8-GEV LINE

SECTION III CHAPTER 05 OF THE FERMILAB SAD

Revision 1 January 6, 2024

This Chapter of the Fermilab Safety Assessment Document (SAD) contains a summary of the results of the Safety Analysis for the 8 GeV Beamline 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 03, Chapter 05 of the Fermi National Accelerator Laboratory (Fermilab) Safety Assessment Document (SAD), *8 GeV Beamline* was prepared and reviewed by the staff of the Accelerator Direct, Main Injector Department in conjunction with the Environment, Safety & Health Division (ESH) Accelerator Safety Department.

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

☐ ____
Line Organization Owner

☐ ____
Accelerator Safety Department Head

☐ ____
SAD Review Subcommittee Chair

Revision History

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

Author	Rev. No.	Date	Description of Change
Dave Capista Marty Murphy	1	January 6, 2024	• Update and structure change to be consistent with updated SAD layout and incorporating Risk Matrix and hazards discussion • MCI methodology
John E. Anderson Jr.	0	January 20, 2012	Initial release of the 8 GeV Line Chapter for the Fermi National Accelerator Safety Assessment Document

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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-5. 8-GeV Line

III-5.1. Introduction

This Section 03 Chapter 05 of the Fermi National Accelerator Laboratory (Fermilab) Safety Assessment Document (SAD) covers the 8 GeV Beamline enclosure segment of the Fermilab Main Accelerator

III-5.1.1 Purpose/Function

The 8-GeV Line segment of the Fermilab Main Accelerator is designed to transport protons with a fixed energy of 8-billion Electron-Volts (8-GeV) from the Booster to either the Recycler, the Main Injector or the BNB beamline in support of the Fermilab high energy physics (HEP) programs. The maximum frequency at which beam may transfer through the 8-GeV line is 15 cycles per second (15 Hz).

III-5.1.2 Current Status

The 8-GeV Line segment of the Fermilab Main Accelerator is currently operational.

III-5.1.3 Description

The 8 GeV Line is located southwest of the Booster accelerator. The enclosure is constructed of concrete approximately 8 feet high and 10 feet wide covered by at least 24.5 feet of earth. The beamline extends from the extraction stub of the Booster accelerator at location 803 to the injection area of the Main Injector location 850. The beamline path is somewhat convoluted for two reasons (see Figure 1). Vertically, the Main Injector is about 11 feet below the level of the Booster accelerator ring. Horizontally, the line must avoid the Antiproton Source and pass under the Transport Enclosure.

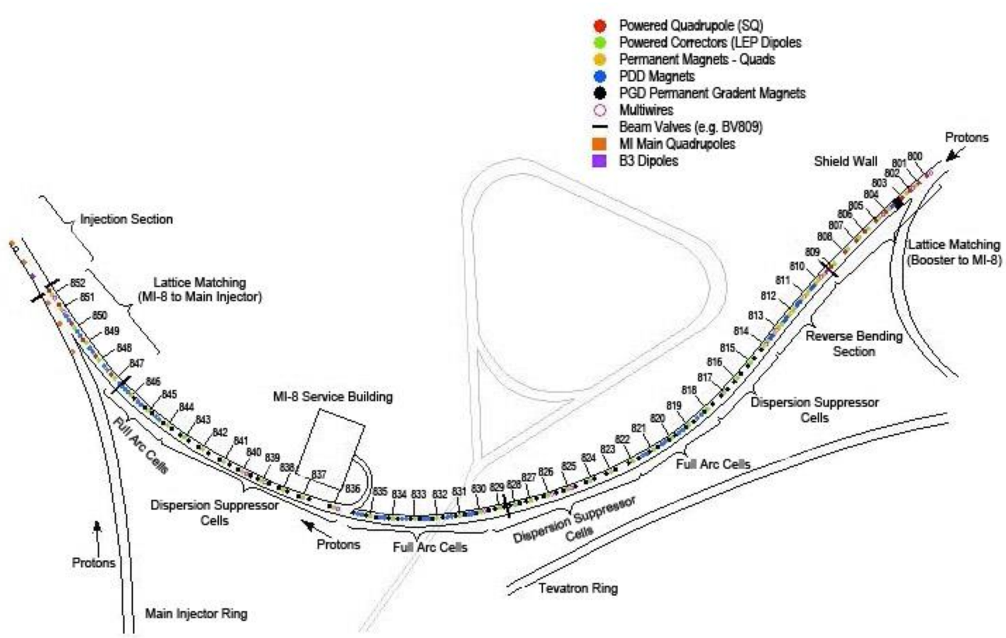

Figure 1. 8 GeV Line Plan View.

III-5.1.4 Location

The the8 GeV Beamline enclosure is located on the Fermilab site in Batavia, IL.

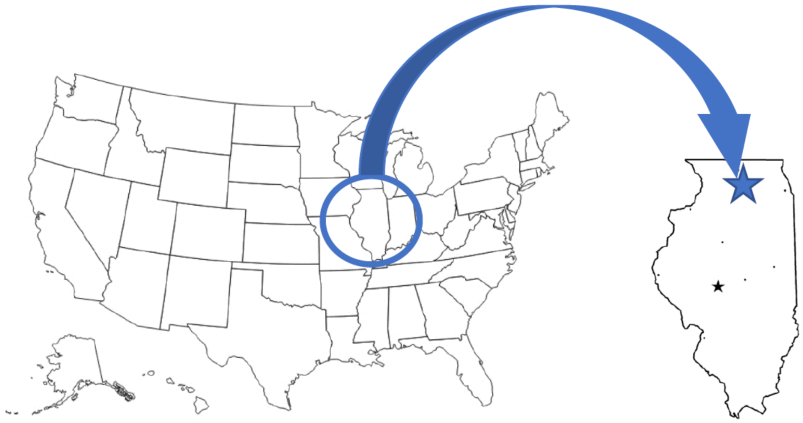

Figure 2. Regional view showing the location of the Fermilab site in Batavia, IL.

The 8 GeV Beamline enclosure is located in the southwest of the Booster accelerator on the Fermilab site.

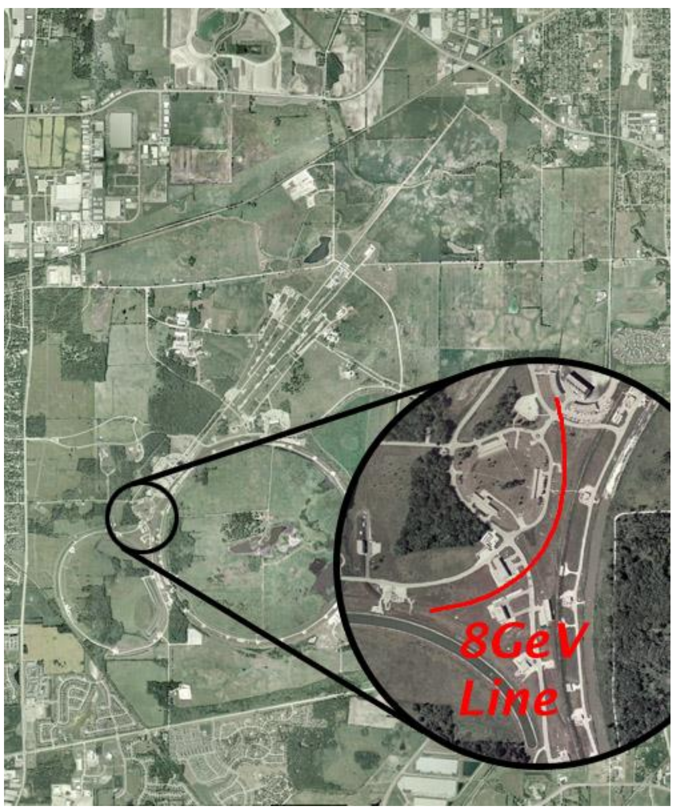

Figure 3. Aerial view of the Fermilab site, indicating the location of the 8 GeV Line.

III-5.1.5 Management Organization

The 8-GeV Line is managed by the Main Injector department. Since this beamline connects the Booster and the Booster Neutrino Beamline, the responsibilities for the operation of the beamline are often shared to optimize the operation of this beamline.

III-5.1.6 Operating Modes

The 8 GeV Beamline receives 8 GeV protons from the Booster extraction line at an operating intensity of ~5.3 x 10^{12} protons/pulse at a 15 Hz repetition rate. The beamline shielding assessment [1] and post-assessment documents demonstrate that the facility can be safely operated at intensities up to 2.84 x 10^{17} protons/hour.

Beam extraction from the Booster is accomplished via an upward kick to the beam from four kicker magnets, MKS05, MKS06, MKS07, and MKS08 in the Long 2 straight section (see Figure 4). The extracted beam passes over the septum plate of MP02 at Long 3 and leaves at a tangent to the Booster ring horizontally at a slight upward angle. The Vertical Bend Center 1 magnet VBC1 removes the vertical kick provided by the septa. The beam continues to V803, the beginning of the 8 GeV Line, on its way to either the Booster Beam Absorber or toward the Main Injector and Booster Neutrino areas. The final beam destination, Booster absorber or 8 GeV Line, is determined by the selected Booster accelerator operating mode. Booster accelerator operating modes are discussed in the Booster chapter of this document.

The 8-GeV Line segment may be operated in three different modes. The first is to deliver protons to the Recycler for either the NuMI, Switch Yard or Muon Campus physics programs. The second mode delivers protons to the Booster Neutrino Beamline (BNB). The third mode sends protons directly into the Main Injector for destinations like the Switch Yard areas or NuMI. Regardless of which mode is used beam energy is 8-GeV and the source is the Booster with a maximum duty cycle rate of 15 Hz. Physics requirements of the experimental program determine which mode is operational at any given time. At present beam transfer to the Recycler and BNB are the most common modes of operation. Any of these three operational modes can be utilized to support accelerator studies as well.

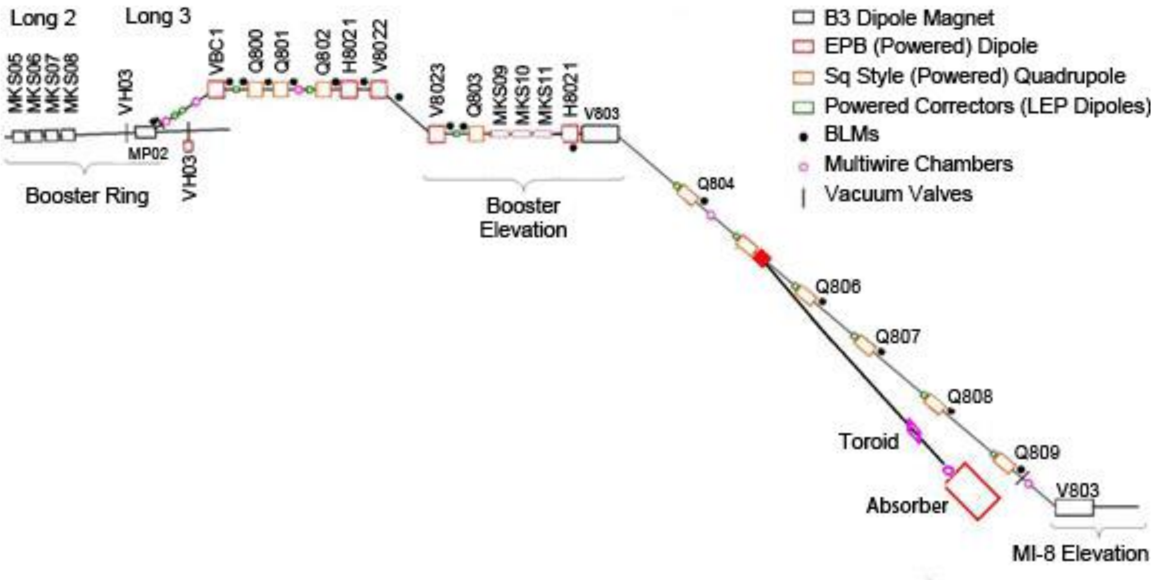

Figure 4. Vertical Profile of the Upstream 8 GeV Line..

III-5.1.7 Inventory of Hazards

The following table lists all the identified hazards found in the 8 GeV Beamline enclosure and support buildings. Section III-5.9 *Appendix – Risk Matrices* describes the baseline risk (i.e., unmitigated risk), any preventative controls and/or mitigative controls in place to reduce the risk, and residual risk (i.e., mitigated risk) for facility worker, co-located worker and Maximally Exposed Offsite Individual (MOI) (i.e., members of the public). A summary of these controls is described within Section III-5.2 *Safety Assessment.*

Prompt ionizing radiation 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 8-GeV Line segment specific controls are identified as **purple/bold** throughout this Chapter.

All other hazards present in the 8 GeV Beamline are safely managed by other DOE approved applicable safety and health programs and/or processes, and their analyses have been performed according to applicable DOE requirements as flowed down through the Fermilab Environment, Safety and Health Manual (FESHM). These hazards are Non-Accelerator-Specific Hazards (NASH), and their analysis will be summarized in this SAD Chapter.

Table 1. Hazard Inventory for 8 GeV Beamline

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

III-5.2. Safety Assessment

All hazards for the 8 GeV Beamline segment of the Fermi Main Accelerator are summarized in this section, with additional details of the analyses for accelerator specific hazards.

III-5.2.1 Radiological Hazards

The 8-GeV Line segment presents radiological hazards in the form of Prompt Ionizing Radiation; Residual Activation; Groundwater Activation; Surface Water Activation; Air Activation; Soil Interactions; Radioactive Waste; Contamination; Beryllium-7; Non-Ionizing Radiation Hazards.

Detailed shielding assessments and post assessment documents address these hazards. The assessments provide a detailed analysis of the 8-GeV Line segment demonstrating the required shielding, controls and interlocks to comply with the Fermilab Radiological Control Manual (FRCM)[2]. Residual activation of components has a substantial impact on the ability to occupy the 8-GeV Line enclosure where recurring access is required for routine maintenance.

The shielding assessment for the 8-GeV Line segment begins at the interlocked gate at Cell 810 adjacent to the Booster accelerator enclosure. They include the entire 8-GeV Line up to the Recycler, Main Injector and BNB interface points noted in the *Description* section above.

The assessment considers groundwater and surface water activation. It lists surface water discharge points and monitoring locations. It calculates air activation, estimates annual release totals, and release points. It considers muon production, longitudinal and transverse shielding requirements; summarizes labyrinth and penetration calculations; calculates residual dose rates; and specifies active shielding controls and monitoring.

Unmitigated, radiological risks for the 8-GeV Line segment are a level I risk. After mitigation all risks have been reduced to level IV.

III-5.2.1.1 Prompt Ionizing Radiation

Prompt ionizing radiation is the principal radiation hazard when beam is transported through the 8-GeV Line segment. It is generated from the particle beam interaction with the materials surrounding the beam, such as the beam pipes, beamline elements, and beamline instrumentation. The interlocked 8 GeV Line enclosure is designed and constructed to provide an exclusion area around the operating beamline elements. This exclusion area limits personnel exposure to prompt ionizing radiation from beam losses to the requirements established in the Fermilab Radiological Control Manual (FRCM).

This hazard has been evaluated via a Maximum Credible Incident (MCI) analysis that is described in Section III-5.3.1.1. This analysis specifies that Fermilab uses Credited Controls that flow down to the Accelerator Safety Envelope (ASE) to mitigate the consequences of the MCI to at or below the acceptable dose levels described in SAD Section I Chapter 4. A detailed description of each of the Credited Controls and their function is provided in Section III-5.4. The conclusion of these analyses is that the mitigated dose level associated with prompt ionizing radiation due to beam loss is acceptable.

III-5.2.1.2 Residual Activation

Losses along the 8 GeV Beamline will result in activation of intercepting beam instrumentation devices and other beam line components. The activation level and quantity of activated material will not be unique relative to other accelerators at Fermilab. Collimators are installed within this beamline to remove high emittance tails from the beam to reduce losses in downstream areas. These collimators introduce a localized hot spot in the enclosure beamline and creates contamination in the local area at Cells 836 and 838, respectively.

The collimators are locally identified as high radiation and contamination areas (including $_7$Be) and physically isolated by barriers and signage indicating no human activity is allowed in the area without prior authorization from RSO.

Residual activation hazards will be managed within the As Low As Reasonably Achievable (ALARA) program established throughout the Fermilab accelerator complex and as prescribed in the FRCM. All potential residual activation hazards are handled operationally as in all other primary beam enclosures. These controls include verification of training, centralized authorization, and key entry. The level of control depends on the level of residual radiation. In most cases, the typical Radiation Work Permit (RWP) for accesses will suffice. A job-specific RWP and an ALARA plan will be required for work on any highly activated equipment such as the collimation area.

III-5.2.1.3 Groundwater Activation

Radioactivity induced by the interaction of high-energy particles with the soil that surrounds the beamline is addressed in this section. The production of Tritium (^{3}H) and Sodium 22 (^{22}Na) is the greatest concern due to production rate and leachability into the groundwater as well as the long half-lives of the radionuclides.

Tritium is biologically most hazardous when in the form of tritiated water. The US Environmental Protection Agency (EPA) sets the maximum contamination levels for the groundwater at 20 pCi/ml for tritium and 0.4 pCi/ml for 22Na. However, because of the State of Illinois "non-degradation of a natural resource" requirement [35 IAC 620-392(C)], the limits used for this calculation are the regulatory standard detection levels [40 CFR Part 141.25], which are 1 pCi/ml for tritium and 0.04 for 22Na. Below these levels, these radionuclides are considered "non-detectable." Due to the presence of under-drains along the entirety of the 8-GeV Line segment, most of the potentially radioactivated water is collected and released to surface waters. Since this fact is not considered in the groundwater analyses, their estimated radioactivity levels are conservative upper limits.

The annual limits for ^{3}H and ^{22}Na with respect to surface water and groundwater are given in Table 2 below. The 1500 kW estimates for surface and ground waters show that a distributed beam loss of 3.63 x 10^{19} protons during a year of operation will produce ^{3}H and ^{22}Na concentrations combined that account for 1.3% of the annual surface water limit if sump pumps discharge to the surface once per week and 0.1% of the groundwater limit, as shown in MI 1500 kW Distributed Groundwater and Surface Water 03-06-18 (Attachment G).

Table 2: Surface water and groundwater summary

Description	Annual Concentration Limits (pCi/ml)		Annual Concentration Estimate (pCi/ml)		Fraction of Annual Limit
	^{3}H	**^{22}Na**	**^{3}H**	**^{22}Na**	**^{3}H + ^{22}Na**
Surface Water (Distributed)	1900	10	69	6.2	1.3×10^{-2}
Groundwater (Distributed)	1	0.04	5.8×10^{-4}	1.8×10^{-5}	1.0×10^{-3}

Sump sample trending reports from the Main Injector indicate surface water concentrations less than 5 pCi/ml from CY 2015 to CY 2017 when average beam power was less than 700 kW.

Groundwater is sampled annually as part of the ES&H Division Environmental Monitoring Program and the surface water sampling locations and frequency are documented in *ES&H RPE Routine Monitoring Programs*.

As discussed in the 8 GeV Fixed Target Shielding Assessment [1], a conservative assumed beam loss rate of 2% over the entire length of the beamline was used to estimate the ground water and surface water tritium activation. The results show that for a yearly beam intensity of 1.18 x 10^{21} protons, after 10 years of operation, the ground water tritium concentration would be less than 3.7 x 10-10 pCi/ml. This is well below the regulatory limit of 20 pCi/ml. The maximum expected surface water tritium concentration using the same assumed 2% beam loss for a thirty-day period of time is 317 pCi/ml. This is sufficiently below the 1900 pCi/ml Derived Concentration Standard (DCS) set forth in DOE Order 458.1. The sump discharge locations along the 8-GeV Line are routinely sampled as part of the ESH Routine Radiological Monitoring Program.

III-5.2.1.4 Surface Water Activation

Routine residual radiation surveys consistently detail the highest activation areas are in the immediate vicinity of the 8-GeV Line collimators at cells 836 and 838, respectively. Activation of the along the rest of the beamline is orders of magnitude lower in comparison.

Surface water activation details are discussed in the above section Groundwater Activation (IV-5.2.1.3)

Sump sample trending reports from the 8-GeV Line indicate surface water concentrations less than 5 pCi/ml from CY 2015 to CY 2017 when average beam power was less than 700 kW.

Groundwater is sampled annually as part of the ES&H Division Environmental Monitoring Program and the surface water sampling locations and frequency are documented in ESH Routine Monitoring Programs.

Radioactivity induced by the interaction of high-energy particles with the soil that surrounds the beamline is addressed in this section. The production of tritium and sodium 22 is the greatest concern due to production rate and leachability into the groundwater as well as the long half-lives of the radionuclides.

As discussed in the 8 GeV Fixed Target Shielding Assessment, a conservative assumed beam loss rate of 2% over the entire length of the beamline was used to estimate the ground water and surface water tritium activation. The results show that for a yearly beam intensity of 1.18 x 10^{21} protons, after 10 years of operation, the ground water tritium concentration would be less than 3.7 x 10^{-10} pCi/ml. This is well below the regulatory limit of 20 pCi/ml. The maximum expected surface water tritium concentration using the same assumed 2% beam loss for a thirty-day period is 317 pCi/ml. This is sufficiently below the 1900 pCi/ml Derived Concentration Standard (DCS) set forth in DOE Order 458.1. The sump discharge locations along the 8 GeV beamline are routinely sampled as part of the ESH Routine Radiological Monitoring Program.

III-5.2.1.5 Radioactive Water (RAW) Systems

N/A.

III-5.2.1.6 Air Activation

The concentration of radionuclides in the 8 GeV Beamline enclosure is below the limit due to very large amounts of air flowing in and out of the enclosure, the short half-life of the isotopes produced, and operational overhead to prepare the enclosure for access.

III-5.2.1.7 Closed Loop Air Cooling

N/A.

III-5.2.1.8 Soil Interactions

Beam losses within the enclosure interact with the soil around the concreate enclosure. To keep these interactions to a minimum, beam loss is monitored and reduced as much as possible. Any excavation is monitored by Radiation Safety for possible contamination.

III-5.2.1.9 Radioactive Waste

Radioactive waste produced during 8-GeV Line segment operations will be managed within the established Radiological Protection Program (RPP) and as prescribed in the Fermilab Radiological Control Manual (FRCM). Waste minimization is an objective of accelerator equipment design and operational procedures.

Production of radioactive waste is not an operational function of the 8-GeV Line segment. That said, beam interaction with accelerator components is impossible to eliminate, and in some cases, is done for diagnostic purposes (e.g. wire beam scanners). Beam loss, both controlled and uncontrolled, cause most of the residual radiation of beamline components (magnets, collimators, beam pipe, stands, etc.). 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.

III-5.2.1.10 Contamination

Activated dust and debris within the 8-GeV Line enclosure results in spreadable material. This hazard is controlled using standard decontamination practices, PPE, radiations surveys, signs, and barriers.

III-5.2.1.11 Beryllium-7

Beryllium-7 (^{7}Be) is produced in areas with high beam losses, such as the collimation area, due to interactions with air. ^{7}Be decays through the electron capture process and only 10% of the decays produce a gamma ray that is hazardous to the worker. This makes the ^{7}Be contamination undetectable to our field survey equipment. The areas that have been measured positive for ^{7}Be are roped off and special access requirements are put in place.

III-5.2.1.12 Radioactive Sources

N/A.

III-5.2.1.13 Nuclear Material

N/A.

III-5.2.1.14 Radiation Generating Devices (RGDs)

N/A.

III-5.2.1.15 Non-Ionizing Radiation Hazards

N/A.

III-5.2.2 Toxic Materials

III-5.2.2.1 Lead

The primary lead hazard is in the form of lead solder from older electronics still in use. Lead radiation shielding is sometimes used in the 8-GeV Line segment, typically in the form of encased lead blankets. This hazard has been evaluated within the common Risk Matrix table included in SAD Section I Chapter 04 Safety Analysis. Work in the 8-GeV Line enclosures involving this hazard implements the controls specified in the common Risk Matrix table. No unique controls are in use.

III-5.2.2.2 Beryllium

The only potential source of Beryllium is in the form of a Copper-Beryllium alloy used in small springs contained in flexible bellows used at beam pipe interfaces.

III-5.2.2.3 Fluorinert & Its Byproducts

N/A.

III-5.2.2.4 Liquid Scintillator Oil

N/A.

III-5.2.2.5 Pseudocumene

N/A.

III-5.2.2.6 Ammonia

N/A.

III-5.2.2.7 Nanoparticle Exposures

N/A.

III-5.2.3 Flammables and Combustibles

III-5.2.3.1 Combustible Materials

This hazard has been evaluated within the common Risk Matrix table included in SAD Section I Chapter 04 *Safety Analysis.* Work in 8 GeV Beamline involving this hazard implements the controls specified in the common Risk Matrix table. No unique controls are in use.

III-5.2.3.2 Flammable Materials

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 8-GeV Line enclosures involving this hazard implements the controls specified in the common Risk Matrix table. No unique controls are in use.

III-5.2.4 Electrical Energy

III-5.2.4.1 Stored Energy 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 8-GeV Line enclosures involving this hazard implements the controls specified in the common Risk Matrix table. No unique controls are in use.

III-5.2.4.2 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 8-GeV Line enclosures involving this hazard implements the controls specified in the common Risk Matrix table. No unique controls are in use.

III-5.2.4.3 Low Voltage, High Current 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 8-GeV Line enclosures involving this hazard implements the controls specified in the common Risk Matrix table. No unique controls are in use.

III-5.2.5 Thermal Energy

III-5.2.5.1 Bakeouts

This hazard has been evaluated within the common Risk Matrix table included in SAD Section I Chapter 04 Safety Analysis. Work in the 8-GeV Line enclosures involving this hazard implements the controls specified in the common Risk Matrix table. No unique controls are in use.

III-5.2.5.2 Hot Work

Qualified welders occasionally work in the 8-GeV enclosures 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 8-GeV Line enclosures involving this hazard implements the controls specified in the common Risk Matrix table. No unique controls are in use.

III-5.2.5.3 Cryogenics

N/A.

III-5.2.6 Kinetic Energy

III-5.2.6.1 Power Tools

Power tools are commonly used when working on 8-GeV Line equipment in the gallery and tunnel. This hazard has been evaluated within the common Risk Matrix table included in SAD Section I Chapter 04 Safety Analysis. Work in the 8-GeV Line enclosures involving this hazard implements the controls specified in the common Risk Matrix table. No unique controls are in use.

III-5.2.6.2 Pumps and Motors

Standard industrial pumps and motors are utilized throughout the 8-GeV Line area for water cooling and vacuum systems. This hazard has been evaluated within the common Risk Matrix table included in SAD Section I Chapter 04 Safety Analysis. Work in the 8-GeV Line enclosures involving this hazard implements the controls specified in the common Risk Matrix table. No unique controls are in use.

III-5.2.6.3 Motion Tables

Technicians use mechanical motion tables to install equipment and improve ergonomics when conducting maintenance or repairs. This hazard has been evaluated within the common Risk Matrix table included in SAD Section I Chapter 04 Safety Analysis. Work in the 8-GeV Line enclosures involving this hazard implements the controls specified in the common Risk Matrix table. No unique controls are in use.

III-5.2.6.4 Mobile Shielding

This hazard has been evaluated within the common Risk Matrix table included in SAD Section I Chapter 04 *Safety Analysis.* Work in 8 GeV Beamline involving this hazard implements the controls specified in the common Risk Matrix table. No unique controls are in use.

III-5.2.7 Potential Energy

III-5.2.7.1 Crane Operations

Trained technicians utilize various hoists lifts, and bridge cranes to move, maintain, and install equipment in the 8-GeV Line building (MI8) and tunnels. This hazard has been evaluated within the common Risk Matrix table included in SAD Section I Chapter 04 Safety Analysis. Work in the 8-GeV Line enclosures involving this hazard implements the controls specified in the common Risk Matrix table. No unique controls are in use.

III-5.2.7.2 Compressed Gasses

Compressed nitrogen, and argon are present in MI/RR areas to facilitate machine operations. Compressed gas cylinders are stored, used, and moved throughout the 8-GeV Line service building (MI8) and tunnels. Compressed air is also used to manipulate pneumatic beam valves. This hazard has been evaluated within the common Risk Matrix table included in SAD Section I Chapter 04 Safety Analysis. Work in the 8-GeV Line enclosures involving this hazard implements the controls specified in the common Risk Matrix table. No unique controls are in use.

III-5.2.7.3 Vacuum/Pressure Vessels/Piping

Vacuum vessels are present in 8-GeV Line segment in the form of beam pipes. This hazard has been evaluated within the common Risk Matrix table included in SAD Section I Chapter 04 Safety Analysis. Work in the 8-GeV Line enclosures involving this hazard implements the controls specified in the common Risk Matrix table. No unique controls are in use.

III-5.2.7.4 Vacuum Pumps

Vacuum pumps are used throughout the 8-GeV Line segment to maintain vacuum on beamline components. This hazard has been evaluated within the common Risk Matrix table included in SAD Section I Chapter 04 Safety Analysis. Work in the 8-GeV Line enclosures involving this hazard implements the controls specified in the common Risk Matrix table. No unique controls are in use.

III-5.2.7.5 Material Handling

Trained personnel operate forklifts, stackers, and hand carts to move materials throughout the 8-GeV Line area. Additionally, heavy equipment may be moved short distances utilizing team lifts. Individual lifting is limited to items 50 pounds or less. This hazard has been evaluated within the common Risk Matrix table included in SAD Section I Chapter 04 Safety Analysis. Work in the 8-GeV Line enclosures involving this hazard implements the controls specified in the common Risk Matrix table. No unique controls are in use.

III-5.2.8 Magnetic Fields

III-5.2.8.1 Fringe Fields

This hazard has been evaluated within the common Risk Matrix table included in SAD Section I Chapter 04 *Safety Analysis.* Work in 8 GeV Beamline involving this hazard implements the controls specified in the common Risk Matrix table. No unique controls are in use.

III-5.2.9 Other Hazards

III-5.2.9.1 Confined Spaces

This hazard has been evaluated within the common Risk Matrix table included in SAD Section I Chapter 04 Safety Analysis. Work in the 8-GeV Line enclosures involving this hazard implements the controls specified in the common Risk Matrix table. No unique controls are in use.

III-5.2.9.2 Noise

Operating cooling water systems creates a potential noise hazard in the 8-GeV Line service building (MI8) and tunnel. This hazard has been evaluated within the common Risk Matrix table included in SAD Section I Chapter 04 Safety Analysis. Work in the 8-GeV Line enclosures involving this hazard implements the controls specified in the common Risk Matrix table. No unique controls are in use.

III-5.2.9.3 Silica

Silica dust may be created when drilling into concrete floors or walls. This hazard has been evaluated within the common Risk Matrix table included in SAD Section I Chapter 04 Safety Analysis. Work in the 8-GeV Line enclosures involving this hazard implements the controls specified in the common Risk Matrix table. No unique controls are in use.

III-5.2.9.4 Ergonomics

Both office and technical work in 8-GeV Line areas may involve sitting or 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 8-GeV Line enclosures involving this hazard implements the controls specified in the common Risk Matrix table. No unique controls are in use.

III-5.2.9.5 Asbestos

Hazard not applicable to the 8-GeV Line enclosures.

III-5.2.9.6 Working at Heights

Technicians utilize ladders, step stools, and mobile work platforms to conduct maintenance in 8-GeV Line 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 8-GeV Line enclosures involving this hazard implements the controls specified in the common Risk Matrix table. No unique controls are in use.

III-5.2.10 Access & Egress

III-5.2.10.1 Life Safety Egress

This hazard has been evaluated within the common Risk Matrix table included in SAD Section I Chapter 04 Safety Analysis. Work in the 8-GeV Line enclosures involving this hazard implements the controls specified in the common Risk Matrix table. No unique controls are in use.

III-5.2.11 Environmental

III-5.2.11.1 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 8-GeV Line enclosures involving this hazard implements the controls specified in the common Risk Matrix table. No unique controls are in use.

III-5.2.11.2 Hazard to Water

Transformer oil found in 8-GeV Line area 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 8-GeV Line enclosures involving this hazard implements the controls specified in the common Risk Matrix table. No unique controls are in use.

III-5.2.11.3 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 8-GeV Line enclosures involving this hazard implements the controls specified in the common Risk Matrix table. No unique controls are in use.

III-5.3. Maximum Credible Incident Scenario(s) for the Accelerator Specific Hazard(s)

III-5.3.1 Definition of Maximum Credible Incident for the “8-GeV Line” Segment.

This section of the “8-GeV Line” SAD evaluates the maximum credible incident (MCI) scenario that could happen in the 8-GeV Line, which is the Main Accelerator Segment that connects the Booster to the MI/RR/BNB. Consideration and analysis of this MCI is focused on an onsite facility worker, onsite co-located worker, and a maximally exposed off-site individual (MOI).

III-5.3.1.1 Radiological Hazard

The 8-GeV Line is designed to transport only 8-GeV protons from the Booster accelerator for injection into either the BNB beamline, the Main Injector or Recycler rings. It is comprised primarily of combined function (both bend and focus) permanent magnets (not electro-magnets). It also employs controllable electromagnets for local beam position adjustments and beam focusing.

The 8-GeV Line segment is 630 meters in length and extends from the interlocked gate at Cell 810 to MI-10 Main Injector accelerator enclosure. There it has two bifurcation nodes. The first node allows from beam to be sent to the Recycler storage ring injection Lamberton or straight ahead toward the second bifurcation node. At this point beam can be bent horizontally to the right toward the BNB beam line segment or straight ahead to the Main Injector Injection Lamberton magnet.

There are many devices that focus & steer the beam pulses to ensure that a maximum number of protons reach the intended destination. Misdirection of this beam so that it impacts surrounding structures inside the 8-GeV Line enclosure can occur from a single failure of many of these devices or erroneous operation of them. An MCI would be one that produces the greatest prompt ionizing radiation from the beam loss.

There are an extremely large number of individual beam loss events that can be imagined. The energy of the beam in 8-GeV Line is always 8-GeV. The 8-GeV line receives beam form the Booster accelerator at a maximum rate of 15Hz and a maximum intensity of 7E12 protons per pulse. Using these parameters and 100% transmission efficiency to the point of beam loss gives us:

15 [pulses/second] * 7 $x10^{12}$ [protons/pulse] * 3600 [seconds/hour] = 3.78 $x10^{17}$ [protons/hour]

This analysis concludes that the maximum credible incident for the Fermilab MI-8 beam line is a beam with an intensity of 3.78 $x10^{17}$ protons per hour at an energy of 8 GeV persistently incident on a beamline component.

Event Causes:

1. The Booster accelerator is delivering beam with intensity of 7E12 protons per pulse.
2. Beam mis-steered with an energy of 8 GeV continually via any of the following events:
    a. Failed component (magnet/power supply/mechanical part/beam diagnostic tool/etc.).
    b. Operator error.
    c. Autotune error.

Assuming no shielding is present, this incident would result in a dose to any individual higher than 8 $x10^{6}$ rem/hr.

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.
- 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-5.4 of the 8-GeV Line section of the SAD. An analysis of the MCI condition in the beamline concludes that 18 e.f.d. is needed to protect a MOI on the berm from receiving a total dose greater than 500 mrem. As stated in section III-5.1.3 of the SAD there is presently a minimum of 24.5 e.f.d. shielding the 8-GeV Line enclosure.

The entirety of the 8-GeV Line is inside the non-public boundary of Fermilab. Consequently, members of the public are neither invited nor expected near the 8-GeV Line. The closest a member of the public can get to the 8-GeV Line is over 400 feet away in the west Wilson Hall parking lot. Conservatively, radioactive doses fall off like 1/r, where r is the distance to the mitigated source. Consequently, no member of the public is at risk of receiving a dose more than 100 mrem/hour in the event of an MCI in the 8-GeV Line enclosure.

III-5.4. Summary of Credited Controls

This section describes the credited controls that are required to reduce the risk associated with the maximum credible incident to a negligible consequence level.

III-5.4.1 Credited Engineering Controls

The purpose of this section is to provide the information necessary to understand the engineering controls that are used to prevent or mitigate the consequences of the maximum credible incident. Engineering controls can be classified as passive or active. This section presents a separate discussion of the engineering controls that fall under each classification.

III-5.4.1.1 Passive Credited Engineering Controls

Passive controls are elements of 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 8-GeV Line segment enclosures are designed and constructed as a permanent concrete and earth-covered radiation shield that uses a combination of permanent shielding and penetration shielding to protect personnel from radiological exposure due to the MCI.

III-5.4.1.1.1 Permanent Shielding Including Labyrinths

The permanent shielding encompasses the structural elements surrounding the beamline components.

This includes the walls, ceilings, doors, berms, labyrinths for both access and penetrations and shielding blocks. Topographical surveys of the 8-GeV Line segment enclosures and berm conclude that there is a minimum of 21.6 Equivalent Feet of dirt (e.f.d.) shielding between the interior surface of the enclosure walls and the surface of the berm.

The efficacy of this permanent shielding has been quantitatively analyzed to simulate the MCI as defined in Section III-5.3.1.1. This analysis finds that, under the conditions present in the MCI, a peak dose rate of 500mrem/hr would occur on the berm on the 8-GeV Line segment, which is a non-public area of the campus. In this condition, a MOI would receive a dose of 500 mrem in one hour if there were 17.9 e.f.d.

The credited control for the permanent shielding is thus defined as 17.9 e.f.d. shielding between the interior surface of the enclosure walls and the surface of the berm. As mentioned above, the 8-GeV Line enclosures have minimum of 24.5 e.f.d. The credited shielding present on the berm of the 8-GeV Line enclosures is therefore adequate to protect the MOI from receiving a dose of 500 mrem of dose in an hour under an MCI condition.

III-5.4.1.1.2 Penetration Shielding

The beamline has several utility penetrations at the MI-8 service building routing between the exclusion areas and occupied areas that were analyzed for required shielding. These penetrations were designed to eliminate the need for additional penetration shielding. In summary, the prompt dose rates at the exits of the penetrations are within the limits established in the FRCM.

Additionally, the MI8-Line has sight riser penetrations that are used for survey and alignment to connect the survey network in the tunnel to the outside. These penetrations have been analyzed and filled with steel plugs (2600 lbs.) and or polyethylene beads to provide the required shielding to keep the MCI below the 500 mrem limit. A complete inventory of the sight riser penetrations can be found in Table 3 below.

Table 3: Inventory of sight-riser penetrations along the 8-GeV Line beam enclosure

Location	Shielding Type	Quantity	Purpose	Preferred Method of Configuration (if specified)	Comments
Cell 812	Steel and Poly	1	Site Riser penetration		A solid steel cylinder 11 5/8" dia x 62 5/8" long followed by a poly bead plug 11" dia. x 30" long
Cell 816	Steel and Poly	1	Site Riser penetration		a solid steel cylinder 11 5/8" dia x 62 5/8" long followed by a poly bead plug 11" dia. x 30" long
Cell 831	Poly	1	Site Riser penetration		Completely filled with loose poly beads.
Cell 833.5	Steel and Poly	1	Site Riser penetration		a solid steel cylinder 11 5/8" dia x 62 5/8" long followed by a poly bead plug 11" dia. x 30" long

III-5.4.1.2 Active Credited Engineering Controls

Active engineered controls are systems designed to reduce the risks from the MCI to an acceptable level. These are automatic systems that limit operations, shutdown operations, or provide warning alarms when operating parameters are exceeded. The active controls in place for MI-8 Line segment operations are discussed below.

III-5.4.1.2.1 Radiation Safety Interlock System

The 8 GeV Line enclosure is part of the Booster Accelerator Radiation Safety Interlock System. The characteristics of the system are described in Chapter I of the Fermilab SAD.

Prior to accelerator operations, a Search and Secure is performed to establish the interlock system for the Exclusion Area(s) (i.e. beamline tunnels). This Search and Secure, which is completed by specially trained

AD accelerator operators, ensures no personnel are remaining within the Exclusion Area(s) during accelerator operations.

There are interlocked gates at each end of the enclosure, three interlocked exit labyrinths, and an interlocked gate at the MI-8 Service Building access labyrinth. The interlock system inhibits transport of beam beyond the Linac extraction point to Booster except when the 8 GeV Line enclosure is properly secured and locked.

The radiation safety interlock system inhibits beam by controlling redundant critical devices. In this case, the B:LAM power supply feeds the extraction Lambertson string and the B:MH1 horizontal down bend power supply located at the end of the Linac enclosure. In the event of a critical device failure, the system has a failure mode function that will reach back and inhibit beam to the Linac, and thus eliminate the possibility of beam reaching the 8 GeV Line enclosure.

The radiation safety interlock systems, including requirements for hardware and system testing, inventory of interlock keys, search and secure procedures for the beamline enclosure, controlled access procedures, personnel training requirements, and procedures for maintenance of interlock systems, are in conformance with the requirements stated in the FRCM.

Required radiation monitors specified in the listed Shielding Assessments, or as required by the assigned Radiation Safety Officer (RSO), must be interlocked to the RSIS.

The Radiation Safety Interlock System (RSIS) must prevent entry into the following Exclusion Area(s) during appliable beam operation:

- MI-8
- MI-10
- Muon Campus Transport Mid
- MI-12A

Required components of the RSIS shall be specified in the 8 GeV Beamline's Operation Authorization Document.

The following components of the Radiation Safety Interlock System (RSIS) shall be in place, with no known loss of safety function, during applicable beam operations.

III-5.4.2 Credited Administrative Controls

All 8-GeV Line segment accelerator 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. The administrative procedures and programs considered necessary to ensure safe accelerator operations are discussed below.

III-5.4.2.1 Operation Authorization Document

For beam to be transported to the 8-GeV Line enclosures, an approved Beam Permit and Running Conditions document is required. The Beam Permit specifies beam power limits as determined and approved by the AD Associate Laboratory Director, in consultation with the ES&H Radiation Physics Operations Department Head, assigned RSO, AD Operations Department Head, and AD Main Injector Department Head. The Running Condition for the MI/RR describes the operating configuration as reviewed by the assigned RSO, AD Operations Department Head, and AD Main Injector Department Head and as approved by the AD Associate Laboratory Director

III-5.4.2.2 Staffing

The MCR must be appropriately staffed according to ensure operations within bounding conditions specified in Operation Authorization Document, and to disable beam operation to the 8 GeV line and initiate an immediate response in the event of a determined ASE violation.

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-5.4.2.3 Accelerator Operating Parameters

To ensure operations within bounding conditions used in the MCI analysis, the following intensity shall not be exceeded: 3.78 x10^{17} protons per hour.

III-5.5. Defense-in-Depth Controls

The Fermilab 8-GeV Line has additional controls in place that reduce the risk associated with the maximum credible incident, but that are not required to mitigate it. These controls are considered defense-in-depth, and they are defined in the following section.

III-5.5.1 Defense-in-Depth Engineering Controls

III-5.5.1.1 Passive Defense-in-Depth Engineering Controls

III-5.5.1.1.1 Permanent Shielding

Additional shielding is present over the 8 GeV Beamline. The 8-GeV tunnel is covered by at least 24.5 equivalent feet of dirt (e.f.d.). 17.9 e.f.d. are required to protect a laboratory worker in the event of the MCI. Thus the 8-GeV Line enclosures have 6.5 e.f.d. of “defense in depth” earth shielding.

III-5.5.1.2 Active Defense-in-Depth Engineering Controls

III-5.5.1.2.1 Interlocked Radiation Monitors

Required radiation monitors specified in the listed Shielding Assessments, or as required by the assigned Radiation Safety Officer (RSO), must be interlocked to the RSIS and serve to reduce the possibility of radiological exposure to working personnel.

Table 4: Defense-in-depth radiation monitors

Type	Location
Chipmunk	Transport Mid/DS Gate
Chipmunk	Transport Mid/US Gate
Chipmunk	MI-8 Service Building Labyrinth Gate

III-5.5.1.2.2 Machine Protection Controls

Accelerator devices, such as loss monitors and power supplies, are connected to a beam permit system to ensure excessive beam loss does not occur. This beam permit system has dozens of available inputs to the system. The beam permit loop has been designed in a fail-safe manner and can remove the beam from the accelerator and moving it to the abort absorber in approximately 66 ms after detection of a fault in a system. The permit system also monitors the accelerator for potential problems before beam is injected and can detect a single lost pulse from booster limiting the total loss incident in the accelerator to a single Booster batch, defined in the MCI as 7E12 protons per pulse.

The machine protection system consists of the following controls:

- Passive control:
    - Destruction of the accelerator components from high intensity beam
        - Beam pipe is 0.065" stainless steel and will melt when exposed to 1MW particle beam. The vacuum will breach. The accelerator will be let up to atmosphere stopping the incident.
- Alarms and Limits
    - Displayed in the MCR for operators. Some alarms require acknowledgement.
- Orbit control and monitoring
    - Semi-automated tuning to keep the beam at desired positions. Some critical beam positions are connected to the permit system.
    - Reduces beam loss, tunnel activation, and aids ALARA.
- Accelerator Time-Line generator
    - Programmed timing for accelerator operations. Modules require approval prior to use.
- Beam Switch Sum Box
    - Allows or prevents beam from the Linac based on requests from the TLG, Status of beam switches, and status of the beam permit system from all machines involved in the operation.

- Beam transfer Permit system
  - Allows or inhibits beam transfers to accelerators. Beam present in an upstream machine will be sent to the Abort absorber.
- Vacuum Interlock System
  - Requires vacuum in the accelerator to be adequate to contain the beam. Will close vacuum valves and trip the permit system if the vacuum is poor.
- Power Supply Permits and Regulation
  - Requires critical power supplies to be on with some monitored for regulation. Will trip the permit system if not at the desired configuration.
- Beam Loss Monitor System
  - Provides information to operators to control of beam losses, aids in ALARA.
  - Used in conjunction with AI for pattern recognition to locate the source of a tuning problem or accelerator drift.
  - Allows for the prediction of tunnel activation for work planning and control.
  - Connected to the Beam Permit System.
  - Monitors integrated beam loss through a cycle and if above limit, will drop the beam permit after extraction.
  - Monitors instantaneous loss and if over the limit, will drop the beam permit immediately. Limits the accident incident to a tens of 15-Hz pulses (on the order of one second).

III-5.5.1.3 Defense-in-Depth Administrative Controls

III-5.5.1.3.1 Training

All personnel engaged in the commissioning, operation, and emergency management of the 8-GeV Line shall have at a minimum, Fermilab's Radiation Worker training current. Furthermore, personnel approved for access into the 8-GeV Line interlocked enclosures shall have Fermilab's Controlled Access training current as well.

Equipment specific to the operation of the 8-GeV Line shall be operated by or with the supervision of the corresponding expert, who ensures that the equipment is being used according to its specifications and unique safety measures.

Training in Fermilab's General or system specific Lock Out-Tag Out procedures shall be required to perform troubleshooting and maintenance as applicable.

III-5.5.1.3.2 Procedures

As applicable, either Fermilab's General Lock Out-Tag Out or Written Departmental Lock Out-Tag Out procedures shall be used. As per Fermilab's FESHM Chapter 2100 [3]**Error! Reference source not found.**, Written Departmental Safety procedures shall be reviewed and re-approved every twelve (12) months, at a minimum, or when the configuration of the equipment has been altered. Re-training for these procedures shall also be carried out every twelve (12) months to remain current.

III-5.6. Decommissioning

DOE Field Element Manager approval shall be obtained prior to the start of any decommissioning activities for 8 GeV Line.

III-5.7. Summary and Conclusion

Specific hazards associated with commissioning and operation of the 8 GeV beam line enclosure and experimental areas are identified and assessed in this Chapter of the Fermilab Safety Assessment Document. The designs, controls, and procedures to mitigate the 8 GeV beam line specific hazards are identified and described. In addition to these specific safety considerations, the 8 GeV beam line is subject to the global and more generic safety requirements, controls and procedures outlined in Section 1 of this Fermilab Safety Assessment Document.

The preceding discussion of the hazards presented by the 8 GeV beamline and experimental operations and the credited controls established to mitigate those hazards demonstrate that the beamline can be operated in a manner that will produce minimal risks to the health and safety of Fermilab workers, visiting scientists, and the public, as well as to the environment.

III-5.8. References

[1] 8 GeV Fixed Target Shielding Assessment, C. Moore, April 19, 2002. MiniBooNE-Era Doses for MI8 Labyrinths & Penetrations, B. Higgins, June 3, 2002. Safety Envelope for 8 GeV Line and MiniBooNE Operation, Michael A. Gerardi, December 4, 2009. 8GeV Line and MiniBooNE Nova-Era Operational Limits, Michael A. Gerardi, December 4, 2009.
[2] Fermilab Radiological Control Manual - The web link is: http://esh.fnal.gov/xms/FRCM
[3] Fermilab Environment Safety & Health Manual. - The web link is: http://esh.fnal.gov/xms/FESHM

III-5.9. 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-5.4 of this Chapter as well as SAD Chapter VII-A.1 *Accelerator Safety Envelope – Fermilab Main Accelerator*.