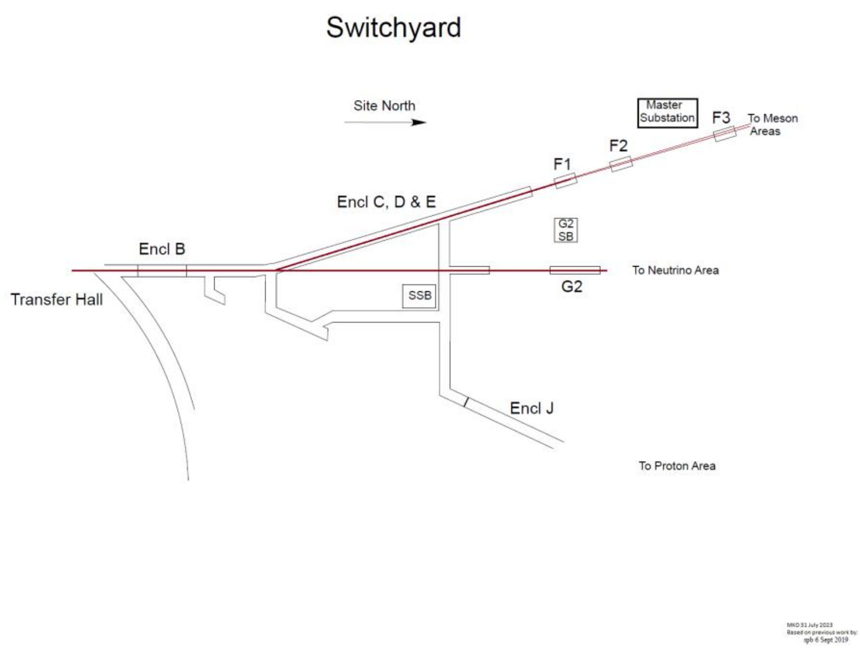

Figure 5: Beam delivery path for Switchyard continental. Operational area beam delivery in Red.

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 P3 beamline receives 120 GeV beam from the P1/P2 segment and transfers beam via Switchyard Continental to the Switchyard Dump, Meson Area, or Neutrino Area. Because these are transfer lines, there is no intrinsic intensity limit for the beamlines; the limit is taken as that of the upstream segment.

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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 a facility worker, co-located worker, and maximally exposed offsite individual (MOI) (i.e., members of the public). A summary of these controls is described within Section III-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 beamlines. 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 beamlines 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 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 or IV 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, and 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 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). It is a standard radiological hazard. Waste minimization is an objective of the equipment design and operational procedures. Although production of radioactive material is not an operational function of the 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 Non-Accelerator Specific 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. For an onsite facility worker, the baseline risk for this hazard was R II and, after control measures were evaluated, the residual risk level was R IV; for an onsite co-located worker or MOI, the baseline risk for this hazard was R III and, after control measures were evaluated, the residual risk level was R IV.

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

The only combustibles identified are due to standard insulation material used in cables. No flammables are in use.

III-12.2.3.1 Combustible Materials

Common combustible materials (paper, wood pallets, etc.) are typically found in the Switchyard Fixed Target Beamlines service buildings. Combustible materials in Switchyard areas have 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. For an onsite facility worker, the baseline risk for this hazard was R I and, after control measures were evaluated, the residual risk level was R IV; for a co-located worker, the baseline risk for this hazard was R II and, after control measures were evaluated, the residual risk level was R IV; for an MOI, the baseline risk for this hazard was R III and, after control measures were evaluated, the residual risk level was R IV.

III-12.2.3.2 Flammable Materials

Common flammable materials, such as industrial lubricants, are used by technicians to maintain equipment and are stored in flammable materials lockers. This hazard has been evaluated within the common risk matrix table included in SAD Section I Chapter 04 *Safety Analysis*. Work in Switchyard involving this hazard implements the controls specified in the common risk matrix table. No unique controls are in use. For an onsite facility worker, the baseline risk for this hazard was R I and, after control measures were evaluated, the residual risk level was R IV; for a co-located worker, the baseline risk for this hazard was R II and, after control measures were evaluated, the residual risk level was R IV; for an MOI, the baseline risk for this hazard was R III and, after control measures were evaluated, the residual risk level was R IV.

III-12.2.4 Electrical Energy

The Switchyard Fixed Target Beamlines present electrical energy hazards identified in Table 1. Electrical hazards are present in the form of low and high voltage power supplies that power magnets, ion pumps, and diagnostic equipment.

After completion of the risk analyses shown in Section III-1.2 *Appendix – Risk Tables*, the baseline risk level I has been reduced to a residual risk level of IV.

III-12.2.4.1 Stored Energy Exposure

This hazard is present from the alternating current (AC) power distribution systems and power supplies in the Switchyard Fixed Target Beamlines. The 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. Baseline risk for this hazard was R I and, after control measures were evaluated, the residual risk level was R IV.

III-12.2.4.2 High Voltage Exposure

This hazard is present in, for example, the electrostatic septa. The 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. Baseline risk for this hazard was R I and, after control measures were evaluated, the residual risk level was R IV.

III-12.2.4.3 Low Voltage, High Current Exposure

This hazard is present in several electromagnets. The 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. Baseline risk for this hazard was R I and, after control measures were evaluated, the residual risk level was R IV.

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 non-accelerator specific 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.

Qualified welders occasionally work in the Switchyard Fixed Target Beamlines tunnels and service buildings to repair waterlines and other metalwork. Hot work in the areas 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. For an onsite worker or a co-located worker, the baseline risk for this hazard was R I and, after control measures were evaluated, the residual risk level was R IV; for an MOI, the baseline risk for this hazard was R III and, after control measures were evaluated, the residual risk level was R IV.

III-12.2.5.3 Cryogenics

N/A

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 NASH 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. For an onsite worker or a co-located worker, the baseline risk for this hazard was R I and, after control measures were evaluated, the residual risk level was R IV; this risk is not-applicable for an MOI.

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. For an onsite worker, the baseline risk for this hazard was R I and, after control measures were evaluated, the residual risk level was R III; for a co-located worker, the baseline risk for this hazard was R I and, after control measures were evaluated, the residual risk level was R IV; this risk is not-applicable for an MOI.

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 NASH 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. The baseline risk for this hazard was R I and, after control measures were evaluated, the residual risk level was R IV.

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. For a facility worker, the baseline risk for this hazard was R I and, after control measures were evaluated, the residual risk level was R IV; for co-located workers and MOI, the baseline risk for this hazard was R I and, after control measures were evaluated, the residual risk level was R III.

III-12.2.7.3 Vacuum/Pressure Vessels/Piping

Pressure vessels are present in the Switchyard Fixed Target Beamlines in the form of air compressors. 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. Baseline risk for this hazard was R I and, after control measures were evaluated, the residual risk level was R III.

III-12.2.7.4 Vacuum Pumps

Vacuum pumps are used throughout the Switchyard Fixed Target Beamlines to maintain vacuum in 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. The baseline risk for this hazard was R I and, after control measures were evaluated, the residual risk level was R III.

III-12.2.7.5 Material Handling

Trained personnel operate forklifts, stackers, and hand carts to move materials throughout 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. For a facility worker, the baseline risk for this hazard was R I and, after control measures were evaluated, the residual risk level was R IV; for a co-located worker, the baseline risk for this hazard was R I and, after control measures were evaluated, the residual risk level was R III; this risk is not applicable for an MOI.

III-12.2.8 Magnetic Fields

The only magnetic fields present when personnel are present are corrector magnets and ion pumps. The electrical safety system prevents energizing of other sources when interlocks are dropped.

III-12.2.8.1 Fringe Fields

The fringe field hazard mainly comes from powered magnets and permanent magnets that are in ion pumps. Fields are nominally only hazardous to people who have medical implants. The likelihood of the fringe field causing a malfunction to individuals with medical implants is reduced by work planning, warnings in the hazard specification sheet, and warning signs at all Linac entry points about this hazard. Baseline risk for this hazard was R I (III) for workers with (without) ferromagnetic or electronic medical devices and, after control measures were evaluated, the residual risk level was R III (IV).

III-12.2.9 Other Hazards

The Switchyard Fixed Target Beamlines present other hazards identified in Table 1. All other hazards present in the Switchyard Fixed Target Beamlines are in the form of NASH 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. For a facility worker, the baseline risk for this hazard was R I and, after control measures were evaluated, the residual risk level was R IV; for a co-located worker and MOI, the baseline risk for this hazard was R III and, after control measures were evaluated, the residual risk level was R III.

III-12.2.9.2 Noise

Operating cooling water systems creates a potential noise hazard in the 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. For an on-site worker, the baseline risk for this hazard was R III and, after control measures were evaluated, the residual risk level was R IV; for an MOI, the baseline risk for this hazard was R IV and, after control measures were evaluated, the residual risk level was R IV.

III-12.2.9.3 Silica

Silica poses a serious health hazard when it becomes airborne as respirable crystalline particulates. Activities that occur in Switchyard including, but not limited to: drilling of concrete, are all capable of exposing personnel to the silica hazard. Measures in place to reduce the risk of silica exposure are training, work planning, PPE, and engineering controls. 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. For an on-site worker, the baseline risk for this hazard was R I and, after control measures were evaluated, the residual risk level was R IV; for co-located worker and MOI, the baseline risk for this hazard was R I and, after control measures were evaluated, the residual risk level was R III.

III-12.2.9.4 Ergonomics

Technical work in the Switchyard Fixed Target Beamlines may involve standing for long periods of time, repetitive motion, cramped conditions, and other ergonomic concerns. Ergonomic hazards have 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. For a facility worker, the baseline risk for this hazard was R I and, after control measures were evaluated, the residual risk level was R IV; this risk is non-applicable for a co-located worker or an MOI.

III-12.2.9.5 Asbestos

N/A

III-12.2.9.6 Working at Heights

Technicians utilize ladders and step stools to conduct maintenance in the Switchyard Fixed Target Beamlines areas. Utilizing fall protection equipment, trained personnel may work on top of equipment where there is a chance of falling. Work at height 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. For a facility worker, the baseline risk for this hazard was R I and, after control measures were evaluated, the residual risk level was R IV.

III-12.2.10 Access & Egress

The Switchyard Fixed Target Beamlines present access and egress hazards in the form of a list of checked off hazards shown in Table 1. All other hazards present in the Switchyard Fixed Target Beamlines are in the form of NASH discussed in SAD Section I Chapter 04.

III-12.2.10.1 Life Safety Egress

Access and egress points in the Switchyard Fixed Target Beamlines vary depending on the tunnel. Life safety egress 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. For a facility worker, the baseline risk for this hazard was R I and, after control measures were evaluated, the residual risk level was R IV; for a co-worker, the baseline risk for this hazard was R II and, after control measures were evaluated, the residual risk level was R IV; this risk is not-applicable for an MOI.

III-12.2.11 Environmental

The Switchyard Fixed Target Beamlines present environmental hazards in the form of a list of checked off hazards shown in Table 1. All environmental hazards present in Switchyard Fixed Target Beamlines are in the form of NASH discussed in SAD Section I Chapter 04.

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. Baseline risk for this hazard was R IV and, after control measures were evaluated, the residual risk level was R IV.

III-12.2.11.2 Hazard to Water

Oil used as an insulator in the Switchyard Fixed Target Areas electrostatic septa has the potential to leak or spill and spread contamination. 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 the electrostatic septa oil implements the controls specified in the common risk matrix table. No unique controls are in use. Baseline risk for this hazard was R I and, after control measures were evaluated, the residual risk level was R IV.

III-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. Baseline risk for this hazard was R IV and, after control measures were evaluated, the residual risk level was R IV.

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

III-12.3.1 Definition of a Maximum Credible Incident

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, an onsite co-located worker, and a maximally exposed off-site individual (MOI).

III-12.3.1.1 Radiological Hazard

The MCI scenario for the Switchyard 120 Fixed Target Beamlines segment is 2.75E15 protons per hour, 4.2E13 protons per cycle, 55 second cycle, 120GeV beam energy, missteered into a magnet, beam pipe in an enclosure, or buried pipe, for one hour.

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 and 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

This section describes the Credited Controls that are required to reduce the risk associated with the maximum credible incident to the conditions outlined in Section III-12.3.1.1.

III-12.4.1 Credited Engineering 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 Passive Credited Engineering Controls

Passive controls are element of the facility design that require no action to function properly. These are fixed elements of the beam line that take direct human intervention to remove. The Switchyard Fixed Target Beamlines enclosures are designed and constructed as permanent concrete- and earth-covered radiation shielding that use a combination of permanent shielding, movable shielding, and penetration shielding to protect personnel from radiological exposure due to the MCI.

III-12.4.1.1.1 Permanent Shielding Including Labyrinths

The required amount of shielding is determined using the Incremental Shielding Assessment (ISA) spreadsheets. The required amount of shielding varies based on one of three categories of losses: loss on a magnet within an enclosure; loss on a long, thin pipe within an enclosure; and loss on a thick pipe buried in soil. The required amount of shielding also varies depending on the exposure limit. The amount of shielding is specified in terms of equivalent feet of dirt (efd), which takes into account the effectiveness of various materials compared to soil (for example, concrete is more effective than soil).

Table 3 lists the minimum amount of efd required to remain below a given exposure assuming the MCI.

Table 3 Minimum Equivalent feet of dirt required to remain within an exposure range based on loss category. The 120 GeV MCI is assumed.

Dose	Beam on Magnet in Enclosure	Beam on Pipe in Enclosure	Beam on Buried Pipe
	[efd]	[efd]	[efd]
5 ≤ D < 100 mrem	16.3	13.8	18.7
100 ≤ D < 500 mrem	13.9	11.4	16.3

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

Where sufficient shielding is lacking, as shown in Table 4, an additional Credited Control is used.

Adequate permanent shielding exists in the Switchyard Fixed Target Beamlines except as listed below. An additional Credited Control is needed, which will be discussed in later sections.

Table 4 Locations with inadequate shielding. Note that although the shielding in locations 1520-1536 is inadequate for a 100 mrem exposure, it is adequate for a 500 mrem exposure.

Location - Station	Location - Name	Maximum Exposure	Shielding - Required	Shielding - Present	Additional Credited Control
		[mrem]	[efd]	[efd]	[]
20390	Transfer Hall	500	13.9	12.0	Chipmunk
124	TG Annex	500	13.9	12.7	Chipmunk
273	WH-C-1 Manhole	500	16.3	15.5	TLM1 – Encl. B
1520-1536	Beam Pipe after Switchyard Dump	100	18.7	18.5	Fence*
3005-3350	Pipe - Master Substation	100	18.7	15.5	Fence
3350-3967	Berm Pipe	100	18.7	17.7-18.6	Fence

Exposure at a labyrinth is assessed using the ISA spreadsheets. This exposure is determined by the fixed labyrinth geometry. Exposure due to an MCI at all labyrinths remains below 500 mrem, the level appropriate for areas to which the public is assumed to be excluded.

The Switchyard Fixed Target Beamlines Shielding Assessments contain transverse and longitudinal shielding summaries. Credited levels of shielding are based on the ES&H shielding assessment categories from the *Incremental Shielding Assessment Methodology*. Tables of credited shielding follow.

Areas onsite in which the public is authorized are evaluated at categories 3A, 3B, or 3C, representing shielding for a dose of 100 mrem in an hour on a magnet, beam pipe in an enclosure, or buried pipe, respectively. Areas to which the public is assumed to be excluded are evaluated at categories 4A, 4B, and 4C, representing a dose of 500mrem in an hour on a magnet, beam pipe in an enclosure, or buried pipe, respectively.

Table 7 lists the credited shielding for the P3 line to the Switchyard Absorber.

Table 5: P3 to Switchyard Absorber Longitudinal Credited Shielding

Z-Range (cell or ft)	**Category**	**CreditedShielding (efd)**
17880-00360	4A	13.9
00360-01520	3C	18.7

The three locations with inadequate shielding, but protected with an active engineered Credited Control, are listed:

Table 6: P3 to Switchyard Absorber Credited Shielding at Locations Protected with an Active Engineered Credited Control.

Transverse Station	Shielding Category	Credited Shielding (efd)
20390	9A	5.5
00124	9A	5.5
00273	9A	5.5

Table 9 lists the credited shielding for the Neutrino Muon beamline.

Table 7: Neutrino Muon Longitudinal Credited Shielding

Z-Range		Credited
(cell or ft)	**Category**	**Shielding (efd)**
1536-1633	3C	18.7
1633-1708	3B	13.8
1708-1752	3C	18.7
1752-2070	3C	18.7
2070-2224	3A	16.3
2224-2285	3A	16.3
2285-2390	3A	16.3
2390-2417	3A	16.3
2417-2420	3A	16.3
2420-2430	3C	18.7
2430-2690	3C	18.7
2690-2763	3C	18.7
2763-3090	3C	18.7
3090-3110	3C	18.7
3110-3146	3C	18.7
3146-3179	3C	18.7

The one location with inadequate shielding, but protected with a passive Credited Control (fence), is:

Table 8: Neutrino Muon Credited Shielding at the One Locations Protected with a Passive Engineered Credited Control (Fence).

Location	Category	Credited Shielding (efd)
1520-1536	3C	17.7

Table 11 lists the credited shielding for the Meson Primary Beamline.

Table 9:Meson Primary Longitudinal Credited Shielding

Z-Range (cell or ft)	Shielding Category	Credited Shielding (efd)
1237-1335	3A	16.3
1335-1615	3C	18.7
1615-1635	3C	18.7
1635-2058	3C	18.7
2058-2130	3C	18.7
2130-2308	3C	18.7
2308-2350	3A	13.9
2350-2370	3C	18.7
2370-2413	3A	13.9
2413-2480	3C	18.7
2480-2850	3C	18.7
2850-2950	3C	18.7
2950-3005	3C	18.7

The two location with inadequate shielding, but protected with a passive Credited Control (fence), are:

Table 10: Meson Primary Transverse Credited Shielding

Location	Category	Credited Shielding (efd)
3005-3350	3C	15.5
3350-3967	3C	14.5

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 ES&H. 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

Exposure at a penetration is assessed using the ISA spreadsheets. The exposure is determined by the geometry of the penetration, amount of fill, and moveable shielding at the penetration.

Table 13 summarizes the penetrations that require shielding ("fill" – shielding material inside the penetration) or an additional Credited Control.

Table 11 Penetrations requiring fill

Cell or Z-Location	Location or Enclosure	Fill	Detector
18569	F25 Cryo 48"	48" filled with sand, 12" 8" 5" and 3" penetrations within unfilled	chipmunk
19368	F35 Cryo 48"	48" filled with sand, 12" 8" 5" and 3" penetrations within unfilled	chipmunk
20121	F45 Cryo 48"	48" filled with sand, 12" 8" 5" and 3" penetrations within unfilled	chipmunk
0	A-0 Kicker Building Short Circuit (South)	3' of Poly Rods with 10% packing factor in three 7" penetrations	chipmunk
0	A-0 Kicker Building Short Circuit(Middle)	3' of Poly Rods with 10% packing factor in three 7" penetrations	chipmunk
0	A-0 Kicker Building Short Circuit (North)	3' of Poly Rods with 10% packing factor in three 7" penetrations	chipmunk
745	EncB Cryo	Sand	TLM1 (Enclosure B)
2333	SY Encl. G2: cryo pen	The 8" header is filled with 24 ft. of sand. Polyethylene beads fill the annulus between 18" carrier and 8" header. Also, a 3 ft. thick sand shield, followed by a 3 ft. thick sand plug, exist at the end of the carrier pipe.	fence
2337	SY Encl. G2: cryo pen	The 8" header is approximately 50% full of piping and insulation. Polyethylene beads fill the annulus between 18" carrier and 8" header. Also, a 3 ft. thick sand shield, followed by a 3 ft. sand plug, exist at the end of the carrier pipe.	fence

III-12.4.1.1.4 Fencing

III-12.4.1.1.5 Radiation Area Fencing

The ISA spreadsheet indicates a deficit of shielding in some regions of the berm through the Master Substation. In consultation with the Radiation Analysis Department, the dose was estimated at the top of the berm, then scaled to the location of the metal fence surrounding the master substation. The resulting dose was 66 mrem/hr. This is below the required 100 mrem for an MCI. The fencing surrounding the Master Substation will be credited.

The ISA spreadsheet indicates a deficit of shielding in several locations between the Master Substation and Enclosure M01. The existing fence surrounding berm, from the Master Substation, to M01, will be credited. The largest deficit is one foot, which would result in an MCI exposure of 197 mrem. The fence is always at least 39 feet from the beamline. Scaling by 1/r results in an exposure of 5.1 mrem.

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

The following fencing is credited:

- The radiation fence around the Master Substation.
- The fencing from the Master Substation to the fencing on the Meson Area Berm.
- The fencing surrounding the G2 Service Building cryogenic penetration.

III-12.4.1.2 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-12.4.1.2.1 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 RSIS inhibits beam transport by controlling redundant critical devices. Beam cannot be transported to downstream areas without both critical devices enabled. In the event of a critical device failure, the system has a failure moved function that reaches back and disables the upstream RSIS, preventing beam from reaching the failed device.

The Switchyard Fixed Target Area enclosures are shown in Figure 6. The protected enclosures, along with the CDC name, critical devices, and location of critical devices, are listed in Table 12.

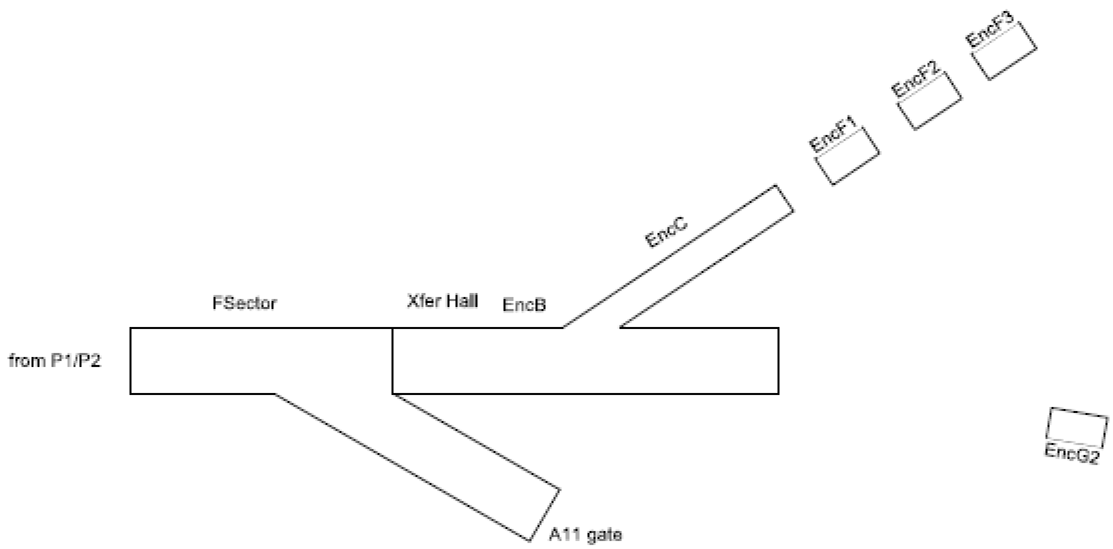

Figure 6: Switchyard Fixed Target Area enclosures

Table 12: Protected Switchyard Enclosures and associated CDC

Protected Enclosure(s)	Critical Device Controller		
	Name	Devices	Location
FSector	MI P150	R:LAM52, R:V703, I:Lam52, I:V701	Main Injector
Xfer Hall, EncB, EncC, EncD, EncE, G1	Switchyard	S:HP3US, S:HP3DS	FSector
EncF1, EncF2, EncF3	Meson	S:MLAM1, S:V204	EncC
EncG2	Neutrino	S:V100	EncC
Neutrino Area (See SAD Section III Chapter 14)	Neutrino	S:V100 S:MuLAM G2ABSORBER	EncC EncG1 EncG2

To run beam in the Switchyard Fixed Target Beamlines, the following enclosures must be secured:

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

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 associated RSIS critical devices to provide radiation protection for those in the area. Such detectors can disable beam within one second of exceeding a predetermined level. The radiation detectors limit the radiation flux from one-pulse accidents to less than the limit appropriate to each 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 13: Credited Radiation Monitors for Switchyard

Device Type	Location		Credited Control Limit
Chipmunk	20390	Transfer Hall	490 mrem/hour
Chipmunk	124	Transfer Gallery North Addition	24.5 mrem/hour
Chipmunk	124	Transfer Gallery North Addition	24.5 mrem/hour
TLM1	273	WH-C-1 Manhole	3400 nC/min
Chipmunk	18569	F25 Cryo 48”	4810 mrem/hour
Chipmunk	19368	F35 Cryo 48”	4940 mrem/hour
Chipmunk	20121	F45 Cryo 48”Refrigerator Building	4950 mrem/hour
Chipmunk	0	A-0 Kicker Building (South)	4900 mrem/hour
Chipmunk	0	A-0 Kicker Building (Middle)	4900 mrem/hour
Chipmunk	0	A-0 Kicker Buiding (North)	4900 mrem/hour
TLM1	745	Enclosure B Cryo Penetration	3400 nC/min

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-12.4.2 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-12.4.2.1 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.

III-12.4.2.2 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-12.4.2.3 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.

Beam shall not exceed 2.75E15 protons per hour at 120 GeV beam energy.

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

The minimum defense-in-depth shielding is listed by beamline. Exceptions are noted.

- P3 to Switchyard Absorber: One foot.
- Neutrino Muon: One foot.
- Meson Primary: One foot, except at the culvert north of Pine Street, where the defense-in-depth is three inches.

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 .

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*.