NEUTRINOS AT THE MAIN INJECTOR (NUMI) BEAMLINE

SECTION III CHAPTER 08 OF THE FERMILAB SAD

Revision 1 January 3, 2024

This Chapter of the Fermilab Safety Assessment Document (SAD) contains a summary of the results of the Safety Analysis for the NuMI of the Fermi Main Accelerator that are pertinent to understanding the risks to the workers, the public, and the environment due to its operation.

SAD Chapter Review

This Section III, Chapter 8 of the Fermi National Accelerator Laboratory (Fermilab) Safety Assessment Document (SAD), *Neutrinos at the Main Injector (NuMI) Beamline*, was prepared and reviewed by the staff of the Accelerator Directorate, Beams Division, External Beams Delivery Department in conjunction with the Environment, Safety & Health Division (ESH) Accelerator Safety Department.

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

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Accelerator Safety Department Head

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Revision History

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

Author	Rev. No.	Date	Description of Change
Tom Kobilarcik Phil Schlabach	1	January 2, 2024	• Update to align with updated SAD layout • Implement Risk Matrix tables and hazard discussion • MCI methodology
John E. Anderson Jr. Craig Moore	0	June 3, 2013	Initial release of the NuMI Beam Line Chapter for the Fermi National Accelerator Laboratory Safety Assessment Document (SAD)

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Acronyms and Abbreviations

ACGIH	American Conference of Governmental Industrial Hygienists
ACNET	Accelerator Control Network System
AD	Accelerator Directorate
AHJ	Authority Having Jurisdiction
ALARA	As Low As Reasonably Achievable
ANSI	American National Standards Institute
APS-TD	Applied Physics and Superconducting Technology Directorate
ARA	Airborne Radioactivity Area
ASE	Accelerator Safety Envelope
ASHRAE	American Society of Heating, Refrigerating and Air Conditioning Engineers
ASME	American Society of Mechanical Engineers
ASO	Accelerator Safety Order, referring to DOE O 420.2D *Safety of Accelerators*
^{7}Be	Beryllium-7
BLM	Beam Loss Monitor
BNB	Booster Neutrino Beam
BPM	Beam Position Monitor
BY	Boneyard
CA	Controlled Area
CA	Contamination Area
CAS	Contractor Assurance System
CC	Credited Control
CCL	Coupled Cavity Linac
CDC	Critical Device Controller
CERN	European Organization for Nuclear Research
CFM	Cubic Feet per Minute
CFR	Code of Federal Regulations (United States)
Ci	Curie
CLW	Co-Located Worker (the worker in the vicinity of the work but not actively participating)
cm	centimeter
CPB	Cryogenics Plant Building
CSO	Chief Safety Officer
CUB	Central Utility Building
CW	Continuous Wave
CX	Categorically Excluded
D&D	Decontamination and Decommissioning
DA	Diagnostic Absorber
DAE	Department of Atomic Energy India

DCS	Derived Concentration Standard
DocDB	Document Database
DOE	Department of Energy
DOT	Department of Transportation
DR	Delivery Ring
DSO	Division Safety Officer
DSS	Division Safety Specialist
DTL	Drift Tube Linac
DUNE	Deep Underground Neutrino Experiment
EA	Environmental Assessment
EA	Exclusion Area
EAV	Exhaust Air Vent
EENF	Environmental Evaluation Notification Form
EMS	Environmental Management System
EOC	Emergency Operations Center
EPA	Environmental Protection Agency
ES&H	Environment, Safety and Health
Fermilab	Fermi National Accelerator Laboratory, see also FNAL
FESHCom	Fermilab ES&H Committee
FESHM	Fermilab Environment, Safety and Health Manual
FHS	Fire Hazard Subcommittee
FIRUS	Fire Incident Reporting Utility System
FNAL	Fermi National Accelerator Laboratory, see also Fermilab
FODO	Focus-Defocus
FONSI	Finding of No Significant Impact
FQAM	Fermilab Quality Assurance Manual
FRA	Fermi Research Alliance
FRCM	Fermilab Radiological Control Manual
FSO	Fermilab Site Office
FW	Facility Worker (the worker actively performing the work)
GERT	General Employee Radiation Training
GeV	Giga-electron Volt
^3H	Tritium
HA	Hazard Analysis
HAR	Hazard Analysis Report
HCA	High Contamination Area
HCTT	Hazard Control Technology Team
HEP	High Energy Physics
HFD	Hold for Decay

HLCF	High Level Calibration Facility
HPR	Highly Protected Risk
Hr	Hour
HRA	High Radiation Area
HSSD	High Sensitivity Air Sampling Detection
HVAC	Heating, Ventilation, and Air Conditioning
HWSF	Hazardous Waste Storage Facility
Hz	Hertz
IB	Industrial Building
IBC	International Building Code
ICW	Industrial Cooling Water
IEPA	Illinois Environmental Protection Agency
IEEE	Institute of Electrical and Electronics Engineers
INFN	Istituto Nazionale di Fisica Nucleare
IMPACT	Integrated Management Planning and Control Tool
IPCB	Illinois Pollution Control Board
IQA	Integrated Quality Assurance
ISD	Infrastructure Services Division
ISM	Integrated Safety Management
ITNA	Individual Training Needs Assessment
KeV	kilo-electron volt
kg	kilo-grams
kW	kilo-watt
LBNF	Long Baseline Neutrino Facility
LCW	Low Conductivity Water
LHC	Large Hadron Collider
LLCF	Low Level Calibration Facility
LLWCP	Low Level Waste Certification Program
LLWHF	Low Level Waste Handling Facility
LOTO	Lockout/Tagout
LPM	Laser Profile Monitor
LSND	Liquid Scintillator Neutrino Detector
LSO	Laser Safety Officer
m	meter
mA	milli-amp
MABAS	Mutual Aid Box Alarm System
MARS	Monte Carlo Shielding Computer Code
MC	Meson Center
MC&A	Materials Control and Accountability

MCR	Main Control Room
MEBT	Medium Energy Beam Transport
MEI	Maximally Exposed Individual
MeV	Mega-electron volt
MI	Main Injector
MINOS	Main Injector Neutrino Oscillation Search
MMR	Material Move Request
MOI	Maximally-Exposed Offsite Individual *(Note: due to the Fermilab Batavia Site being open to the public, the location of the MOI is taken to be the location closest to the accelerator that is accessible to members of the public.)*
MP	Meson Polarized
mrad	milli-radian
mrem	milli-rem
mrem/hr	milli-rem per hour
MT	Meson Test
MTA	400 MeV Test Area
MTF	Magnet Test Facility
^{22}Na	Sodium-22
NC	Neutrino Center
NE	Neutrino East
NEC	National Electrical Code
NEPA	National Environmental Policy Act
NESHAPS	National Emissions Standards for Hazardous Air Pollutants
NFPA	National Fire Protection Association
NM	Neutrino Muon
NMR	Nuclear Material Representative
NOvA	Neutrino Off-axis Electron Neutrino (ve) Appearance
NPH	Natural Phenomena Hazard
NRTL	Nationally Recognized Testing Laboratory
NIF	Neutron Irradiation Facility
NTSB	Neutrino Target Service Building, see also TSB
NuMI	Neutrinos at the Main Injector
NW	Neutrino West
ODH	Oxygen Deficiency Hazard
ORC	Operational Readiness Clearance
OSHA	Occupational Safety and Health Administration
pCi	pico-Curie
pCi/mL	pico-Curie per milliliter
PE	Professional Engineer

PIN	Personal Identification Number
PIP	Proton Improvement Plan
PIP-II	Proton Improvement Plan - II
PHAR	Preliminary Hazards Analysis Report
PPD	Particle Physics Directorate
PPE	Personnel Protective Equipment
QA	Quality Assurance
QAM	Quality Assurance Manual
RA	Radiation Area
RAF	Radionuclide Analysis Facility
RAW	Radioactive Water
RCT	Radiological Control Technician
RF	Radio-Frequency
RFQ	Radio-Frequency Quadrupole
RIL	RFQ Injector Line
RMA	Radioactive Material Area
RMS	Root Mean Square
RPCF	Radiation Physics Calibration Facility
RPE	Radiation Physics Engineering Department
RPO	Radiation Physics Operations Department
RRM	Repetition Rate Monitor
RSI	Reviewed Safety Issue
RSIS	Radiation Safety Interlock System
RSO	Radiation Safety Officer
RWP	Radiological Work Permit
SA	Shielding Assessment
SAA	Satellite Accumulation Areas
SAD	Safety Assessment Document
SCF	Standard Cubic Feet
SCFH	Standard Cubic Feet per Hour
SEWS	Site-Wide Emergency Warning System
SNS	Spallation Neutron Source
SR	Survey Riser
SRF	Superconducting Radio-Frequency
SRSO	Senior Radiation Safety Officer
SSB	Switchyard Service Building
SSP	Site Security Plan
SWIC	Segmented Wire Ionization Chambers
TLM	Total Loss Monitor

TLVs	Threshold Limit Values
TPC	Time Projection Chamber
TPES	Target Pile Evaporator Stack
TPL	Tagged Photon Lab
TSB	Target Service Building, see also NTSB
TSCA	Toxic Substances Control Act
TSW	Technical Scope of Work
T&I	Test and Instrumentation
UPB	Utility Plant Building
UPS	Uninterruptible Power Supply
USI	Unreviewed Safety Issue
VCTF	Vertical Cavity Test Facility
VHRA	Very High Radiation Area
VMS	Village Machine Shop
VMTF	Vertical Magnet Test Facility
VTS	Vertical Test Stand
WSHP	Worker Safety and Health Program
μs	micro-second

III-8. Neutrinos at the Main Injector (NuMI) Beamline

III-8.1. Introduction

This Section III, Chapter 8 of the Fermi National Accelerator Laboratory (Fermilab) Safety Assessment Document (SAD) covers the NuMI segment of the Fermilab Main Accelerator. For purposes of this document this chapter covers the section of beamline from the exit of the Main Injector tunnel at the upstream end of the carrier pipe to the exit of the absorber. This includes the 4 muon alcoves and the radiation area at outside the absorber exit. The rest of the area is covered in the MINOs Underground Segment. We are tenants in both the Main Injector and the Main Injector Neutrino Oscillation Search (MINOS) service buildings.

III-8.1.1 Purpose/Function

The purpose of the NuMI Beam Line is to produce an intense beam of neutrinos for physics experiments designed to detect and study neutrino oscillations. The NuMI Beam Line extracts a 120 Giga-electron volt (GeV) beam of protons from the Main Injector (MI) and directs a high intensity beam of neutrinos to near-detectors at Fermilab and far-detectors at Ash River, Minnesota

III-8.1.2 Current Status

The NuMI segment of the Main Injector is currently operational.

III-8.1.3 Description

The NuMI Beam Line receives an extracted beam of 120 GeV protons from the MI. The extracted beam strikes a target to produce short-lived hadrons. Neutrino horns focus the hadrons before the hadrons enter the NuMI decay pipe. A fraction of the hadrons in the decay pipe decay to neutrinos and muons as they travel through the decay pipe. At the end of the decay pipe, the remaining hadrons are absorbed in the hadron absorber.

The native rock in place downstream of the hadron absorber absorbs the muons produced with the neutrinos in the decay region. Muon monitors along the beam line monitor the direction of the beam by measuring muon distributions. Figure 1 depicts the process for production of the neutrino beam.

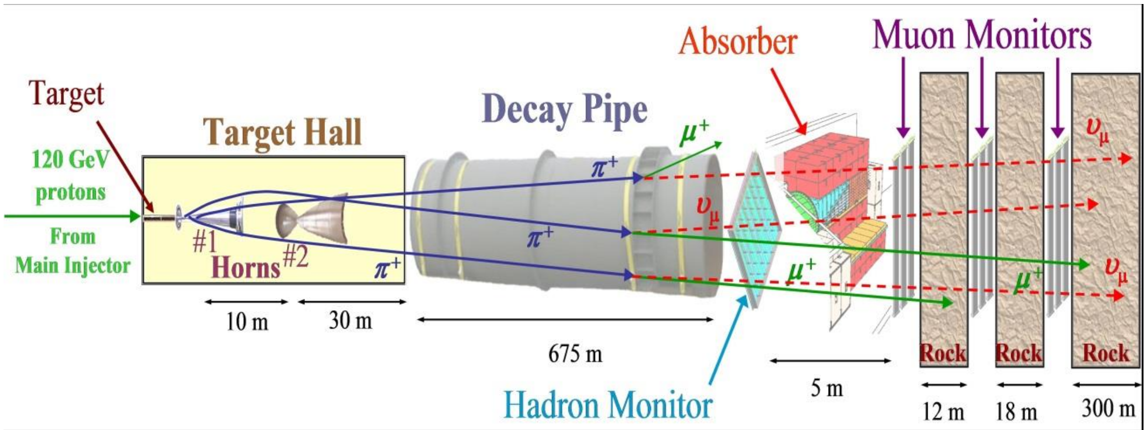

Figure 1. Process for Production of the NuMI Neutrino Beam.

Research and support facilities constructed for the NuMI Project also include access shafts, support rooms (Figure 2), and a bypass tunnel for the rock region downstream of the absorber. The main components of the NuMI Beam Line include:

- An underground lined Carrier Tunnel starting at the NuMI stub in the MI;
- An underground unlined Carrier Tunnel;
- Underground Pre-Target/Target enclosure;
- An underground Decay Tunnel;
- An underground Hadron Absorber Enclosure and Access Tunnel with Muon Alcoves; and
- Surface MI-65 and MINOS Service Buildings

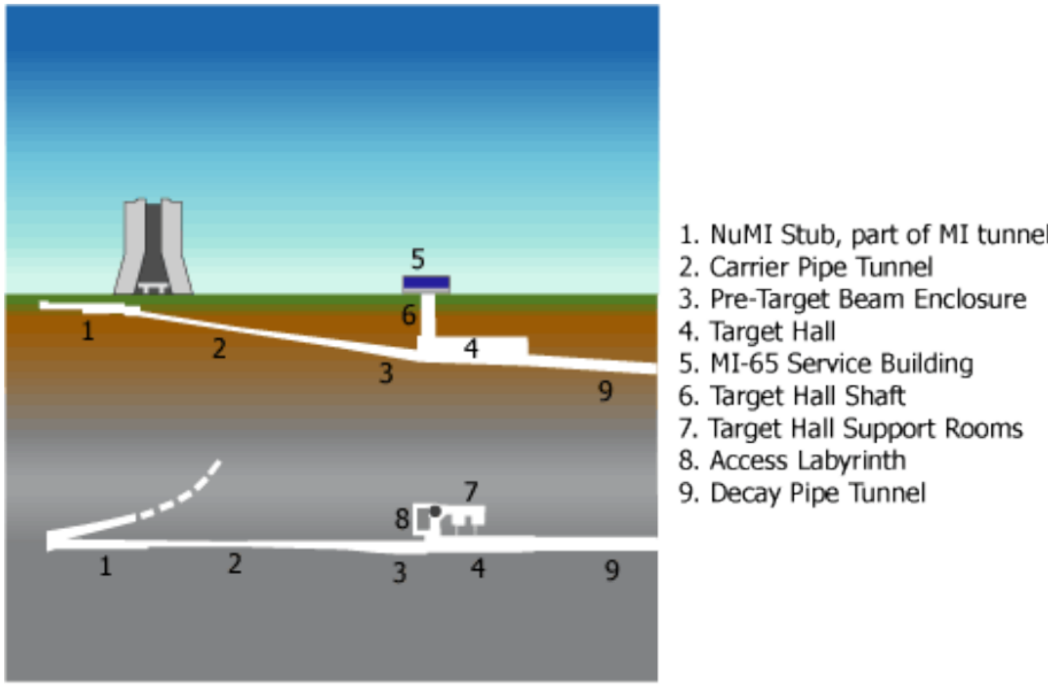

Figure 2. Major Elements of the NuMI Bream Line.

The NuMI Beam Line instrumentation assures that the beam is on target and directed to the near and far detectors by maintaining beam losses to a minimum level. This outcome is accomplished through the use of position information to assure that the beam is in the center of its vacuum chamber with profiles to allow unexpected beam tails and halo to be observed. Sensitive loss measurements allow beam problems to be immediately addressed, and intensity measurements monitor for large beam losses.

The NuMI Profile Monitors are secondary emission monitors designed to place minimal material in the beam. Toroids or beam current transformers are used in the NuMI Beam Line for intensity measurements. Total and local Loss Monitors (TLM and BLM) used in the NuMI Beam Line provide continuous coverage from the NuMI extraction enclosure through the final targeting elements.

III-8.1.4 Location

The NuMI segment of the Main Injector is located on the Fermilab site in Batavia, IL (Figure 3).

Figure 3. Regional view showing the location of the Fermilab site in Batavia, IL.

The NuMI beamline is located between the MI Injector and the near detector halls in the MINOS cavern on the Fermilab site (Figure 4).

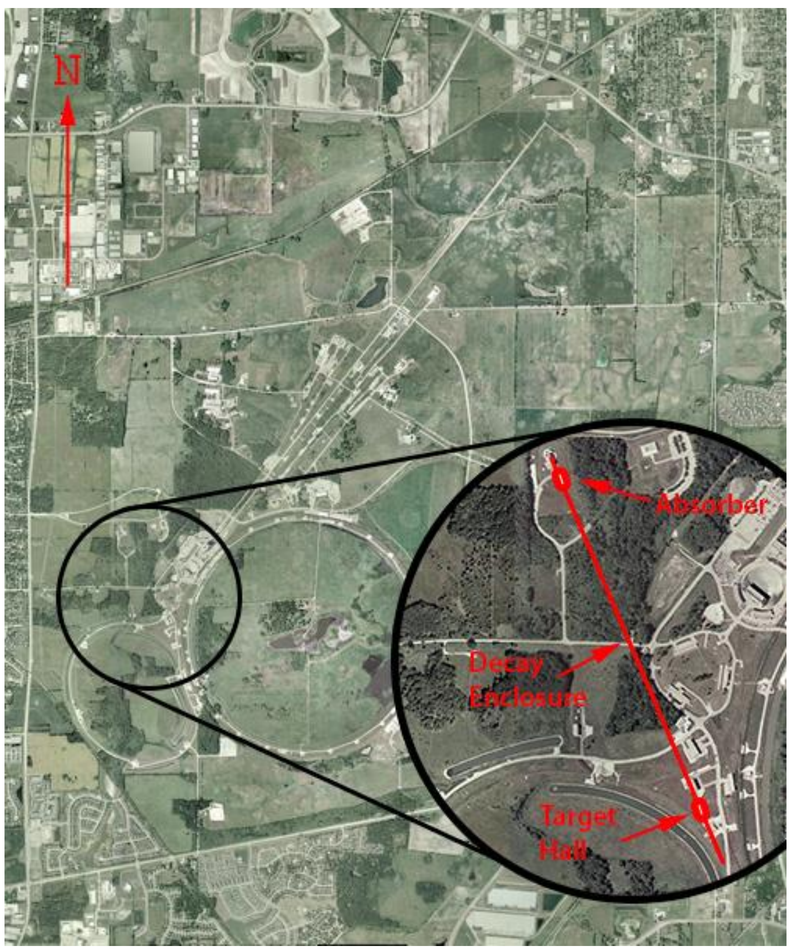

Figure 4. Aerial view of the Fermilab site, indicating the location of the NuMI beamline.

III-8.1.5 Management Organization

The NUMI Area is Managed by Accelerator Directorate, Beams Division, External Beam Delivery Department. This chapter covers the section from the exit of the Main Injector tunnel to the exit of the absorber. We are tenants in both the Main Injector and the MINOS service buildings.

III-8.1.6 Operating Modes

The NuMI Beam Line transports 120 GeV MI protons at a maximum intensity of 60×10^{12} protons every 1.067 seconds. This transport rate amounts to 2.02×10^{17} protons/hr. NuMI has two operating modes: "High Energy Physics" and "Horn/Target Scan."

III-8.1.7 Inventory of Hazards

The following table lists all of the identified hazards found in the NuMI beamline enclosure and support buildings. Section III-8.9 *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-8.2 *Safety Assessment.*

Prompt ionizing has been identified as an accelerator specific hazard, and as such 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 Main Injector. Accelerator specific controls are identified as **purple/bold** throughout this Chapter.

All other hazards present in the NuMI 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 Non-Accelerator-Specific Hazards (NASH), and their analysis will be summarized in this SAD Chapter.

Table 1. Hazard Inventory for NuMI beamline.

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

III-8.2. Safety Assessment

All hazards for the NuMI beamline segment of the Main Accelerator complex are summarized in this section, with additional details of the analyses for accelerator specific hazards. The unique beam line specific hazards for the NuMI area are analyzed in this section. The radiological hazards include ionizing radiation, residual activation, groundwater and surface water activation, air activation, and radioactive waste. In addition to the radiological hazards, the NuMI Beam Line has a unique electrical hazard, life safety emergency egress, and flooding hazards that are addressed.

III-8.2.1 Radiological Hazards

The NuMI beamline presents radiological hazards in the form of prompt and residual ionizing radiation from particle beams, residual radiation due to activation of beam line components, and environmental radioactivity in the form of potential groundwater, surface water, and air activation resulting from the operation of the beam transport systems Soil interaction, radioactive waste, and contamination are also addressed.

III-8.2.1.1 Prompt Ionizing Radiation

Prompt ionizing radiation is the principal radiation hazard when beam is transported through the NuMI Beam Line. In order to protect workers and the general public, the enclosures and beam pipes are surrounded either by sufficient amounts of shielding (soil, concrete, or iron), and/or networks of interlocked detectors to keep any prompt radiation exposure within acceptable levels. Operation of the area conforms to the FRCM and to maintain exposures for operating personnel as-low-as-reasonably-achievable (ALARA).

This hazard has been evaluated via a Maximum Credible Incident (MCI) analysis that is described in Section III-8.3.1.1. 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-8.4. The conclusion of these analyses is that the mitigated dose level associated with prompt ionizing radiation due to beam loss is acceptable.

III-8.2.1.2 Residual Activation

The shielding assessment estimates residual activation of NuMI Beam Line components. The beam line is designed to keep residual dose rates in the primary beam region below 100 milli-rem per hour (mrem/hr) and below 30 mrem/hr in the Hadron Absorber Hall where personnel have access. Radiological surveys taken over the past six years of operation with 120 GeV protons show dose rates in the primary beamline region and in the accessible areas of the Hadron Absorber Hall of less than 15 mrem/hr.

The shielding assessment estimates residual activation of NuMI Target Chase components. The standard residual dose rate values quoted are for a 30-day irradiation and a 1 day cool down, designated (30d, 1d). Estimated values for (30d, 1d) at operations of 700-kilowatt (kW) beam power are 6 rem/hr for the Target, 400 rem/hr for Horn 1, and 33 rem/hr for Horn 2.

When the NuMI Beam Line is not in operation, the enclosure area will remain radioactive and access to these components will be tightly controlled with the level of control dependent on the level of residual radiation. The control measures include training and training verification, centralized access authorization, and key entry. Controls required for different levels of residual radiation are specified in the FRCM and are detailed in the Radiological Work Permit (RWP) for the work to be performed.

In most situations, general RWPs for accesses will suffice. A job-specific RWP and an as-low-as-reasonably-achievable (ALARA) plan will be required for work on any highly activated equipment with a potential individual exposure greater than 200 mrem or potential job exposure greater than 1000 person-mrem. These tasks will be supervised by members of the Environment, Safety, and Health (ES&H) Radiation Physics Operations Department under the direction of the Radiation Safety Officer (RSO).

III-8.2.1.3 Groundwater Activation

Operation of the NuMI Beam Line will activate water in the vicinity of the NuMI Beam Line tunnel. The majority of the activation occurs within a few meters of the beam line tunnel wall. Groundwater modeling of the subsurface hydrologic systems suggests that the NuMI tunnel functions as a well that captures nearby groundwater.

Water flowing into the NuMI tunnel is pumped to the surface from the sump at the base of the MINOS Access Shaft. The shielding assessment estimates that with 6×10^{20} protons on target each year, the ^{3}H (tritium) and ^{22}Na (sodium-22) concentrations of the sump water will be 35 pico Curie (pCi)/milliliter (ml) for ^{3}H with no detectable ^{22}Na, approximately 2% of the surface water discharge limits. At the surface, the water is discharged to a holding tank for use in the Fermilab Industrial Cooling Water (ICW) system, which confines the tritiated water to the Fermilab site.

ES&H Radiation Physics Operations Department monitors beam line losses to maintain water activation and residual dose rates in the tunnel below limits defined in the FRCM as part of the Fermilab environmental monitoring program. Water is sampled periodically at monitoring well S-1274 located down-gradient of the lined section of the Carrier Tunnel and a holding tank located near the MINOS Service Building. The NuMI Beam Line sumps are sampled periodically in accordance with Fermilab monitoring procedures and tested for radionuclides. Releases of ^{3}H and ^{22}Na constitute the radionuclides of most significant concern from the standpoint of groundwater and surface water activation. Table 2 presents measured concentrations of ^{3}H and ^{22}Na associated with the NuMI beamline at the S-1274 monitoring well and associated regulatory limits.

Table 2. Release Concentrations and Regulatory Limits Associated with NuMI Beamline-Produced Radionuclides in Groundwater and Surface Water.

10.75×10^{20} protons on target	Monitoring Well Measured Concentrations	Regulatory Limits*
^{3}H	< 0.2 pCi/ml	20 pCi/ml Groundwater 1900 pCi/ml Surface Water
^{22}Na	< 0.03 pCi/ml	0.4 pCi/ml Groundwater 10 pCi/ml Surface Water
* ^{3}H Regulatory Limit from 40CFR141 Federal Drinking Water Standards. ^{22}Na Regulatory Limits from the DOE STD-1196-2011 Derived Concentration Standards.		

III-8.2.1.4 Surface Water Activation

See discussion of groundwater activation. This hazard has also been evaluated within the common Risk Matrix table included in SAD Section I Chapter 04 *Safety Analysis*. Work in NuMI involving this hazard implements the controls specified in the common Risk Matrix table.

III-8.2.1.5 Radioactive Water (RAW) Systems

The NuMI horns, decay pipe, and the hadron absorber are cooled by water. The water in these cooling systems will become activated with ^{3}H, and to a lesser extent ^{7}Be (beryllium-7). The controls, interlocks and alarms designed for these systems prevent catastrophic losses and damage to the equipment[3]. The release of RAW from any of the NuMI cooling systems does not cause any significant increase to the concentration of radionuclides in the discharge to the ICW system[3].

III-8.2.1.6 Air Activation

The methodology used to assess NuMI air activation concerns has been documented in the shielding assessment**Error! Reference source not found.**. Delayed ventilation is used at NuMI to reduce radioactive air emissions. The vast majority of the radioactivity produced is short-lived. A delay time of one hour from production of the radionuclides to release will reduce the levels of radioactivity by roughly one order of magnitude at the stack release point.

There are six NuMI Beam Line exhaust air vents (EAV). EAV1 is the vent for the Carrier Tunnel and Pre-Target area. EAV2, Target Pile Evaporator Stack (TPES), and Survey Riser (SR) SR3 are the exhaust vents for the Target Hall area and upstream decay region. EAV3 is the exhaust vent for the Hadron Absorber area and downstream decay region. The highest levels of air activation are from the Target Hall/upstream decay region (EAV2, TPES, and SR3) and the Hadron Absorber/downstream decay region (EAV3). The air from EAV1, EAV2, TPES, SR3 and EAV3 is routinely monitored by the Environment, Safety & Health (ES&H) Division to ensure air emissions stay well below 0.1 mrem/yr level at the site boundary.

During the early operation of the NuMI Beam Line, increases in tritium concentration were observed in the water discharged from the NuMI sumps to the Fermilab ICW system. The increase in tritium concentrations in the water discharged from the NuMI sumps has been directly correlated to humidity levels inside the NuMI Target Hall and target chase. Dehumidification systems have been installed to reduce the humidity levels in air within the Target Hall and target chase.

A condensate collection system has been installed to collect tritiated water condensed on the cooling coils of the NuMI target chase air cooling and desiccant re-circulation systems. The water is pumped from a holding tank in the NuMI Beam Line tunnel to a holding tank located in the southwest corner of the MI-65 service building. The water from the holding tank is gravity fed to an evaporation unit where the evaporated water is exhausted out the TPES through the roof of the MI-65 service building. A high velocity fan on the roof of MI-65 mixes outside air with the exhausted moist air from the evaporator. This mixing prevents condensation of the evaporated water on the MI-65 service building roof and area surrounding the building. Tritium released through the MI-65 exhaust stacks contributes less than 1 micro-rem /year to Fermilab site boundary dose. The evaporator system is not presently being operated. The neutralized condensate effluent is disposed of as radioactive waste.

Secondary particles and un-interacted protons within the beam line will also interact with helium in the NuMI decay pipe to produce tritium and other radionuclides. Monte Carlo Shielding Computer Code (MARS)[3] simulations predict that about 0.12 Ci of tritium will be produced in the helium and 9 Ci of tritium will be produced in the decay pipe steel for every 1 $x10^{20}$ protons on target. Approximately half of the tritium in the decay pipe steel or 5 Ci of tritium are expected to leak from the steel into the helium. However, measurements of the decay pipe tritium contents showed no evidence of tritium migration from the decay pipe steel into the helium. This is attributed to the lack of air and moisture inside the decay pipe.

After ten years of running with helium in the decay pipe, irradiation of 5×10^{21} protons on target, the airborne activation in the Target Hall from a decay pipe window failure would result in a dose rate of 12 mrem/hr. The release of all the tritium accumulated in the decay pipe helium into the air will contribute less than 0.1 micro-rem to the Fermilab site boundary dose.

The NuMI Beam Line shielding assessment calculates the annual maximum anticipated equivalent dose to an individual located at the Fermilab site boundary to be 0.025 mrem from all emission sources.

This hazard has also been evaluated within the common Risk Matrix table included in SAD Section I Chapter 04 *Safety Analysis.* Work in NuMI involving this hazard implements the controls specified in the common Risk Matrix table.

III-8.2.1.7 Closed Loop Air Cooling

N/A.

III-8.2.1.8 Soil Interactions

There are no beamline components in direct contact with soil. The beamline is designed to have low losses. The beam dump is shielded and located in an enclosure below the soil level.

Soil activation hazards from long-term low-level beam losses has also been evaluated within the common Risk Matrix table included in SAD Section I Chapter 04 Safety Analysis. Work in NuMI involving this hazard implements the controls specified in the common Risk Matrix table.

III-8.2.1.9 Radioactive Waste

Radioactive waste produced in the course of NuMI beamline operations will be managed within the established Radiological Protection Program (RPP) and as prescribed in the FRCM.

Radioactive waste is a standard radiological hazard that is managed within the established RPP and as prescribed in the 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 NuMI 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.

Tritiated water from the Target Chase and Absorber Hall air chiller condensate is no longer evaporated per the previous discussion. It is disposed of as radioactive waste in accordance with the FRCM requirements. Fermilab reports the amount of ^{3}H evaporated in Fermilab Radionuclide Air Emissions Annual Reports provided to the DOE Fermi Site Office for transmission to State and Federal regulatory agencies in accordance with 40 CFR Part 61 Subpart H, National Emission Standards for Emissions of Radionuclides Other Than Radon from Department of Energy Facilities. Tritiated RAW is solidified and disposed of as solid low level radioactive waste.

Some used components will be stored in the Target Hall storage area until preparations are made for safe storage at the C0 assembly building, another location on site, or for disposal. Other items that can be taken up the access shaft are characterized and disposed of as solid low-level radioactive waste.

III-8.2.1.10 Contamination

Contamination is common in the target pile and associated systems. Shielding surrounding the target pile limits the spread of contamination. Work is performed as per a radiological work permit, which specifies preventative measures, such as surveying and cleaning; mitigative measures, such as the material survey and release process, and the use of personal protective equipment, reduce the spread of contamination.

III-8.2.1.11 Beryllium-7

Beryllium-7 is produced in the RAW water systems as described above. The raw water is a closed loop with filtering to capture contaminates. Engineered controls and secondary containment limit possible loss of water. Work planning and control, and radiological work permits limits possible exposure.

III-8.2.1.12 Radioactive Sources

N/A.

III-8.2.1.13 Nuclear Material

N/A.

III-8.2.1.14 Radiation Generating Devices (RGDs)

N/A.

III-8.2.1.15 Non-Ionizing Radiation Hazards

N/A.

III-8.2.2 Toxic Materials

Hazards associated with beryllium are discussed below. Lead is not a hazard in NuMI.

III-8.2.2.1 Lead

N/A.

III-8.2.2.2 Beryllium

There are beryllium vacuum windows in the target hall. These are engineered and used in such a way that the rupture of a window releases no beryllium into exposed areas. Due to the nature of the physical process, beryllium is sucked back into the vacuum pipe and captured in the short piece of vacuum tube that penetrates the target hall wall to the pre-target enclosure. For removal, processes and procedures are in place for replacement of the components comprising this assembly. They are disposed of in accordance with FRCM requirements.

III-8.2.2.3 Fluorinert & Its Byproducts

N/A.

III-8.2.2.4 Liquid Scintillator Oil

N/A.

III-8.2.2.5 Pseudocumene

N/A.

III-8.2.2.6 Ammonia

N/A.

III-8.2.2.7 Nanoparticle Exposures

N/A.

III-8.2.3 Flammables and Combustibles

The only combustibles identified are cables. No flammables are in use. ^3H is produced in the target gas cooling system.

III-8.2.3.1 Combustible Materials

The combustible hazard from the use of cables has been evaluated within the common Risk Matrix table included in SAD Section I Chapter 04 *Safety Analysis*. Work in NuMI involving this hazard implements the controls specified in the common Risk Matrix table. No unique controls are in use.

III-8.2.3.2 Flammable Materials

The ^3H produced in the target gas cooling system is diluted by Ar to a non-flammable level and exhausted. This system is inaccessible to the public; the system is in the underground enclosure.

III-8.2.4 Electrical Energy

Operation of the neutrino focusing horns poses electrical hazards from the stripline connections between the power supply capacitor bank and the horns, and the 60 kilo Jules of stored energy in the power supply capacitor bank. The Target Hall Power Supply Room horn stripline is an electromagnetic transmission line constructed of a series of aluminum conductors that carry the very high current needed to pulse the focusing horns in the target chase. Access to the stripline is controlled by the NuMI radiation safety interlock system and the stripline is located behind a fence.

The power supply capacitor bank is designed, installed, operated, and maintained in accordance with FESHM requirements. Performing Lock out Tag out (LOTO) is required before performing maintenance on devices connected to hazardous energy sources.

Stored energy is present in the horn power supply capacitor banks. LOTO and grounding procedures are in place for work required. The horn stripline has protective shielding and the horns are under shielding blocks and not routinely accessible. This is a standard industrial hazard and described in Section I, Chapter 4.

III-8.2.4.1 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 NuMI involving this hazard implements the controls specified in the common Risk Matrix table. No unique controls are in use.

III-8.2.4.2 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 NuMI involving this hazard implements the controls specified in the common Risk Matrix table. No unique controls are in use.

III-8.2.4.3 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 NuMI involving this hazard implements the controls specified in the common Risk Matrix table. No unique controls are in use.

III-8.2.5 Thermal Energy

Hazards associated with thermal energy are described below.

III-8.2.5.1 Bakeouts

N/A.

III-8.2.5.2 Hot Work

Qualified welders occasionally work in NuMI to repair waterlines and other metalwork. Hot work in NuMI areas has been evaluated within the common Risk Matrix table included in SAD Section I Chapter 04 *Safety Analysis*. Work in NuMI involving this hazard implements the controls specified in the common Risk Matrix table. No unique controls are in use.

III-8.2.5.3 Cryogenics

N/A.

III-8.2.6 Kinetic Energy

Hazards associated kinetic energy are described below.

III-8.2.6.1 Power Tools

Power tools are commonly used when working on NuMI equipment. Power tool use has been evaluated within the common Risk Matrix table included in SAD Section I Chapter 04 *Safety Analysis*. Work in NuMI involving this hazard implements the controls specified in the common Risk Matrix table. No unique controls are in use.

III-8.2.6.2 Pumps and Motors

Standard industrial pumps and motors are utilized throughout the NuMI areas for water cooling and vacuum systems. These have been evaluated within the common Risk Matrix table included in SAD Section I Chapter 04 *Safety Analysis*. Work in NuMI involving this hazard implements the controls specified in the common Risk Matrix table. No unique controls are in use.

III-8.2.6.3 Motion Tables

N/A.

III-8.2.6.4 Mobile Shielding

N/A.

III-8.2.7 Potential Energy

The hazards associated with potential energy are described below.

III-8.2.7.1 Crane Operations

Trained technicians utilize various hoists lifts, and bridge cranes to move, maintain, and install equipment in the NuMI areas. Crane hazards have been evaluated within the common Risk Matrix table included in SAD Section I Chapter 04 *Safety Analysis*. Work in NuMI involving this hazard implements the controls specified in the common Risk Matrix table. No unique controls are in use.

III-8.2.7.2 Compressed Gasses

Compressed nitrogen and argon are present in the NuMI areas to facilitate machine operations. Compressed gas cylinders are stored, used, and moved throughout the NuMI areas. Compressed gas hazards have been evaluated within the common Risk Matrix table included in SAD Section I Chapter 04 Safety Analysis. Work in NuMI involving this hazard implements the controls specified in the common Risk Matrix table. No unique controls are in use.

III-8.2.7.3 Vacuum/Pressure Vessels/Piping

Vacuum vessels are present in the NuMI areas in the form of beam pipes and other beamline components. Vacuum vessels have been evaluated within the common Risk Matrix table included in SAD Section I Chapter 04 Safety Analysis. Work in NuMI involving this hazard implements the controls specified in the common Risk Matrix table. No unique controls are in use.

NUMI has a number of air compressor tanks which are pressure vessels. They are located in the MI65 service building, upstairs and downstairs in the power supply room and target hall. Fermilab follows the rules laid out in FESHM Chapter 5031. This chapter points to the ASME BPVC (Boiler and Pressure Vessel Code) Section VIII (Division 1 or Division 2) for compliance.

The compressor tanks have a U-Stamp on the tank that denotes the pressure vessel is in compliance with ASME BPVC Section VIII, fabricated at a code shop and welding facility, and require a Fermilab Engineering Note detailing the compressor input mass flow rate and appropriate pressure relief device rating.

The tank gets a Fermilab Silver Sticker denoting that the Fermilab Engineering Note has been reviewed and approved (even though the U-Stamp validates the design, fabrication, and testing of the tank for the appropriate Maximum Allowable Working Pressure – MAWP).

III-8.2.7.4 Vacuum Pumps

Vacuum pumps are used throughout the NuMI areas 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 NuMI involving this hazard implements the controls specified in the common Risk Matrix table. No unique controls are in use.

III-8.2.7.5 Material Handling

Trained personnel operate forklifts, stackers, and hand carts to move materials throughout the NuMI areas. This hazard has been evaluated within the common Risk Matrix table included in SAD Section I Chapter 04 Safety Analysis. Work in NuMI involving this hazard implements the controls specified in the common Risk Matrix table. No unique controls are in use.

III-8.2.8 Magnetic Fields

The only magnetic fields present when personnel are present are corrector magnets. The electrical safety system prevents energizing of other sources when interlocks are dropped. Access also requires the LOTO of the supplies to the magnets. No permanent magnets are present.

III-8.2.8.1 Fringe Fields

The fringe field hazard mainly comes from powered magnets and permanent magnets that are in ion pumps. Fields are nominally only hazardous to people who have medical implants. The likelihood of the fringe field causing a malfunction to individuals with medical implants is reduced by work planning, warnings in the hazard specification sheet, and warning signs at NuMI entry points about this hazard. This hazard has been evaluated within the common Risk Matrix table included in SAD Section I Chapter 04 *Safety Analysis*. Work in NuMI involving this hazard implements the controls specified in the common Risk Matrix table. No unique controls are in use.

III-8.2.9 Other Hazards

Hazards are identified and described below. All are standard industrial hazards that are described in Section I, Chapter 4.

III-8.2.9.1 Confined Spaces

There are two confined spaces. One is the utility chase behind the elevator. The other is the "Gollum's cave" area, which is also in a sense, a utility chase. Neither is accessed routinely.

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

III-8.2.9.2 Noise

Operating cooling water systems creates a potential noise hazard in the "raw room" and pulsing of the NuMI horns creates a noise hazard in the Target Hall Power Supply Room. This hazard has been evaluated within the common Risk Matrix table included in SAD Section I Chapter 04 Safety Analysis. Work in NuMI involving this hazard implements the controls specified in the common Risk Matrix table. No unique controls are in use.

III-8.2.9.3 Silica

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

III-8.2.9.4 Ergonomics

Technical work in NuMI areas may involve sitting or standing for long periods of time, repetitive motion, cramped conditions, and other ergonomic concerns. Ergonomic hazards have been evaluated within the common Risk Matrix table included in SAD Section I Chapter 04 Safety Analysis. Work in NuMI involving this hazard implements the controls specified in the common Risk Matrix table. No unique controls are in use.

III-8.2.9.5 Asbestos

N/A.

III-8.2.9.6 Working at Heights

Technicians utilize ladders, step stools, and mobile work platforms to conduct maintenance in NuMI areas. Utilizing fall protection equipment, trained personnel may work on top of equipment where there is a chance of falling. Work at heights has been evaluated within the common Risk Matrix table included in SAD Section I Chapter 04 Safety Analysis. Work in NuMI involving this hazard implements the controls specified in the common Risk Matrix table. No unique controls are in use.

III-8.2.10 Access & Egress

Access is controlled by various key systems. The building is restricted. Access underground requires a special key. Access to the pre-target, target hall, absorber, and muon alcoves is interlocked. Access to the "raw room" is also restricted.

III-8.2.10.1 Life Safety Egress

Life safety considerations have been used to set the Target area occupancy limit to 50 persons with a subsidiary limitation of four occupants in the downstream area of the Carrier Tunnel region during installation and maintenance activities. There is an 8-person limit at the Target underground area during normal operations.

Occupancy limits and tracking of those in the underground area are maintained through a badging process that requires a NuMI underground access badge when entering the underground areas. The individual entering the underground leaves their Fermilab badge at the entrance to the respective NuMI access shaft. A NuMI underground badge is then assigned to each individual. Upon completing their time underground, the individual returns the NuMI underground badge and retrieves their Fermilab badge providing for an accurate head count of those underground.

Methods of emergency egress have been established for each of the NuMI Beam Line areas:

- Exiting from the NuMI stub is through the usual MI emergency egress system. A secondary route is through the Carrier Tunnel to the Target Access Shaft staircase;
- Exiting from the Carrier Tunnel is either upstream via the MI, or downstream via the Target Access Shaft staircase;
- Primary exiting from the Target Hall and support rooms is through the Target Access Shaft staircase;
- Secondary Target Hall exiting is through the decay tunnel walkway to the MINOS Access Shaft and up the enclosed MINOS elevator;
- Tertiary exiting route from the Target Hall is through the Carrier Tunnel and the MI;
- The primary exit from the Absorber areas is through the isolated MINOS Access Shaft elevator; and
- The secondary exit from the Absorber area is through the Decay Tunnel walkway upstream to the Target area and out the Target Hall Access Shaft staircase.

National Institute of Occupational Safety and Health approved escape packs are provided adjacent to the shaft elevators to provide 10 minutes of breathing air to personnel during emergency egress. All personnel working in the underground facilities are required to take Fermilab Underground Safety Training as well as appropriate radiation training, and LOTO II training.

The secondary exit from the MINOS detector caverns is via the decay pipe passageway to the MI65 shaft.

Incoming groundwater from the length of the NuMI tunnels collects in the MINOS Access Shaft sump pit. The water is pumped to the surface. If the pumping system is non-operational, approximately one hour can pass before the water will reach the MINOS Access Shaft floor level defining the beginning of a flooding condition. This hazard is addressed in the MINOS Hall Detectors Section III, Chapter 5.

Underground areas are inherently tornado shelters. Surface buildings have designated tornado shelters.

This is a standard hazard and described in Section I, Chapter 4.

III-8.2.11 Environmental

NuMI presents environmental hazards in the form of the list of checked off hazards shown in Table 1. All environmental hazards present in NuMI areas are in the form of Standard Industrial Hazards. This hazard has been evaluated within the common Risk Matrix table included in SAD Section I Chapter 04 *Safety Analysis*. Work in NuMI involving this hazard implements the controls specified in the common Risk Matrix table. No unique controls are in use.

III-8.2.11.1 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 NuMI involving this hazard implements the controls specified in the common Risk Matrix table. No unique controls are in use.

III-8.2.11.2 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 NuMI involving this hazard implements the controls specified in the common Risk Matrix table. No unique controls are in use.

III-8.2.11.3 Hazard to Soil

N/A.

III-8.3. Maximum Credible Incident (MCI) Scenario(s) for the Accelerator Specific Hazard(s)

III-8.3.1 Definition of the Maximum Credible Incident

This section of the NuMI SAD evaluates the maximum credible incident (MCI) scenario that could happen in this segment of the accelerator. 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-8.3.1.1 Radiological Hazard

NuMI is designed to transport all beam provided by the upstream machines to the NuMI target in the target hall. After consideration of various scenarios, the intensity of the MCI is determined to be the maximum intensity that can be delivered by the booster to the Recycler Ring (RR)/MI and extracted to the NuMI beamline. The maximum booster output of 7E12 at 15 Hz when transported through the RR/MI at normal efficiencies for both machines yields 1.03E14 ppp. At 1.067s min rep rate, this is 2.83E17 protons/hr. This beam could either be lost on a component for an hour or it would be transported to the target. In the latter case, it is simply normal beam operation at an abnormal intensity for one hour. Both scenarios were evaluated. Assuming no shielding is present, this incident would result in a dose that far exceeds acceptable levels for radiation exposure to workers or members of the public.

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-8.4.

The accumulated dose outside of the shielding on the NuMI berm is mitigated, by use of Credited Controls, to less than 500 mrem in an MCI. The closest possible location of a member of the public to the NuMI enclosure is the west parking lot. This location is more than five feet away from the berm, which would result in dose of less than 100 mrem applying a conservative dose reduction of 1/r.

III-8.4. Summary of Credited Controls

A summary of credited controls follows.

III-8.4.1 Credited Engineered Controls

III-8.1.1 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-8.4.1.1 Passive Credited Engineered Controls

Passive controls are accelerator elements that are part of the physical design of the facility that require no action to function properly. These passive controls are fixed elements of the beam line that take direct human intervention to remove. The NuMI Beam Line is designed to optimize the effect of these passive controls with permanent concrete and earth-covered radiation shields that use a combination of permanent shielding, movable shielding, and penetration shielding to protect personnel from radiological exposure during beam line operations.

Most shielding is permanent. Components in the target hall (target assembly and two horn assemblies) are under removable shielding that is removed and stored as described above and below for replacement of those consumable components.

III-8.4.1.1.1 Permanent Shielding Including Labyrinths

The permanent shielding encompasses the structural elements surrounding the beam line components. The NuMI concrete structure is contiguous with the MI beam line. Labyrinths and penetrations in the NuMI tunnels and halls have been assessed for radiation dose rates under normal operating and MCI conditions. The areas assessed in the Shielding Assessment include the following:

- Survey Risers 1, 2, and 3;
- Exhaust Stacks EAV1, EAV2 and EAV3;
- Target Hall Labyrinth;
- Target Hall Equipment Door;
- Horn Stripline Penetration;
- RAW System Penetration;
- Hadron Absorber Access Labyrinth;
- Muon Alcoves 2, 3 and 4 gates;
- RAW Room Door;
- Target Chase Air Cooling Labyrinth;

- MINOS Access Shaft and EAV4; and
- Muon Alcove Bypass Tunnel.

The largest potential NuMI Beam Line radiological losses under both normal operating and accident conditions are at Survey Risers SR1 and SR2. Permanent shielding at these locations reduces the potential dose rate to 0.1 mrem/hr under both normal and MCI conditions. These were done using existing shielding assessments and rad notes.

The following tables evaluating passive shielding were evaluated for the MCI using standard spreadsheets. The first 24.0 e.f.d. are the credited control. Clarifying the "to MI-8 tunnel" entry as there was no previous discussion of this, the NuMI beamline passes under the MI-8 beamline. This is the transverse shielding from the NuMI enclosure to the MI-8 enclosure.

Table 3: Permanent shielding

Cell or 0Longitudinal Range (ft)	Description	Current Shielding (efd)	Required (efd)
514-929	Carrier Tunnel	41.5	18.2
929-1105	Pre-Target Tunnel	100.0	20.7
1105-1331	Target Hall	94.3	20.7
1288-1298	To MI-8 Tunnel	62.0	20.7
1331-3523	Decay Tunnel	138.1	23.1
3523-3577	Absorber Hall	264.8	23.1
3577-3587	Muon Alcove 1	266.7	23.1
3626-3636	Muon Alcove 2	270.5	23.1
3695-3705	Muon Alcove 3	274.3	23.1
3803-3813	Muon Alcove 4	280.0	23.1

III-8.4.1.1.2 Movable Shielding

Assessments of movable Target Hall shielding components have been made foremost for access to the Target Hall and the handling of irradiated components within the Target Hall. A movable concrete door is put in place during beam operations to preclude access to the Target Hall from the NuMI access shaft area. MARS calculations predict a dose rate on the Target Hall side of the shield door which corresponds to less than 1 micro-rem/hr penetrating through the gaps in the shield door. Measurements of the dose rate immediately outside the door would be less than 1 mrem/hr due to leaking air through the penetrations and other small sources.

Table 4: Movable shielding

Location	Shielding Type	Quantity	Purpose	Preferred Method of Configuration	Comments
SR-1 z=488'	Concrete + Steel	1 plug	sight riser	None	3 ft of iron 1 ft of concrete
SR-2 z=990'	Concrete + Steel	1 plug	sight riser	None	2 ft of iron 1 ft of concrete
***z=1331'**	Concrete	Many Blocks	Shield bottom of elevator shaft	MI-65 Reset Key (NS 11) & RSO Padlock	Two stacks of blocks in front of roll up door
Target Hall	Concrete	Many R-Blocks	Shield Target and Horn Modules	PAD 118	See 9-6-7-4 drawing set
Absorber	Concrete	6 C, 2 D, 12 K Blocks	Shield Alcove 2 Entry	Pad 118 & Muon Alcove Enclosure Key	
Absorber	Concrete	Many Blocks (20) Handstack sand bags	Shield Labyrinth	None	

*This shielding is not required in Target/Horn Scan Mode.

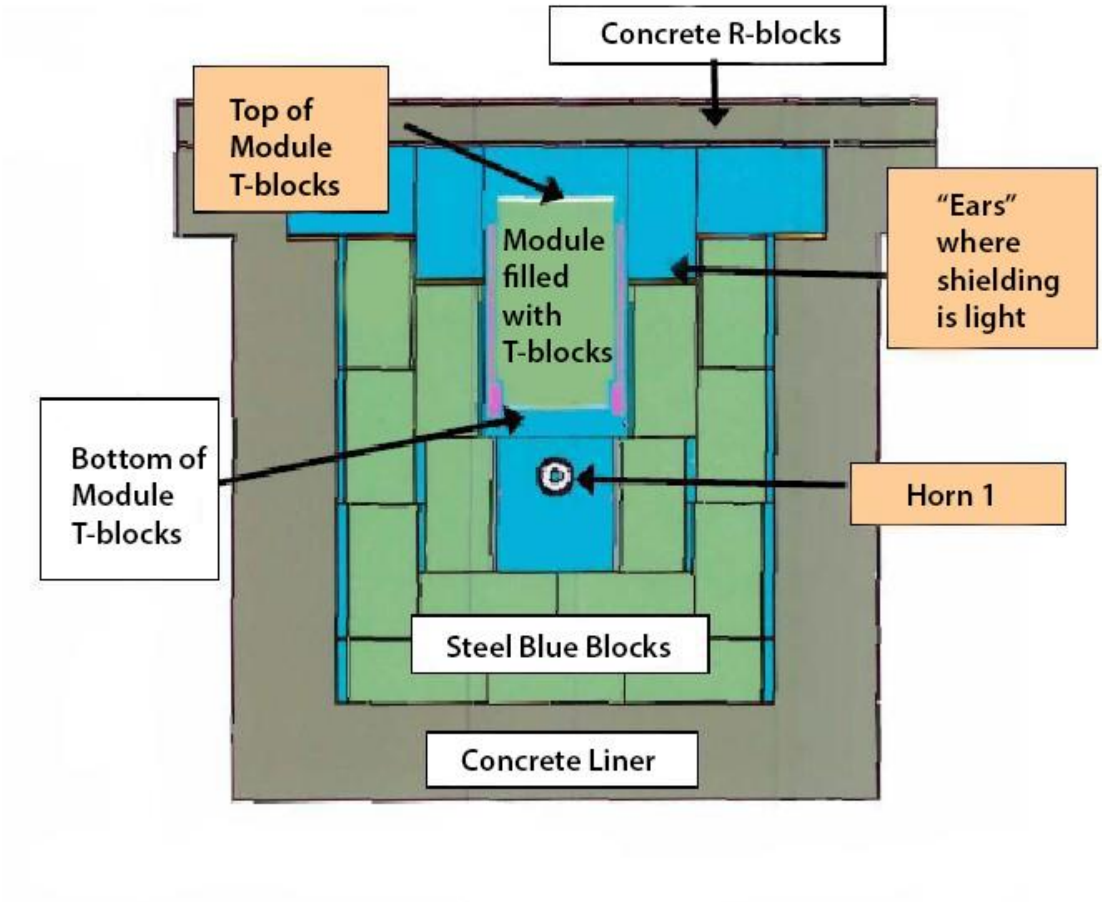

Figure 3. Cross Section of the NuMI Target Hall Component Region.

NuMI component handling is done remotely. Resultant radiation fields following relocation of the movable Target Hall shielding does not pose a hazard to workers. Continual attention is devoted to ensuring that component access, repair, or replacement activity dose rate levels are maintained within FRCM acceptable limits.

III-8.4.1.1.3 Penetration Shielding

Movable shielding for SR-1 and SR-2 must be in place.

III-8.4.1.2 Active Credited Engineering Controls

Active engineered controls are systems designed to reduce the risks from the MCI to an acceptable level. The active controls in place for NuMI operations are discussed below.

III-8.4.1.2.1 Radiation Safety Interlock System

The NuMI Beam Line employs a Radiation Safety Interlock System (RSIS). The characteristics of the system are described in Section I of the Fermilab SAD.

The NuMI Beam Line connects the MI RSIS and the NuMI RSIS. The boundary between the two systems is the door located at the mid-point of the NuMI Carrier Tunnel. The lined section of the Carrier Tunnel is a separately interlocked area to avoid the necessity of routine search and secure of this area. This lined section of the Carrier Tunnel is not accessible when the MI is operating.

The downstream end of the Carrier Tunnel is part of the NuMI RSIS and access to this region disables the NuMI critical devices. The primary critical devices are the NuMI Extraction Lambertson string (ACNET designation I: LAM60 & I: LAM61), and the Horizontal/Vertical Bend Magnet string (ACNET designation I: HV101A, B, & C). In the event of a critical device failure, the system has a failure mode function that will reach back and disable the upstream Booster RSIS. The NuMI RSIS prevents personnel access to Pre-Target, the Target Hall area, Decay Pipe tunnel, Hadron Absorber area and Muon Alcoves. With beam enabled, access is not allowed to these areas unless the critical devices are disabled.

Prior to accelerator operations, a Search and Secure is performed to establish the interlock system for the Exclusion Area(s). This Search and Secure ensures no personnel are remaining within the Exclusion Area(s) during accelerator operations.

There are interlocked detectors in the Carrier Tunnel region to minimize losses along the primary beam, and power supply room. These detectors disable the critical devices when set points are exceeded. The chipmunk in the power supply room is required to protect workers from the MCI.

Table 5: Summary of credited radiation detectors used by the NuMI RSIS

Type	Location	CC Limit (mrem/hr)
Chipmunk	MI-65 Horn Power Supply Room	5000

The RSIS for the NuMI Beam Line includes the underground enclosures with the exception of the following areas that are accessible during operations:

- MI-65 Target Access Shaft Including Stairwell and Elevator;
- MI-65 Below Ground Elevator and Landing Area;
- Target Hall Power Supply Room;
- Absorber Access Tunnel up to the Absorber Area Door; and
- MINOS Access Shaft including elevators.

Trained and qualified personnel from the AD Operations Department are required to search and secure the enclosure before permits from the RSIS may be reestablished following any personnel access to the enclosure, except under strictly specified controlled access conditions. The RSIS requirements including requirements for hardware and system testing, inventory of interlock keys, and procedures for maintenance of interlock systems. The RSIS hardware enforces the administrative Search and Secure and Controlled Access processes. The RSIS is designed, installed, and configuration managed in conformance with the requirements stated in the FRCM.

III-8.4.2 Credited Administrative Controls

All NuMI Beam Line operations with potential to impact the safety of employees, researchers, or members of the public or to adversely impact the environment are performed using approved laboratory, division or department procedures. These procedures are the administrative controls that encompass the human interactions and form the foundation for safe accelerator operations. The administrative procedures and programs considered necessary to ensure safe accelerator operations are discussed.

III-8.4.2.1 Operation Authorization Document

Beam will not be transported to the NuMI Beam Line without an approved Beam Permit and Running Condition. The Beam Permit specifies beam power limits as determined and approved by the AD Associate Laboratory Director, in consultation with the ES&H RPO Head, assigned RSO, AD Operations Department Head, and AD External Beams Department Head. The Running Condition for NuMI describes the operating configuration as reviewed by the assigned RSO, AD Operations Department Head, and AD External Beams Department Head and as approved by the AD Associate Laboratory Director.

III-8.4.2.2 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 NuMI Beam 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-8.4.2.3 Accelerator Operating Parameters

To ensure operations within bounding conditions used in the MCI analysis, the following intensity shall not be exceeded: 2.83E17 protons/hr.

III-8.5. Summary of Defense-in-Depth Controls

The NuMI Beam 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 sections.

III-8.5.1 Defense-in-Depth Engineering Controls

III-8.5.1.1 Passive Defense-in-Depth Engineering Controls

III-8.5.1.1.1 Permanent Shielding

The defense-in-depth control for the permanent shielding is defined as all shielding in excess of the required 24 e.f.d. present in the NuMI Beam Line areas. Credited controls collectively protect the MOI from receiving an unacceptable dose even if unforeseen modifications to the defense-in-depth permanent shielding were to occur. Such acts could include erosion of the berm or digging into the berm by a human or animal.

III-8.5.1.2 Active Defense-in-Depth Engineering Controls

III-8.5.1.2.1 Machine Protection Controls

NuMI has a machine protection system. Major elements are beam losses, magnet currents, and beam positions.

III-8.5.1.3 Defense-in-Depth Administrative Controls

III-8.5.1.3.1 Fencing and Posting

Fences are used and posted to designate potential Radiation Areas during machine operations. The entire NuMI berm was fenced and posted consistent with its identification as a Radiation Area in accordance with the FRCM.

III-8.5.1.3.2 Training

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

Equipment specific to the operation of the NuMI Beam Line such as magnet and horn power supplies 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-8.5.1.3.3 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, 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-8.6. Decommissioning

DOE Field Element Manager approval shall be obtained prior to the start of any decommissioning activities for the NuMI beamline.

III-8.7. Summary and Conclusion

Specific hazards associated with commissioning and operation of the NuMI Beam Line are identified and assessed in this chapter of the Fermilab SAD. The designs, controls, and procedures to mitigate NuMI Beam Line-specific hazards are identified and described. The NuMI Beam Line is subject to the global and more generic safety requirements, controls and procedures outlined in Section 1 of the Fermilab SAD.

The preceding discussion of the hazards associated with NuMI Beam Line operations and the credited controls established to mitigate those hazards demonstrate that the NuMI Beam Line can be operated in a manner that will produce minimal risk to the health and safety of Fermilab workers, researchers, the public, as well as to the environment.

III-8.8. References

[1] Fermilab Radiological Control Manual

[2] 2013 Neutrino at Main Injector (NuMI) Beam Line Shielding Assessment for 778 kilowatt (kW) Operation of Neutrino Off-axis Electron Neutrino Appearance (NOvA) Experiment. 2018 Addendum to the NuMI Beamline Shielding Assessment for 1 MW Operation of the NOvA Experiment. RP note 147: Radiation Dose Rates from the NuMI Labyrinths and Penetrations (Vaziri, 2004).

[3] N.V. Mokhov, "The MARS Code System User's Guide", Fermilab-FN-628 (1995); N.V. Mokhov, O.E. Krivosheev, "MARS Code Status", Proc. Monte Carlo 2000 Conf., p. 943, Lisbon, October 23-26, 2000; Fermilab-Conf-00/181 (2000).

III-8.9. 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-8.3 of this Chapter as well as SAD Chapter VII-A.1 *Accelerator Safety Envelope – Fermi Main Accelerator*.