NEUTRINO AREA

SECTION III CHAPTER 14 OF THE FERMILAB SAD

Revision 2 August 9, 2023

This Chapter of the Fermilab Safety Assessment Document (SAD) contains a summary of the results of the Safety Analysis for the Neutrino Area 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 3, Chapter 14 of the Fermi National Accelerator Laboratory (Fermilab) Safety Assessment Document (SAD), Neutrino Area was prepared and reviewed by the staff of the External Beam 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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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
T. Kobilarcik	0	14 February 2012	• Initial release of the Neutrino Area Chapter for the Fermi National Accelerator Safety Assessment Document (SAD).
T. Kobilarcik	1	6 October 2022	Revision for E1039 running • Inclusion of Shielding Assessment Addendum • Updated target station information • Sleeve around buried beampipe between G2 and N01 enclosures Editorial & Organizational Change Edits
S. McGimpsey	2	August 9, 2023	Updated for use with the new template and editorial changes.

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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-14. Neutrino Area

III-14.1. Introduction

This Section III, Chapter 14 of the Fermi National Accelerator Laboratory (Fermilab) Safety Assessment Document (SAD) covers the Neutrino Area segment of the Fermilab Main Accelerator.

III-14.1.1 Purpose/Function

The purpose of the Neutrino Area is to provide beam lines for the transport of 120 GeV/c protons, and associated secondary beams, to various end-users. The name "neutrino area" is historic; from this name one must neither infer that only neutrinos are transported through this area, nor that neutrino physics is the only scientific topic studied in this location.

Various types of fixed-target physics can be accommodated in this area. Examples are particle production, cross section measurements, and nuclear effects in the sea quark distribution.

III-14.1.2 Current Status

The Neutrino Muon segment of the Fermilab Main Accelerator is currently: Operational.

All other Neutrino Areas are currently: in stand by status.

III-14.1.3 Description

The Neutrino Area, includes enclosures N01, NW2, NW3, NW4, NW5, NW6, and NW7; NM2, NM3 and NM4. Associated services buildings are NS0, NS1, NS2, NS3 and NS7. The Target Service Building (TSB) is also in the neutrino area.

Enclosure N01 contains components for the transport of beam to the Neutrino East (NE), Neutrino Center (NC), Neutrino West (NW), and New Muon (NM) beam lines. Enclosure N01 contains an alcove at lower elevation, referred to as "NM1". The target for the NC primary beam is also located in N01. Access to N01 can be gained through the NS0, NS1, the N01 doorway, or the TSB.

The TSB houses an area for component storage and repair. It is connected to N01 by a tunnel and rail spur. The tunnel is filled with shielding, and the access door is interlocked.

Enclosures NW2 and NW3 allow access to the NC decay pipe.

Enclosure NW4 contains the primary beam absorbers for the NC and NW beam lines. The NE primary beam also passes through the east side of this building. Access is gained through the NS2 service building.

Enclosure NW5 allows access to the NW beam line.

Enclosure NW6 allows access to the NW and NC beam lines.

Enclosure NW7 allows access to the NW beam line.

Vacuum pipe, used to transport primary beam, connects the enclosures.

Enclosure NM2 is to the east of, and at a lower elevation than, N01. This enclosure is accessed by the NS7 service building. Enclosures NM1 and NM2 are connected by buried vacuum pipe. Enclosure NM3 is connected to NM2 by buried vacuum pipe. Enclosure NM3 extends into NM4 (which is used as the experimental hall).

III-14.1.3.1 Description of the NE, NC, and NW Beamlines

The NC beam line could be used to transport primary beam to a target located in N01. Magnetic elements would capture the secondary and un-interacted primary particles and steer them into a decay pipe running through the remainder of N01, NW2, NW3, and into the beam absorber in NW4. Beyond this point, the “secondary beam” would consist of muons and neutrinos. The muons would be absorbed in the berm, while the neutrinos would pass through to the previous NC experimental areas.

The NW beam line would consist of secondary and un-interacted primary beam from the NC target. It would be formed by an off-axis aperture in the NC beam absorber (located in NW4). Between N01 and NW4, the NC and NW beam lines share a common decay pipe.

The NE beam line would be transported through N01 into the east side of NW4. The NE and NC beam lines are distinct as they enter N01. A beam pipe, separate from the NC decay pipe, allows primary beam to be transported from N01 to NW4.

The aperture in Switchyard, which would allow the transport of beam to NC and NE areas, has been blocked with a steel block which is 5’4” long, 11” wide, and 5 ¾” high. The 5’4” of steel, approximately 10 nuclear interaction lengths, along the incident beam trajectory provides an intensity reduction of greater than 10,000 if beam were to be inadvertently misdirected. Thus, beam can no longer be transported to the NC, NW, or NE beam lines. These beamlines are currently in standby until they are needed for future experiments. If these beamlines are restored or reconfigured to be operational, this chapter will be revised appropriately.

III-14.1.3.2 Description of the Neutrino Muon (NM) Beam Line

The NM Beamline extends through Enclosure NM1, into NM2, and terminates in Enclosure NM3 and is the only beam line in this area that is anticipated to have beam reestablished. Dipole magnets located in NM2 constitute the principle bend points in the beamline. Additional dipole magnets, referred to as “trim magnets” or “correctors”, are found along the beam line. These magnets are used to make small corrections to the beam’s trajectory.

One pair of quadrupole magnets (“doublet”) focuses the beam onto the target, which is located in NM4 (the experimental hall).

Devices for monitoring the beam’s position (“Beam Position Monitors” or “BPM”) are located along the beam line, as are devices for showing the beam’s profile (known as “Segmented Wire Ionization Chambers” or “SWIC”). Ionization chambers, which measure the beam’s intensity, are in NM2 and NM3. Loss monitors are located along the beam line.

The last 30 feet of NM3 extends into the NM4 experimental hall and is physically isolated by steel and concrete shielding blocks. The shielding blocks are part of NM4.

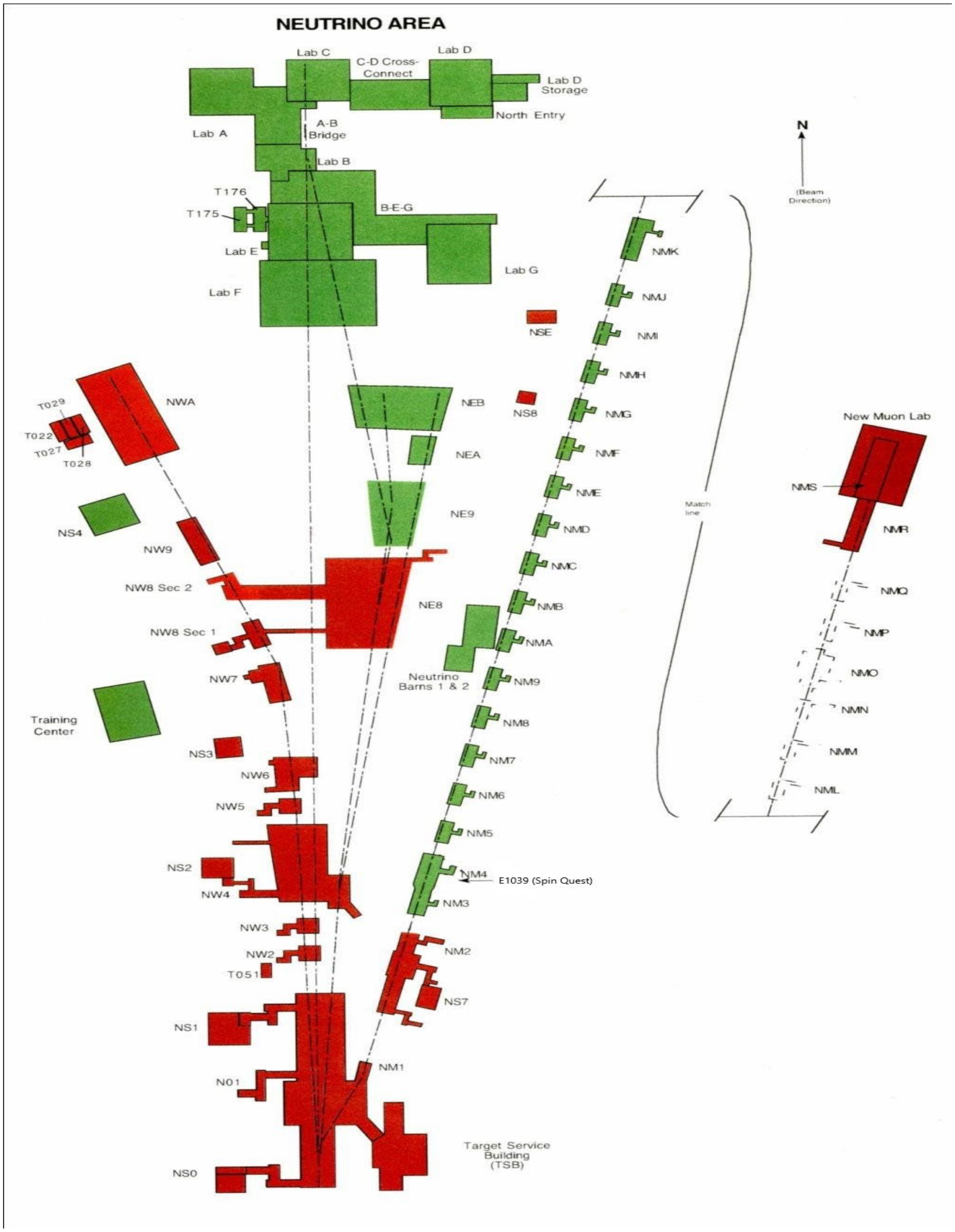

Figure 1. Layout of the Neutrino Beamline Area.

III-14-1.4 Location

The Neutrino Area is located on the Fermilab site in Batavia, IL.

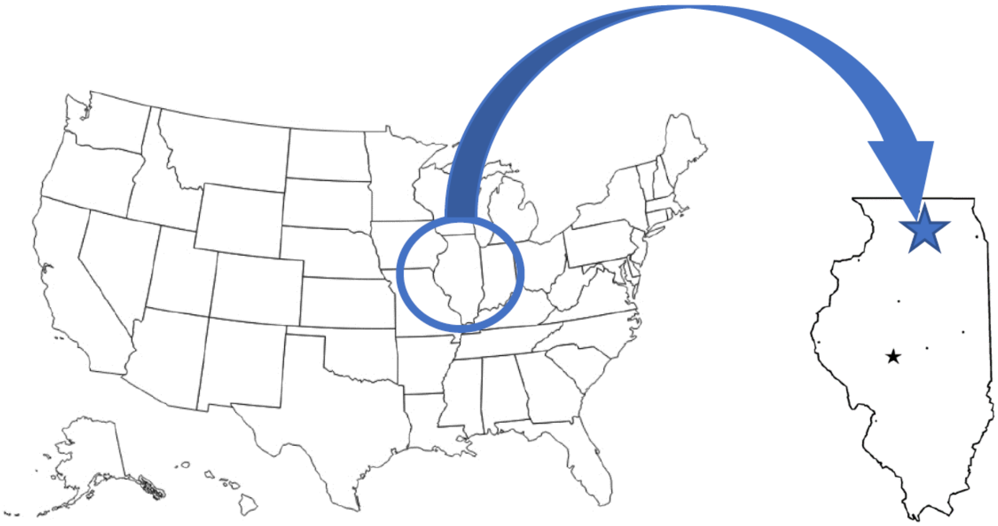

Figure 2. Regional view showing the location of the Fermilab site in Batavia, IL.

The Neutrino Area is located in the central campus on the Fermilab site.

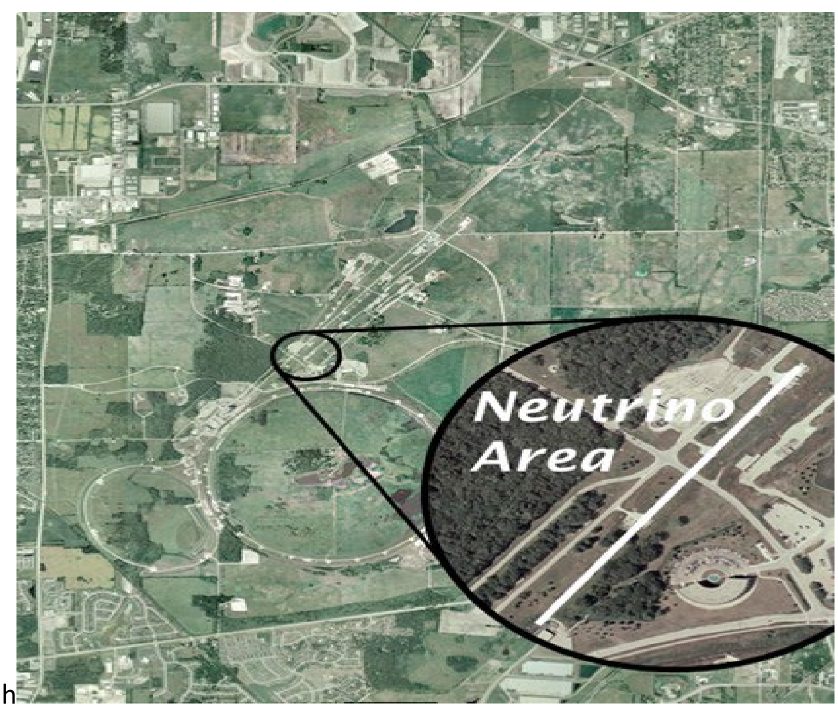

Figure 3. Aerial view of the Fermilab site, indicating the location of the Neutrino Area.

III 14.1.5 Management Organization

The Neutrino Area beamlines and enclosures are owned and operated by the Accelerator Directorate.

III-14.1.6 Operating Modes

The NM Beamline is capable of transporting 120 GeV/c protons from Enclosure NM1 to Enclosure NM3 at a variable spill rate and an intensity of $1x10^{13}$ protons per minute or $6.00×10^{14}$ protons per hour. A "spill" is a transfer of protons out of the Main Injector, the duration of which ranges from microseconds to several seconds. The allowed rate and spill may be limited by upstream shielding assessments, or an assessment associated with a particular experimental configuration.

III-14.1.7 Inventory of Hazards

The following table lists all of the identified hazards found in the Neutrino Area enclosures and support buildings. Section III-14.10 *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-14.2 *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 Neutrino Area. Accelerator specific controls are identified as **purple/bold** throughout this Chapter.

All other hazards present in the Neutrino Area 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 Standard Industrial Hazards (SIH), and their analysis will be summarized in this SAD Chapter.

Table 1. Hazard Inventory for Neutrino Area.

	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-14.2. Safety Assessment

All hazards for the Neutrino Area segment of the Fermilab Main Accelerator are summarized in this section, with additional details of the analyses for accelerator specific hazards.

III-14.2.1 Radiological Hazards

The Neutrino Area presents radiological hazards in the form of Prompt Ionizing Radiation, Residual Activation, Groundwater Activation, Surface Water Activation, Radioactive Water (RAW) Systems, Air Activation, Soil Interactions, Radioactive Waste, Contamination, Beryllium-7, and Radioactive Sources. A detailed shielding assessment and post assessment documents [2][6] address these hazards and provide a detailed analysis of the facility demonstrating the required shielding, controls and interlocks to comply with the Fermilab Radiological Control Manual (FRCM)[1].

Radiation safety has been carefully considered in the design of the NM Beamline. The 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 air, soil, and potential groundwater activation resulting from operating the beam transport and targeting systems.

A detailed shielding assessment and subsequent addendum [2][6] address these concerns. The assessments provide a detailed analysis of this facility, demonstrating the required overburden, use of signs, fences, and active interlocks to comply with the Fermilab Radiological Control Manual (FRCM). Residual activation of components has a substantial impact on the ability to occupy the beamline enclosures where recurring access is required for routine maintenance. The 2012 shielding assessment for the Neutrino area extends from Enclosure C, where the first critical device is located, and continues through the G1, G2, NM1, NM2, and NM3 enclosures.

Enclosures C through NM2 are unchanged from the 2012 operation of the beamline. A “shadow collimator”, to protect cryogenic equipment from inadvertently steered beam, and radiological shielding have been added to the downstream end of NM3; these are assessed in the 2019 shielding assessment addendum.

The assessments consider transverse and longitudinal shielding requirements; summarized labyrinth and penetration calculations; calculated air activation, estimated annual release, and listed release points; calculated ground and surface water activation, listed surface water discharge points and monitoring locations; considered muon production; calculated residual dose rates; and specified active shielding controls and monitoring.

III-14.2.1.1 Prompt Ionizing Radiation

Prompt ionizing radiation is the principal radiation hazard when beam is transported through the NM beam line. In order to protect workers and the general public, the enclosures and beam pipes are surrounded either by sufficient amounts of shielding (earth, concrete or iron), and/or networks of interlocked detectors to keep any prompt radiation within acceptable levels.

Locations along the NM beamline with potential for individuals to receive 100 mrem in a year are currently within Restricted Access Areas, beyond “Authorized Personnel Only” signage, and are not Public Access Areas. Additional controls for outdoor areas where members of the public could receive 100 mrem in a year may be implemented in accordance with the plans, currently under development, in response to the 2022 DOE Review of the Environmental Radiological Protection Program. Additional controls for areas where members of the public could potentially be exposed to radiation levels above background may also be implemented in accordance with the plans under development in response to the August 25, 2022, letter EXPOSURE OF THE PUBLIC AND VISITORS TO RADIATION.

The Fermilab Shielding Assessment Review Panel reviewed the detailed shielding assessments to address ionizing radiation concerns. The assessments provide a detailed analysis of the beam line; assess both passive and active shielding; assess required overburden or soil shielding; and review the use of signs, fences, and active interlocks to maintain any prompt radiation within acceptable levels.

The 2019 Shielding Assessment addendum requires that:

- All penetrations be filled with shielding as specified.
- All movable shielding blocks be installed as specified.
- The average beam intensity shall not exceed 6.00×10^{14} protons per hour.
- Annual limit of $5.26\text{x}10^{18}$ protons.
- The instantaneous beam intensity shall not exceed 1.00×10^{13} protons over a 4-second spill.

Section 13 of the 2019 NM Beam Line SA addendum stipulates the required controls and monitoring:

- *The radiation safety interlock system will be certified as working.*
- *Radiation detectors around the NM4 enclosure will be installed and interlocked to the radiation safety interlock system.*

Section 15.2 for the 2012 shielding assessment requires that the interlocked repetition rate monitor, used to limit beam spill frequency and spill duration, will be in place and certified for use.

Additionally, the baseline, qualitative risks due to this hazard were assessed, and determined to be risk level I (major concern) for workers and co-located workers, but through the use of preventive and mitigative hazard controls, the likelihood and consequence of this hazard is reduced, resulting in a risk level of IV, meaning residual risks are of minimal concern. For the public, the baseline qualitative risk due to this hazard are managed through a series of preventive controls, so that the likelihood of experiencing this hazard is Beyond Extremely Unlikely, with an overall residual risk of III, meaning the risk is a minor concern, not subject to additional evaluation.

III-14.2.1.2 Residual Activation

Residual radiation in the NM Beamline except at the target station (located in NM4, but accessed through NM3) is expected to be low by design. Beam interaction which would cause a high level of residual radiation would compromise the efficient transport of primaries to the target. The target and upstream face of the absorber magnet, referred to collectively as the “target station”, will become radioactive during operation. Access to these components will be tightly controlled with the control dependent on the level of residual radiation. The control measures include training and training verification, centralized access authorization, and key entry. Controls required for different levels of residual radiation are specified in the FRCM and are detailed in the Radiological Work Permit (RWP) for the work to be performed.

When the NM Beamline is not in operation, the target station will remain radioactive and possibly be a Contamination Area; therefore, access to these components is tightly controlled by the ES&H Section Radiation Physics Operations Department under the direction of the assigned RSO.

In most situations, general RWPs for access will suffice. A job-specific RWP and/or ALARA (“as-low-as-reasonably-achievable”) plan will be required for work on any highly activated or potentially contaminated equipment with a potential individual exposure greater than 100 millirem (mrem) or potential exposures for all persons on the job greater than 600 person- mrem. These tasks will be supervised by members of the Radiological Control Organization under the direction of the assigned Radiation Safety Officer (RSO).

Additionally, the baseline, qualitative risks due to this hazard were assessed, and determined to be risk level I (major concern) for workers and co-located workers, but through the use of preventive and mitigative hazard controls, the likelihood and consequence of this hazard is reduced, resulting in a risk level of IV, meaning residual risks are of minimal concern. For the public, the baseline qualitative risk due to this hazard are managed through a series of preventive controls, so that the likelihood of experiencing this hazard is Beyond Extremely Unlikely, with an overall residual risk of III, meaning the risk is a minor concern, not subject to additional evaluation.

III-14.2.1.3 Groundwater Activation

Methodologies have been designed to provide conservative estimates of groundwater activation. The ground water methodologies calculate the estimated annual concentration and then calculate the concentration buildup for continuous operations over an extended period.

Neutrino area sump and retention pit concentrations are regularly sampled as part of the ES&H Radiological Routine Monitoring Programs, ESHQS-RPE-001.

In addition, the baseline, qualitative risks due to this hazard were assessed, and determined to be risk level I (major concern), but through the use of preventive and mitigative hazard controls, the likelihood and consequence of this hazard is reduced, resulting in a risk level of IV for workers, co-located workers, and the public, meaning residual risks are of minimal concern and are not subject to additional evaluation.

III-14.2.1.4 Surface Water Activation

Methodologies have been designed to provide conservative estimates of surface water activation. The surface water methodologies calculate the estimated annual concentration and then calculate the concentration buildup for continuous operations over an extended period.

Neutrino area sump and retention pit concentrations are regularly sampled as part of the ES&H Radiological Routine Monitoring Programs, ESHQS-RPE-001.

Lastly, the baseline, qualitative risks due to this hazard were assessed, and determined to be risk level I (major concern), but through the use of preventive and mitigative hazard controls, the likelihood and consequence of this hazard is reduced, resulting in a risk level of IV for workers, co-located workers, and the public, meaning residual risks are of minimal concern and are not subject to additional evaluation.

III-14.2.1.5 Radioactive Water (RAW) Systems

The hazards due to Radioactive Water (RAW) Systems was evaluated, for the potential hazards associated with workers, co-located workers and the public potentially being exposed to radioactive water beyond regulatory limits. The baseline, qualitative risks due to this hazard were assessed, and determined to be risk level I (major concern) for workers and co-located workers and risk level III (minor concern) for the public. Through the use of preventive and mitigative hazard controls, the likelihood and consequence of this hazard is reduced, resulting in a risk level of IV to workers and co-located workers, meaning residual risks are of minimal concern. For the public, the baseline qualitative risk due to this hazard are managed through a series of preventive controls (locked facilities, interlocked systems preventing entry), so that the likelihood of experiencing this hazard remains Beyond Extremely Unlikely, with an overall residual risk of III, meaning the risk is a minor concern, not subject to additional evaluation.

III-14.2.1.6 Air Activation

The existing ventilation systems in NM beamlines slow transit time adequately to allow for radioactive decay of short-lived positron emitters. Access to these areas is tightly controlled, and will not be allowed without an adequate cool-off period. The cool-off period is determined by the assigned RSO, based on the shielding assessments. The shielding assessment addendum [6] specifies a 120-minute cool-off period prior to allowing access into the NM3 or NM4 enclosures to keep personnel exposure below 20% of the Derived Air Concentration (DAC) values. The shielding assessment[2][6] estimates that based on 5.26×10^{18} protons delivered per year, the annual air releases from operations will be 2 + 0.6 Curies per year. This is a few percent of the laboratory annual air release budget.

In addition, the baseline, qualitative risks due to this hazard were assessed, and determined to be risk level I (major concern) for workers and co-located workers, but through the use of preventive and mitigative hazard controls, the likelihood and consequence of this hazard is reduced, resulting in a risk level of IV for workers and co-located workers. The baseline qualitative risk to the public, without prevention or mitigation remained at a level of IV, meaning the baseline qualitative risks were of minimal concern and are not subject to additional hazard controls or evaluation, Hazard controls identified for other receptors, provided additional defense-in-depth protection to the public.

III-14.2.1.7 Closed Loop Air Cooling

N/A.

III-14.2.1.8 Soil Interactions

The hazards due to soil interactions were evaluated, for the potential hazards associated with workers, co-located workers and the public potentially being exposed to contaminated soil. The baseline, qualitative risks due to this hazard were assessed, and determined to be risk level he hazard due to soil interactions was assessed and determined to be risk level IV, meaning that the baseline risks were of minimal concern and do not require additional preventive or mitigative measures to reduce risks further. The hazard controls identified by the facility reduce the likelihood of potential exposure to the hazard to all receptors, and consequences remain negligible, resulting in a residual risk level IV (minimal).

III-14.2.1.9 Radioactive Waste

Radioactive waste produced in the course of Neutrino Area 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 Neutrino Area, 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.

The baseline, qualitative risks due to this hazard were assessed, and determined to be risk level III (minor concern), but through the use of preventive and mitigative hazard controls, the likelihood and consequence of this hazard is further reduced, resulting in a risk level of IV for workers, co-located workers, and the public, meaning residual risks are of minimal concern and are not subject to additional evaluation.

III-14.2.1.10 Contamination

The hazards due to contamination was evaluated, for the hazards to workers, co-located workers and the public potentially being exposed to contamination. The baseline, qualitative risks due to this hazard were assessed, and determined to be risk level I (major concern) for workers and co-located workers and risk level III (minor concern) for the public. Through the use of preventive and mitigative hazard controls, the likelihood and consequence of this hazard is reduced, resulting in a risk level of IV to workers and co-located workers, meaning residual risks are of minimal concern. For the public, the baseline qualitative risk due to this hazard are managed through a series of preventive controls (locked facilities, interlocked systems preventing entry), so that the likelihood of experiencing this hazard remains Beyond Extremely Unlikely, with an overall residual risk of III, meaning the risk is a minor concern, not subject to additional evaluation.

III-14.2.1.11 Beryllium-7

The hazards due to worker, co-located worker or public interaction with Beryllium-7 have been evaluated by a qualitative assessment. The baseline qualitative risk was determined to be a risk level of IV (minimal concern). The consequences from potential exposure to this material is considered to be of negligible consequence, and since this material is inaccessible to workers, co-located workers and public due to where it may found within the facility, coupled with its very short half-life, no preventive or mitigative measures are required, the risk is of a minimal concern, and not subject to additional evaluation.

III-14.2.1.12 Radioactive Sources

The hazards due to exposure to radioactive sources was evaluated for potential to expose workers, co-located workers, and the public beyond allowed exposure limits. For workers and co-located workers. the baseline, qualitative risk associated with exposure was determined to be risk level I (major concern) and risk level III (minor concern) for the public. Through the use of preventive and mitigative hazard controls, the likelihood and consequence of this hazard is reduced, resulting in a risk level of IV to workers and co-located workers, meaning residual risks are of minimal concern. For the public, the baseline qualitative risk due to this hazard are managed through a series of preventive controls (locked facilities, interlocked systems preventing entry), and with an added mitigation (requiring training) reducing potential consequences, the likelihood of experiencing this hazard remains Beyond Extremely Unlikely, and with lowered consequences the overall residual risk is reduced to IV, meaning the risk is a minimal concern, not subject to additional evaluation.

III-14.2.1.13 Nuclear Material

N/A.

III-14.2.1.14 Radiation Generating Devices (RGDs)

N/A.

III-14.2.1.15 Non-Ionizing Radiation Hazards

N/A.

III-14.2.2 Toxic Materials

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

III-14.2.2.1 Lead

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

III-14.2.2.2 Beryllium

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

III-14.2.2.3 Fluorinert & Its Byproducts

N/A.

III-14.2.2.4 Liquid Scintillator Oil

N/A.

III-14.2.2.5 Pseudocumene

N/A.

III-14.2.2.6 Ammonia

N/A.

III-14.2.2.7 Nanoparticle Exposures

N/A.

III-14.2.3 Flammables and Combustibles

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

III-14.2.3.1 Combustible Materials

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

III-14.2.3.2 Flammable Materials

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

III-14.2.4 Electrical Energy

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

III-14.2.4.1 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 the Neutrino Area involving this hazard implements the controls specified in the common Risk Matrix table. No unique controls are in use.

III-14.2.4.2 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 the Neutrino Area involving this hazard implements the controls specified in the common Risk Matrix table. No unique controls are in use.

III-14.2.4.3 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 the Neutrino Area involving this hazard implements the controls specified in the common Risk Matrix table. No unique controls are in use.

III-14.2.5 Thermal Energy

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

III-14.2.5.1 Bakeout

N/A.

III-14.2.5.2 Hot Work

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

III-14.2.5.3 Cryogenics

N/A.

III-14.2.6 Kinetic Energy

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

III-14.2.6.1 Power Tools

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

III-14.2.6.2 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 the Neutrino Area involving this hazard implements the controls specified in the common Risk Matrix table. No unique controls are in use.

III-14.2.6.3 Motion Tables

N/A.

III-14.2.6.4 Mobile Shielding

N/A.

III-14.2.7 Potential Energy

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

III-14.2.7.1 Crane Operations

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

III-14.2.7.2 Compressed Gasses

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

III-14.2.7.3 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 the Neutrino Area involving this hazard implements the controls specified in the common Risk Matrix table. No unique controls are in use.

III-14.2.7.4 Vacuum Pumps

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

III-14.2.7.5 Material Handling

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

III-14.2.8 Magnetic Fields

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

III-14.2.8.1 Fringe Fields

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

III-14.2.9 Other Hazards

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

III-14.2.9.1 Confined Spaces

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

III-14.2.9.2 Noise

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

III-14.2.9.3 Silica

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

III-14.2.9.4 Ergonomics

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

III-14.2.9.5 Asbestos

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

III-14.2.9.6 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 the Neutrino Area involving this hazard implements the controls specified in the common Risk Matrix table. No unique controls are in use.

III-14.2.10 Access & Egress

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

III-14.2.10.1 Life Safety Egress

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

III-14.2.11 Environmental

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

III-14.2.11.1 Hazard to Air

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

III-14.2.11.2 Hazard to Water

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

III-14.2.11.3 Hazard to Soil

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

III-14.3. Summary of Hazards to Members of the Public

All hazards to the public have been evaluated within the common Risk Matrix table included in SAD Section I Chapter 04 *Safety Analysis*. Work in the Neutrino Area involving these hazards implements the controls specified in the common Risk Matrix table. No unique controls are in use.

III-14.4. Summary of Credited Controls

III-14.4.1 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 accelerator that take direct human intervention to remove. The NM Beam line uses a combination of permanent shielding, movable shielding, penetration shielding, and radiation area fences to protect personnel from radiological exposure during beam operations.

III-14.4.1.1 Shielding

III-14.4.1.1.1 Permanent Shielding Including Labyrinths

The permanent shielding encompasses the structural elements surrounding the beamline components and experimental hall. The permanent shielding for the enclosure is documented in the NM Beam Line SA and addendum [2][6] and consists of sufficient earth overburden such that unacceptable levels of prompt radiation cannot occur based on the assessed beam conditions.

III-14.4.1.1.2 Movable Shielding

The downstream portion of Enclosure NM3 extends into the experimental hall NM4. This downstream end of NM3 consists of a combination of steel, concrete shielding blocks and the primary beam absorber. The steel, shielding blocks and absorber, along with the size of NM4 and its internal shielding, mitigate the prompt radiation from targeting beam to acceptable levels.

The large shielding blocks range in weight from approximately 10,000 pounds to approximately 26,000 pounds and cannot be moved without the use of the NM4 crane. The shielding for this area is defined in the shielding assessment and addendum[2][6]. The AC power disconnect switch for the NM4 crane is locked out and configuration controlled by the assigned RSO.

The 2019 shielding assessment requires movable steel shielding above the beam pipe at the downstream end of NM3. The shielding and beam pipe are installed on a movable cart, which is locked in place and controlled by the assigned RSO.

III-14.4.1.1.3 Penetration Shielding

Penetrations along the NM beam line have been analyzed in the shielding assessments. The 2012 shielding assessment found that no penetrations were identified as exceeding the allowed dose rate limits. The 2019 shielding assessment reassessed penetrations impacted by reconfiguration for E1039 and found that the exit dose rates of all labyrinths and penetrations conform to guidance specified in FRCM.

III-14.4.1.2 Fencing

III-14.4.1.2.1 Radiation Area Fencing

The NM beam line has posted and locked radiological fences to prohibit access to outside berm areas. These include fences from N01 through the east side of the NM3 berm, up to the south wall of NM4. Beyond that point, the east interior wall of the NM4 enclosure, an interlocked area, provides adequate protection.

III-14.4.1.2.2 Controlled Area Fencing

N/A.

III-14.4.2 Active Engineered Credited Controls

Active engineered controls are systems designed to reduce the risks from accelerator operations to acceptable levels. These are automatic systems that limit or terminate operations when operating parameters are exceeded. The active controls in place for the NM beam line is the radiation safety interlock system. Enclosures N01/NM1, NM2, and NM3 are ODH Class 0; as such, in-place oxygen deficiency monitors, and alarm systems are not needed.

III-14.4.2.1 Radiation Safety Interlock System

Two critical devices, V100 and MuLam, are used to inhibit beam from entering the NM beam line. V100 consists of two vertically bending dipole magnets, wired in series, and energized by a single power supply. The critical device is the contactor which energizes the magnets. Similarly, MuLam consists of three horizontally bending dipole magnets, wired in series, and energized by a single power supply. The critical device is the contactor which energizes the magnets. Disabling either of these devices will preclude delivery of beam to the NM beam line. Both V100 and MuLam are in the Switchyard Area upstream of the Neutrino Area beam lines. Compromising the radiation safety interlock system for N01/NM1, NM2, NM3, or NM4 or exceeding the trip setting of any interlocked chipmunks will disable the critical devices, thus preventing transport of primary beam into N01/NM1, NM2, and NM3.

III-14.4.2.2 ODH Safety System

N/A.

III-14.4.3 Administrative Credited Controls

All NM accelerator 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-14.4.3.1 Operation Authorization Document

In accordance with AD Administrative Procedure on *Beam Permits, Running Conditions, and Startup* (ADAP-11-0001), beam will not be transported to the Neutrino Muon beam line without an approved Beam Permit and Running Condition for the operating area. The Beam Permit specifies the Accelerator Safety Envelope (ASE) and Operating beam intensity limits and is approved by the AD Division Head in consultation with the ES&H Section Radiation Physics Operations Department Head, assigned RSO, AD Operations Department Head, and AD Systems Department Head. The Running Conditions list the operating modes, ASE and Operating beam intensity limits for the Neutrino Muon beam line. Running Conditions are issued by the AD Division Head, and are signed by the AD Operations Department Head, assigned RSO, AD Systems Department Head, and AD Division Head.

III-14.4.3.2 Staffing

MCR must be appropriately staffed according to the Accelerator Safety Envelope.

III-14.4.3.3 Accelerator Operating Parameters

The NM beam line is assessed to run at $1x10^{13}$ protons per pulse, at a rate of sixty pulses per hour, and a momentum of 120 GeV/c or any combination of spill rates not exceeding $1x10^{13}$ protons per minute. This results in an operating envelope of $6.0x10^{14}$ protons per hour, at 120 GeV/c. Accelerator operational approvals shall be obtained by following the AD Procedure ADAP-11-0001 Beam Permits, Running Conditions, and Startup administered by the AD Head. Beam Permit and Running Condition documents shall identify the beam power and operating parameters allowed for the NM Beam Line within the current Accelerator Safety Envelope. The Beam Permit specifies beam power limits as determined and approved by the AD Directorate Head in consultation with the ES&H Division Radiation Physics Operations Department Head, assigned RSO, AD Operations Department Head, and AD Systems Department Head. The Running Condition for the NM Beam Line describes the operating configuration as reviewed and signed by the AD Operations Department Head, assigned RSO, AD Systems Department Head, and AD Directorate Head.

III-14.5. Defense-in-Depth Controls

There are no identified defense-in-depth controls.

III-14.6. Machine Protection Controls

Beam Loss Monitors routinely determine when beam is being lost at unacceptable regions and/or rates. Beam Position Monitors and segmented wire chambers (SWICS) determine the trajectories of the beam so that the Main Control Room may control losses. The Beam Budget Monitor continually monitors the integrated beam delivered to the Neutrino Area on an hourly basis.

III-14.7. Decommissioning

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

III-14.8. Summary and Conclusion

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

The preceding discussion of the hazards presented by NM Beam Line operations and the credited controls established to mitigate those hazards demonstrate that the beam line can be operated in a manner that will produce minimal hazards to the health and safety of Fermilab workers, visiting scientists, and the public, as well as to the environment.

III-14.9. References

[1] Fermilab Radiological Control Manual

[2] Neutrino Muon Beam Line Shielding Assessment, February 2012.
[3] TeamCenter reference EN04847.
[4] G2 and NM1/N01 ODH Evaluation and Classification, B. DeGraff, January 2012.
[5] Fermilab Environment, Safety, and Health Manual
[6] C. Johnstone and I. Rakhno, Neutrino Muon Beamline Shielding Assessment Addendum for E1039, December 18, 2019.

III-14.10. 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-14.4 of this Chapter as well as SAD Chapter VII-A.1 *Accelerator Safety Envelope – Fermi Main Accelerator*.