8-GEV LINE

SECTION III CHAPTER 05 OF THE FERMILAB SAD

Revision 1 August 3, 2023

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	1	August 3, 2023	• Update and structure change to be consistent with updated SAD layout and incorporating Risk Matrix and hazards discussion
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	Harge 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 purpose of the 8 GeV Line is to transport 8 GeV protons extracted from the Booster accelerator for injection into either the Main Injector (MI) Ring or for use within the Booster Neutrino experimental area.

III-5.1.2 Current Status

The 8 GeV Beamline enclosure 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.

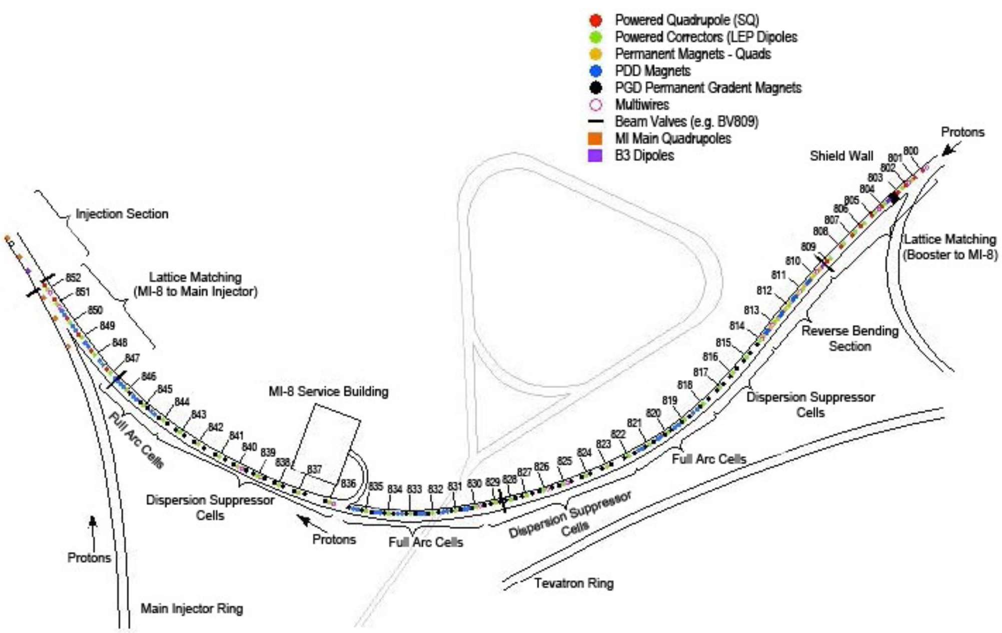

Figure 1. 8 GeV Line Plan View.

III-5.1.4 Location

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

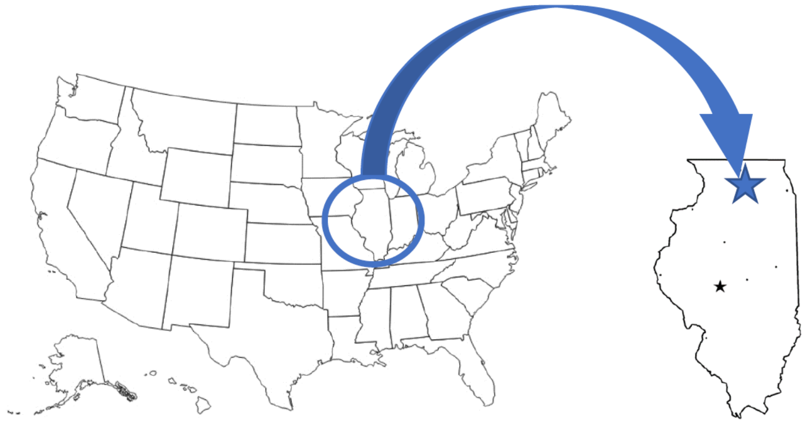

Figure 2. Regional view showing the location of the Fermilab site in Batavia, IL.

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

on the Fermilab site.

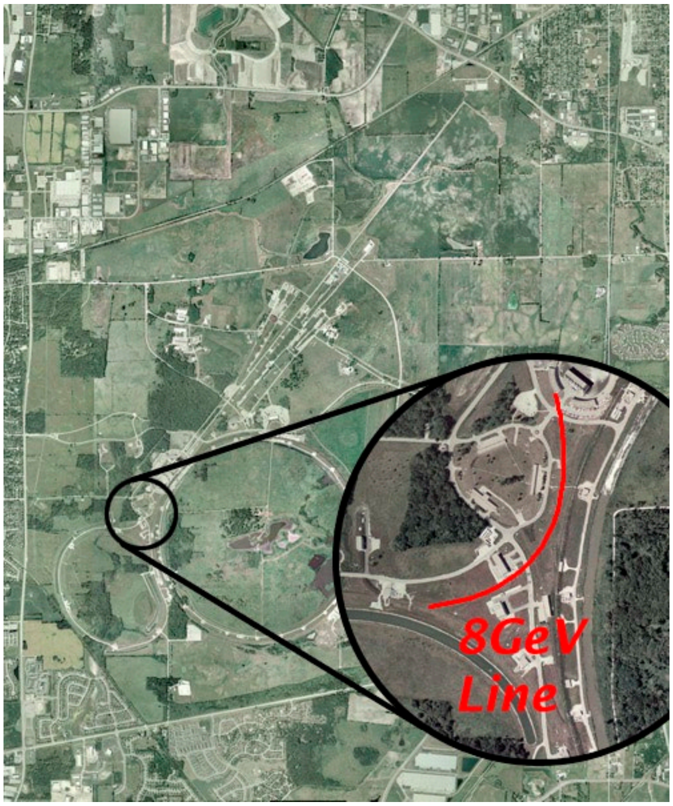

Figure 3. Aerial view of the Fermilab site, indicating the location of the 8 GeV Line.

III-5.1.5 Management Organization

The 8 GeV Beamline 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 the 8 GeV Beamline.

III-5.1.6 Operating Modes

The 8 GeV Beamline is capable of receiving 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 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 beamline transports the beam to location 850, the end of the 8 GeV Line, where the beam is either extracted to the Booster Neutrino area or injected into the Main Injector. Details of the Main Injector injection are discussed in the Main Injector chapter of this document and the details of Booster Neutrino area extraction are discussed in the Booster Neutrino area chapter of this document.

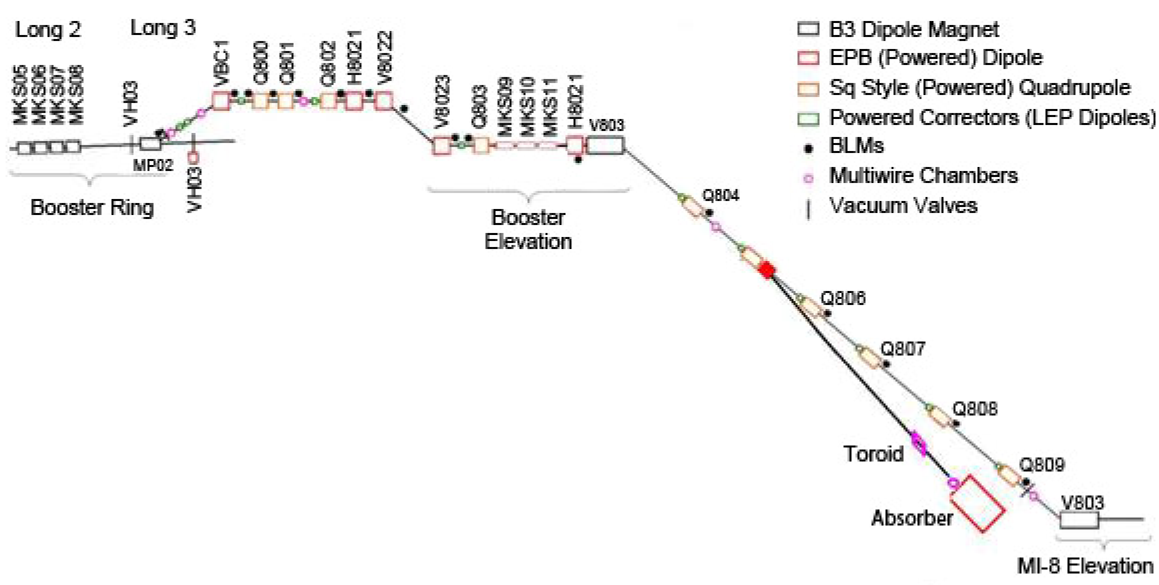

Figure 4. Vertical Profile of the Upstream 8 GeV Line..

III-5.1.7 Inventory of Hazards

The following table lists all of the identified hazards found in the 8 GeV Beamline enclosure and support buildings. Section III-5.10 *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, Oxygen Deficiency Hazards due to cryogenic systems within accelerator enclosures, and fluorinert byproducts due to use of fluorinert that is subject to particle beam have been identified as accelerator specific hazards, and as such their controls are identified as Credited Controls. The analysis of these hazards and their Credited Controls will be discussed within this SAD Chapter, and their Credited Controls summarized in the Accelerator Safety Envelope for the Fermilab Main Accelerator Accelerator-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 considered to be Standard Industrial Hazards (SIH), 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
☐	Cryogenic Liquids	☒	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 Beamline presents radiological hazards in the form of prompt and residual ionizing radiation from particle beams, residual radiation due to activation of beamline components, and environmental radioactivity in the form of soil and potential groundwater activation resulting from operating the beam transport system.

Detailed shielding assessments[2] addresses these hazards and provide a detailed analysis of the facility demonstrating the required shielding, controls and interlocks to comply with the Fermilab Radiological Control Manual (FRCM)[1].

The risks from the radiological hazards have been assessed, and the control measures in place reduce the baseline risk level from a R I to a R IV.

III-5.2.1.1 Prompt Ionizing Radiation

Prompt ionizing radiation 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).

The shielding provided by the enclosure and earthen overburden has been specifically and quantitatively analyzed for both normal and accidental loss conditions and documented in the 8 GeV Fixed Target Shielding Assessment and post assessment documents. These documents demonstrate that that facility can safely operate within the guidelines of the FRCM at a beam energy of 8 GeV and intensities up to 2.84 x 10^{17} protons per hour.

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.

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 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 1021 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 beamline are routinely sampled as part of the ESH Routine Radiological Monitoring Program.

III-5.2.1.4 Surface Water 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 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 1.18×10^{21} protons, after 10 years of operation, the ground water tritium concentration would be less than 3.7×10^{-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 beamline are routinely sampled as part of the ESH Routine Radiological Monitoring Program.

III-5.2.1.5 Radioactive Water (RAW) Systems

Hazard not applicable to the 8 GeV Beamline

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

Hazard not applicable to the 8 GeV Beamline

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 in the course of 8 GeV Beamline operations will be managed within the established Radiological Protection Program (RPP) and as prescribed in the Fermilab Radiological Control Manual (FRCM).

Radioactive waste is a standard radiological hazard that is managed within the established Radiological Protection Program (RPP) and as prescribed in the Fermilab Radiological Control Manual (FRCM). Waste minimization is an objective of the equipment design and operational procedures. Although production of radioactive material is not an operational function of the 8 GeV Beamline, 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.

III-5.2.1.10 Contamination

Activated dust and debris within the 8 GeV Beamline enclosure results in spreadable material. This hazard is controlled using 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

Hazard not applicable to the 8 GeV Beamline

III-5.2.1.13 Nuclear Material

Hazard not applicable to the 8 GeV Beamline

III-5.2.1.14 Radiation Generating Devices (RGDs)

Hazard not applicable to the 8 GeV Beamline

III-5.2.1.15 Non-Ionizing Radiation Hazards

Hazard not applicable to the 8 GeV Beamline

III-5.2.2 Toxic Materials

III-5.2.2.1 Lead

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-5.2.2.2 Beryllium

Hazard not applicable to the 8 GeV Beamline

III-5.2.2.3 Fluorinert & Its Byproducts

Hazard not applicable to the 8 GeV Beamline

III-5.2.2.4 Liquid Scintillator Oil

Hazard not applicable to the 8 GeV Beamline

III-5.2.2.5 Pseudocumene

Hazard not applicable to the 8 GeV Beamline

III-5.2.2.6 Ammonia

Hazard not applicable to the 8 GeV Beamline

III-5.2.2.7 Nanoparticle Exposures

Hazard not applicable to the 8 GeV Beamline

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

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-5.2.4 Electrical Energy

III-5.2.4.1 Stored Energy Exposure

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

III-5.2.4.2 High Voltage Exposure

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

III-5.2.4.3 Low Voltage, High Current Exposure

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

III-5.2.5 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 8 GeV Beamline involving this hazard implements the controls specified in the common Risk Matrix table. No unique controls are in use.

III-5.2.5.2 Hot Work

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

III-5.2.5.3 Cryogenics

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-5.2.6 Kinetic Energy

III-5.2.6.1 Power Tools

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-5.2.6.2 Pumps and Motors

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-5.2.6.3 Motion Tables

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-5.2.6.4 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

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-5.2.7.2 Compressed Gasses

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-5.2.7.3 Vacuum/Pressure Vessels/Piping

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

III-5.2.7.4 Vacuum Pumps

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

III-5.2.7.5 Material Handling

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

III-5.2.8 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 8 GeV Beamline involving this hazard implements the controls specified in the common Risk Matrix table. No unique controls are in use.

III-5.2.9.2 Noise

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-5.2.9.3 Silica

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-5.2.9.4 Ergonomics

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-5.2.9.5 Asbestos

Hazard not applicable to the 8 GeV Beamline

III-5.2.9.6 Working at Heights

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

III-5.2.10 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 8 GeV Beamline involving this hazard implements the controls specified in the common Risk Matrix table. No unique controls are in use.

III-5.2.11 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 8 GeV Beamline involving this hazard implements the controls specified in the common Risk Matrix table. No unique controls are in use.

III-5.2.11.2 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 8 GeV Beamline involving this hazard implements the controls specified in the common Risk Matrix table. No unique controls are in use.

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

III-5.3. Summary of Hazards to Members of the Public

The 8 GeV Beamline enclosure is located beyond the public access gate. The hazard to the public are limited to ground water activation and surface water activation as water can travel out of this area.

III-5.4. Summary of Credited Controls

III-5.4.1 Passive Credited Controls

Passive controls are elements that are part of the physical design of the facility that require no action to function properly. These are fixed elements of the beamline that take direct human intervention to remove. The 8 GeV Line enclosure is a passive control designed and constructed as a permanent concrete and earth-covered radiation shield to protect personnel from radiological exposure during beam operations. Other passive controls within this design are discussed.

III-5.4.1.1.1 Permanent Shielding Including Labyrinths

The permanent shielding encompasses the structural elements surrounding the beamline components. The concrete structure is contiguous with the Booster and Main Injector enclosures. It includes three personnel exit labyrinths, one major equipment and personnel access labyrinth at the MI-8 Service Building, utility penetrations, and earthen berms and overburden.

The permanent shielding for the enclosure is documented in the 8 GeV Fixed Target Shielding Assessment and post assessment documents. It consists of sufficient earth overburden such that unacceptable levels of prompt radiation cannot occur under the assessed beam conditions.

III-5.4.1.1.2 Movable Shielding

Shielding walls are used in the enclosure during access to reduce worker exposure to residual radiation.

III-5.4.1.1.3 Penetration Shielding

The beamline has several utility penetrations routing between the exclusion areas and occupied areas which 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.

III-5.4.1.2 Fencing

Required fencing specified in the listed Shielding Assessment will be installed in its proper configuration during applicable beam operations.

III-5.4.1.2.1 Radiation Area Fencing

No fencing is required for this area.

III-5.4.1.2.2 Controlled Area Fencing

No fencing is required for this area.

III-5.4.2 Active Engineered Credited Controls

Active engineered controls are systems designed to reduce the risks from accelerator operations to an acceptable level. These are automatic systems that limit operations, shutdown operations, or provide warning alarms when operating parameters are exceeded.

Based on the Nominal Operating Intensity of 2.84e17 protons/hr, analyzed in the following Shielding Assessments, the RSIS is established with interlocked barriers around the Exclusion Area, as well as inclusion of required interlocked radiation monitors.

III-5.4.2.1 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.

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.

Trained and qualified personnel from the AD Operations Department are required to search and secure the enclosure before permits from the radiation safety interlock system may be reestablished

following any personnel access to the enclosure, except under strictly specified controlled access conditions. 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.

Radiation Safety System – 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.

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

III-5.4.2.2 ODH Safety System

Hazard not applicable to the 8 GeV Beamline

III-5.4.3 Administrative Credited Controls

All 8 GeV beamline 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-5.4.3.1 Operation Authorization Document

An approved 8 GeV Beamline Beam Permit & Running Condition shall be in place during applicable beam operations

III-5.4.3.2 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 shift.

- At least one member of the AD Operations Department shall be present in the Main Control Room (MCR).

III-5.4.3.3 Accelerator Operating Parameters

The 8 GeV Beamline segment will be operated within the following parameters:

Mode	Intensity	Energy
Beam transport from Cell 803 to Cell 850	2.35e19 protons/hr	8 GeV

These parameters are further specified in the Operation Authorization Document.

8 GeV Beamline intensity is monitored via: B:BBM800

III-5.5. Defense-in-Depth Controls

Additional shielding is present over the 8 GeV Beamline.

III-5.6. 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.

III-5.7. Decommissioning

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

III-5.8. Summary and Conclusion

The 8 GeV beamline is assessed for a pulsed proton beam with a maximum kinetic energy of 8 GeV, with a beam intensity of 5.3 x 10^{12} protons per pulse, and a maximum spill rate of 15 Hz, which equates to an hourly intensity rate of 2.84 x 10^{17} protons/hour. The beamline is assessed for continuous operations at this intensity.

Accelerator operational approvals shall be obtained by following the AD Procedure ADAP-11-0001 Beam Permits, Run Conditions, and Startup administered by the AD ES&H Department and AD Head. Beam Permit and Run Condition documents shall identify the beam power and operating parameters allowed for the 8 GeV Line within the current Accelerator Safety Envelope. The Beam Permit specifies beam power limits as determined and approved by the AD Head in consultation with the AD ES&H Department Head, AD RSO, AD Operations Department Head, and AD MI Department Head. The Run Condition for the 8 GeV Line describes the operating configuration as reviewed by the AD RSO, AD Operations Department Head, and as approved by the AD Head.

III-5.9. References

[1] Fermilab Radiological Control Manual
[2] 8 GeV Fixed Target Shielding Assessment, C. Moore, page 1, 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.

III-5.10. 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*.