P1 AND P2 BEAMLINES

SECTION III CHAPTER 9
OF THE FERMILAB SAD

Revision 1 February 13, 2024

This chapter of the Fermilab Safety Assessment Document (SAD) contains a summary of the results of the safety analysis for the P1 and P2 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.

SAD Chapter Review

This Section III Chapter 09 of the Fermi National Accelerator Laboratory (Fermilab) Safety Assessment Document (SAD), *P1 and P2 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

Revision History

Printed versions of this Chapter of the Fermilab 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 Tom Kobilarcik Jerry Annala	1	February 13, 2024	• Updated to align with updated SAD template • Included risk matrix tables and hazard discussion • 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 • Separate P1 and P2 from SY120
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
^3H	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-9. P1 and P2 Beamlines

III-9.1. Introduction

This Section III Chapter 9 of the Fermi National Accelerator Laboratory (Fermilab) Safety Assessment Document (SAD) covers the P1 and P2 Beamlines.

III-9.1.1 Purpose/Function

The P1 and P2 Beamlines transport beams of 120 Giga-electron Volt (GeV) protons from the Main Injector to the Switchyard 120 fixed-target beam lines, or 8 GeV protons from the Recycler to the Muon Campus.

III-9.1.2 Current Status

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

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

The P2 Beamline is currently **Operational**.

III-9.1.3 Description

The P1 beamline starts in the Tevatron F-Sector at E48 and the P2 line ends at F17. The F0, F1, and F17 Service Buildings are included in the P1 and P2 Beamlines.

III-9.1.4 Location

The P1 and P2 area is located on the Fermilab site in Batavia, IL. as shown in Figure 1, beyond Obvious and Operating Barriers to ensure only authorized access. These barriers are located at: Wilson Hall West, Wilson Hall East, and Site 55.

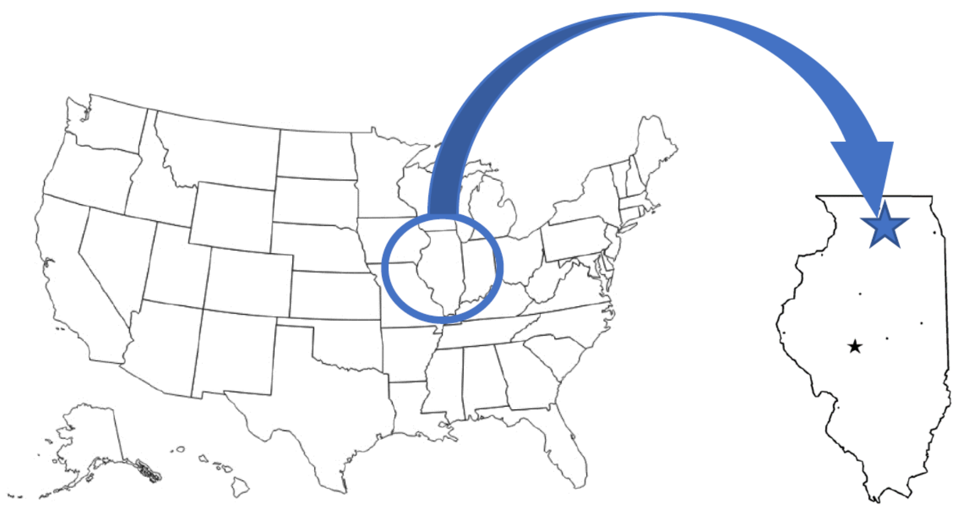

Figure 1. Regional view showing the location of the Fermilab site in Batavia, IL.

The P1 and P2 area is located to the east of Wilson Hall on the Fermilab site with detailed location shown in Figure 2 and beam path shown in Figure 3.

Figure 2. Aerial view of the Fermilab site, indicating the location of the P1 and P2 Beamlines.

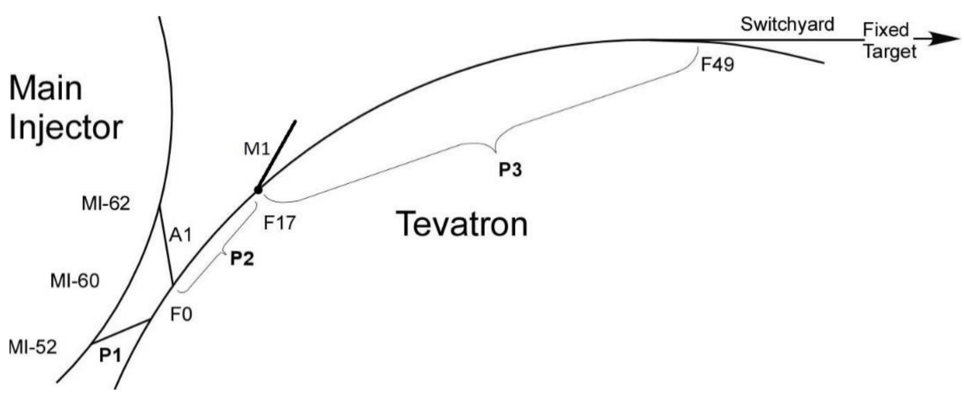

Figure 3: Beam delivery path for P1 and P2 Beamlines (M1 Beamline begins at F17)

Figure 4 Location of Obvious and Operating Barriers

III-9.1.5 Management Organization

The P1 and P2 Beamlines are managed by Accelerator Directorate, Beams Division, External Beam Delivery Department.

III-9.1.6 Operating Modes

The P1 and P2 Beamlines transport a 120-GeV proton beam from the Main Injector to the Switchyard120 fixed target beamlines, or 8-GeV protons to the Muon Campus

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-9.1.7 Inventory of Hazards

The following table lists all the identified hazards found in the P1 and P2 Beamline enclosures and support buildings. Section III-9.9 *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-9.2 *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 P1 and P2 Beamlines. Accelerator-specific controls are identified as **purple/bold** throughout this chapter.

All other hazards present in the P1 and P2 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 P1 and P2 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

III-9.2. Safety Assessment

All hazards for the P1 and P2 Beamlines are summarized in this section, with additional details of the analyses for accelerator-specific hazards.

III-9.2.1 Radiological Hazards

The P1 and P2 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] 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 P1 and P2 Beamlines assess the areas described in Section III-9.1.3.

As shown in the risk analysis in Section III-9.10 *Appendix – Risk Tables* 13.1-13.3, the baseline risk level I has been reduced to a residual risk level of III or lower.

III-9.2.1.1 Prompt Ionizing Radiation

Prompt ionizing radiation is the principle radiological hazard that arises when beam is transported through the P1 and P2 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-9.3. 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-9.4. The conclusion of these analyses is that the mitigated dose level associated with prompt ionizing radiation due to beam loss is acceptable.

III-9.2.1.2 Residual Activation

Losses along the P1 and P2 Beamlines will result in activation of intercepting beam instrumentation devices and other beamline components. The activation level and quantity of activated material will not be unique relative to other accelerators at Fermilab. 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-9.10 *Appendix – Risk Tables*, Tables 13.1-13.3, the baseline risk level I has been reduced to a residual risk level of III or lower.

III-9.2.1.3 Groundwater Activation

Groundwater and surface water activation hazards are assessed in detailed shielding assessments.[2] 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-9.10 *Appendix – Risk Tables*, Tables 13.1-13.3, the baseline risk level I has been reduced to a residual risk level of III or lower.

III-9.2.1.4 Surface Water Activation

Surface water activation in the P1 and P2 Beamlines is characterized in Section III Chapter 9.2.1.3.

III-9.2.1.5 Radioactive Water (RAW) Systems

N/A

III-9.2.1.6 Air Activation

In the P1 Beamline and P2 Beamline, the beam traverses a continuous vacuum. There is no activation from known loss points.[2] Based on hazard analysis in Section III-9.10 *Appendix – Risk Tables*, Tables 13.1-13.3, the baseline risk level I has been reduced to a residual risk level of III.

III-9.2.1.7 Closed Loop Air Cooling

N/A

III-9.2.1.8 Soil Interactions

Scattered beam has potential to activate soil at low levels calculated in the shielding assessment. This usually occurs very near the walls of the enclosure at the point of the beam loss. Beam loss monitoring is used to keep beam losses low to minimize these interactions. Based on hazard analysis in Section III-9.10 *Appendix – Risk Tables*, Tables 13.1-13.3, the baseline risk was IV and, after control measures were evaluated, the residual risk level was IV.

III-9.2.1.9 Radioactive Waste

Radioactive waste produced during P1 and P2 Beamline 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 P1 and P2 Beamlines, 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-9.10 *Appendix – Risk Tables*, Tables 13.1-13.3, the baseline risk level I has been reduced to a residual risk level of IV.

III-9.2.1.10 Contamination

Contamination of components caused by beam interaction may exist in the P1 and P2 Beamlines. Minimizing the possibility of exposing individual to contamination if it is present is implemented in several ways. RWPs must be written and followed in accordance with the FRCM requirements. During controlled access to the beam enclosures, individuals are required to wear appropriate PPE for their work, and they are required to use a log survey meter to identify locations of activation. When an individual enters an enclosure under supervised access, they are required to review the radiation survey maps made since beam was last present. An RWP for enclosure access is used to inform personnel of radiological hazards for any enclosure access.

When exiting the enclosure, individuals are required to use a frisker on themselves and on items being removed from the enclosure. Accessing an enclosure requires either that the individual is a trained radiation worker, or they are escorted by a radiation worker and receive a radiation briefing before accessing.

Based on hazard analysis in Section III-9.10 *Appendix – Risk Tables*, Tables 13.1-13.3, the baseline risk level I has been reduced to a residual risk level of IV.

III-9.2.1.11 Beryllium-7

^{7}Be is not hazardous in this pattern of use by the facility. Based on hazard analysis in Section III-9.10 *Appendix – Risk Tables*, Tables 13.1-13.3, the baseline risk level IV required no further preventative or mitigative controls.

III-9.2.1.12 Radioactive Sources

Radioactive sources may be used in shutdown and maintenance activities. These sources, when used in the P1 and P2 Beamlines, are handled in accordance with FRCM. Based on hazard analysis in Section III-9.10 *Appendix – Risk Tables*, Tables 13.1-13.3, the baseline risk level I has been reduced to a residual risk level of IV.

III-9.2.1.13 Nuclear Material

N/A

III-9.2.1.14 Radiation Generating Devices (RGDs)

N/A

III-9.2.1.15 Non-Ionizing Radiation Hazards

N/A

III-9.2.2 Toxic Materials

The P1 and P2 Beamlines present toxic material hazards identified in Table 1. All toxic material hazards present in the P1 and P2 Beamlines are in the form of non-accelerator specific hazards discussed in SAD Section I Chapter 04.

III-9.2.2.1 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 P1 and P2 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 II and, after control measures were evaluated, the residual risk level was R IV.

III-9.2.2.2 Beryllium

N/A

III-9.2.2.3 Fluorinert & Its Byproducts

N/A

III-9.2.2.4 Liquid Scintillator Oil

N/A

III-9.2.2.5 Pseudocumene

N/A

III-9.2.2.6 Ammonia

N/A

III-9.2.2.7 Nanoparticle Exposures

N/A

III-9.2.3 Flammables and Combustibles

III-9.2.3.1 Combustible Materials

Common combustible materials (paper, wood pallets, etc.) are typically found in the P1 and P2 Beamlines service buildings. Combustible materials in P1 and P2 areas have been evaluated within the common risk matrix table included in SAD Section I Chapter 04 *Safety Analysis*. Work in the P1 and P2 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-9.2.3.2 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 the P1 and P2 areas 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-9.2.4 Electrical Energy

III-9.2.4.1 Stored Energy Exposure

This hazard is present from the alternating current (AC) power distribution systems and power supplies in the P1 and P2 Beamlines. This hazard has been evaluated within the common risk matrix table included in SAD Section I Chapter 04 *Safety Analysis*. Work in the P1 and P2 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-9.2.4.2 High Voltage Exposure

Electrical hazards are controlled by the Fermilab LOTO procedures. This hazard has been evaluated within the common risk matrix table included in SAD Section I Chapter 04 *Safety Analysis*. Work in the P1 and P2 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-9.2.4.3 Low Voltage, High Current Exposure

This hazard is present in several electromagnets. This hazard has been evaluated within the common risk matrix table included in SAD Section I Chapter 04 *Safety Analysis*. Work in the P1 and P2 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-9.2.5 Thermal Energy

The P1 and P2 Beamlines present thermal energy hazards identified in Table 1. All thermal energy hazards present in the P1 and P2 Beamlines are in the form of Standard Industrial Hazards discussed in SAD Section I Chapter 04.

III-9.2.5.1 Bakeouts

N/A

III-9.2.5.2 Hot Work

Qualified welders occasionally work in the P1 and P2 Beamlines tunnels and service buildings to repair waterlines and other metalwork. This hazard has been evaluated within the common risk matrix table included in SAD Section I Chapter 04 *Safety Analysis*. Work in the P1 and P2 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-9.2.5.3 Cryogenics

N/A

III-9.2.6 Kinetic Energy

The P1 and P2 Beamlines present kinetic energy hazards identified in Table 1. All kinetic energy hazards present in the P1 and P2 Beamlines are in the form of Standard Industrial Hazards discussed in SAD Section I Chapter 04.

III-9.2.6.1 Power Tools

Power tools are commonly used when working on components in the P1 and P2 Beamlines. This hazard has been evaluated within the common risk matrix table included in SAD Section I Chapter 04 *Safety Analysis*. Work in the P1 and P2 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-9.2.6.2 Pumps and Motors

Standard industrial pumps and motors are utilized throughout the P1 and P2 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 P1 and P2 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-9.2.6.3 Motion Tables

N/A

III-9.2.6.4 Mobile Shielding

N/A

III-9.2.7 Potential Energy

The P1 and P2 Beamlines present potential energy hazards identified in Table 1. All potential energy hazards present in the P1 and P2 Beamlines are in the form of Standard Industrial Hazards discussed in SAD Section I Chapter 04.

III-9.2.7.1 Crane Operations

Trained technicians use various cranes to move, maintain, and install equipment in the P1 and P2 Beamlines. This hazard has been evaluated within the common risk matrix table included in SAD Section I Chapter 04 *Safety Analysis*. Work in the P1 and P2 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-9.2.7.2 Compressed Gasses

Compressed air, nitrogen, and $ArCO_2$ are present in the P1 and P2 Beamlines to facilitate machine operations. Compressed gas cylinders are used, stored, and moved throughout the P1 and P2 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 P1 and P2 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-9.2.7.3 Vacuum/Pressure Vessels/Piping

Pressure vessels are present in the P1 and P2 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 P1 and P2 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-9.2.7.4 Vacuum Pumps

Vacuum pumps are used throughout the P1 and P2 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 P1 and P2 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-9.2.7.5 Material Handling

Trained personnel operate forklifts, stackers, and hand carts to move materials throughout the P1 and P2 Beamlines. This hazard has been evaluated within the common risk matrix table included in SAD Section I Chapter 04 *Safety Analysis*. Work in the P1 and P2 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-9.2.8 Magnetic Fields

III-9.2.8.1 The P1 and P2 Beamlines present magnetic field hazards identified in Table 1. Unusual hazards are present in the form of fringe fields, which may interfere with implanted medical devices. 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 entry points about this hazard. This hazard has been evaluated within the common risk matrix table included in SAD Section I Chapter 04 *Safety Analysis*. Work in the P1 and P2 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 (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-9.2.9 Other Hazards

III-9.2.9.1 Confined Spaces

Confined spaces in the P1 and P2 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 P1 and P2 Beamlines 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 or lower.

III-9.2.9.2 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 P1 and P2 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 III and, after control measures were evaluated, the residual risk level was R IV.

III-9.2.9.3 Silica

Silica dust may be created when drilling into concrete floors or walls. Silica hazards have been evaluated within the common risk matrix table included in SAD Section I Chapter 04 *Safety Analysis*. Work in the P1 and P2 Beamlines involving silica dust 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-9.2.9.4 Ergonomics

Technical work in the P1 and P2 Beamlines may involve standing for long periods of time, repetitive motion, cramped conditions, and other ergonomic concerns. This hazard has been evaluated within the common risk matrix table included in SAD Section I Chapter 04 *Safety Analysis*. Work in the P1 and P2 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-9.2.9.5 Asbestos

N/A

III-9.2.9.6 Working at Heights

Technicians utilize ladders and step stools to conduct maintenance in the P1 and P2 Beamlines areas. Utilizing fall protection equipment, trained personnel may work on top of equipment where there is a chance of falling. This hazard has been evaluated within the common risk matrix table included in SAD Section I Chapter 04 *Safety Analysis*. Work in the P1 and P2 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-9.2.10 Access & Egress

III-9.2.10.1 Life Safety Egress

Access and egress points in the P1 and P2 Beamlines vary depending on the tunnel. This hazard has been evaluated within the common risk matrix table included in SAD Section I Chapter 04 *Safety Analysis*. Work in the P1 and P2 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-9.2.11 Environmental

III-9.2.11.1 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 P1 and P2 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-9.2.11.2 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 P1 and P2 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-9.2.11.3 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 P1 and P2 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-9.3. Maximum Credible Incident Scenario(s) for Accelerator Specific Hazards

This section evaluates the maximum credible incident (MCI) scenario that could happen in the P1 and P2 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-9.3.1 Definition of a Maximum Credible Incident

The MCI scenario evaluated for the P1 and P2 Beamlines is 7 E12 protons per pulse at a 15-Hz repetition rate and 8-GeV beam energy, resulting in 3.78 E17 protons/h.

Note that the 120-GeV scenario of 4.2 E13 protons every 55s resulting in 2.75E15 protons/h requires less-stringent controls.

Fermilab uses Credited Controls that flow down to the ASE to mitigate the consequences of the MCI to the following conditions:

- Worker Basis: Mitigated consequence of any credible postulated accident scenario at maximum operating intensity that could potentially result in 5 rem in one hour in any area accessible by facility workers and co-located workers.
- General Site Basis: Mitigated consequence of any credible postulated accident scenario at maximum operating intensity that could potentially result in 500 mrem in one hour in areas to which the public is assumed to be excluded.
- Public Area Basis: Mitigated consequence of any credible postulated accident scenario at maximum operating intensity that could potentially result in 100 mrem in one hour at Fermilab's site boundary AND/OR in any areas onsite in which the public is authorized.

These Credited Controls are discussed in Section III-9.4.

The MCI for the P1 and P2 Beamlines utilizes the General Site Basis, therefore requiring the passive Credited Control of Obvious and Operating Barriers to ensure only authorized access. The the P1 and P2 Beamlines are located beyond the Obvious and Operating Barriers. The accumulated dose outside of the shielding on the P1 and P2 Beamlines berm is mitigated, by use of Credited Controls, to less than 500 mrem in an MCI. The closest possible location of a member of the public to the P1 and P2 Beamlines enclosure is Wilson Hall. This location is more than five feet away from the berm, which would result in dose of less than 100 mrem applying a conservative dose reduction of 1/r.

A change in the MCI for upstream segments will be evaluated for its effect on the P1 and P2 Beamlines through the USI process.

III-9.4. Summary of Credited Controls

III-9.4.1 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 P1 and P2 Beamlines were designed with a concrete and earth covered radiation shield to protect personnel from radiological exposure during beam operations.

III-9.4.1.1 Passive Credited Controls

III-9.4.1.1.1 Permanent Shielding

The P1 and P2 Beamlines shielding assessment contains 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*. 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.

The credited shielding is 17.9 e.f.d. in all locations except in the 520-701 region (MI 8400-8475) where the loss is on a buried thick pipe, which requires 20.3 e.f.d.

III-9.4.1.1.2 Penetration Shielding

The F13 10" diameter Cryo penetration must be filled with at least 16.8 feet of sand. The F13 6" diameter Cryo penetration must be filled with at least 14.7 feet of sand. The F15 48" diameter Cryo penetration must be filled to the top of the berm with sand. No other penetrations are required to be filled.

III-9.4.1.1.3 Obvious and Operating Barriers to Ensure Only Authorized Access

To permit entry to only authorized individuals into the area where the General Site Basis applies (see Figure 4) surrounding the P1 and P2 Beamlines segment of the Fermilab Main Accelerator, Obvious and Operating Barriers shall be established at the following locations to permit only authorized access:

- Wilson Hall West
- Wilson Hall East
- Site 5

III-9.4.2 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 P1 and P2 Beamlines are discussed below.

III-9.4.2.1 Radiation Safety Interlock System

The P1 and P2 Beamlines employ a Radiation Safety Interlock System (RSIS). The characteristics of the system are described in Section I of the Fermilab SAD.

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 (MI) 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. Beam cannot be transported into the P1 Beamline 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 MI RSIS, preventing beam from entering the MI and Recycler.

Radiation detectors are placed around the P1 and P2 Beamlines. They are configured so that a beam loss producing a radiation flux that exceeds the allowable limit will inhibit the MI P150 extraction RSIS critical devices to provide radiation protection for those in the area. The trip levels of radiation detectors are interlocked to the MI 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. 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 2: Credited Radiation Monitors for P1 and P2 Beamlines

Device Type	Location	Credited Control Limit
Chipmunk	F15 Air Handler	440 mrem/hour

A Repetition Rate Limiter is credited for 120-GeV beam only to prevent more than one MI extraction per 55s. The Repetition Rate Limiter monitors the current of the ramped magnet VH94. If the VH94 current stays above a threshold for longer than a specified duration, then I:LAM52 is inhibited, that is, 120-GeV extraction from the Main Injector to the P1 and P2 Beamlines is inhibited.

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-9.4.3 Administrative Credited Controls

All P1 and P2 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-9.4.3.1 Operation Authorization Document

Beam will not be transported to the P1 and P2 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 P1 and P2 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 P1 and P2 Beamlines, the following enclosures must be secured:

- MI/TeV Crossover
- Tevatron F-Sector
- Tevatron Transfer Hall
- Muon Pre-Target Enclosure

In addition, all interlocked radiation detectors must be in place and active.

III-9.4.3.2 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-9.4.3.3 Accelerator Operating Parameters

To ensure operations within bounding conditions used in the MCI analysis, the following limits are applied.

Beam shall not exceed 3.78 E17 protons per hour at 8 GeV beam energy.

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

III-9.5. Summary of Defense-in-Depth Controls

III-9.5.1 Defense-in-Depth Engineering Controls

III-9.5.1.1 Passive Defense-in-Depth Engineering Controls

III-9.5.1.1.1 Permanent Shielding

For the P1 and P2 Beamlines:

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

Table 3: 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 4: 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

III-9.5.1.2 Active Defense-in-Depth Engineering Controls

III-9.5.1.2.1 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 on an hourly basis.

III-9.5.1.3 Defense-in-Depth Administrative Controls

III-9.5.1.3.1 Fencing and Posting

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

III-9.5.1.3.2 Training

All personnel engaged in the commissioning, operation, and emergency management of the P1 and P2 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-9.6. Decommissioning

DOE Field Element Manager approval shall be obtained prior to the start of any decommissioning activities for the P1 and P2 Beamlines.

III-9.7. Summary and Conclusion

Specific hazards associated with the operation of the P1 and P2 area enclosures are identified and assessed in this chapter of the Fermilab SAD. The designs, controls, and procedures to mitigate P1 and P2 specific hazards are identified and described. The P1 and P2 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 P1 and P2 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-9.8. References

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

III-9.9. Appendix – Risk Tables

Risk assessment methodology was developed based on the methodology described in DOE-HDBK-1163-2020 and is presented in Tables 13.1-13.31. 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-9.4 of this chapter as well as SAD Chapter VII-A.1 *Accelerator Safety Envelope – Fermi Main Accelerator*.