



# NEUTRINO AREA

## SECTION III CHAPTER 14 OF THE FERMILAB SAD

Revision 2 January 19, 2024

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	<ul style="list-style-type: none"> <li>Initial release of the Neutrino Area Chapter for the Fermi National Accelerator Safety Assessment Document (SAD).</li> </ul>
T. Kobilarcik	1	6 October 2022	Revision for E1039 running <ul style="list-style-type: none"> <li>Inclusion of Shielding Assessment Addendum</li> <li>Updated target station information</li> <li>Sleeve around buried beampipe between G2 and N01 enclosures</li> </ul> Editorial & Organizational Change Edits
S. McGimpsey	2	January 19 2023	Updated for use with the new template and editorial changes.  Incorporation of the maximum credible incident for a radiological hazard and a description of the credited controls that mitigate it, along with any elements that are considered defense in depth.



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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 <i>Safety of Accelerators</i>
<sup>7</sup> 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
<sup>3</sup> H	Tritium
HA	Hazard Analysis
HAR	Hazard Analysis Report
HCA	High Contamination Area
HCTT	Hazard Control Technology Team
HEP	High Energy Physics
HFD	Hold for Decay

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

MCI	Maximum Credible Incident
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 <i>(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.)</i>
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
<sup>22</sup> 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. See Figure 1 for a layout of the Neutrino beamline areas.

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. The ES&H Division, Radiation Physics Operations (RPO) department manages all movable shielding through a configuration control management system. All moveable required shielding is also labeled as such and the use of chains and locks is used where feasible. 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 only beam line capable of currently transporting beam is the NM beam line and is the focus of this SAD chapter. The NM beam line is the only line that is considered for the Maximum Credible Incident (MCI). Should that change, this SAD chapter will be updated. The NM Beamline extends through Enclosure NM1, into NM2, and terminates in Enclosure NM3. This is the only beam line in the Neutrino area that is anticipated to have beam reestablished. Dipole magnets located in NM2 constitute the principal 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 also 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.

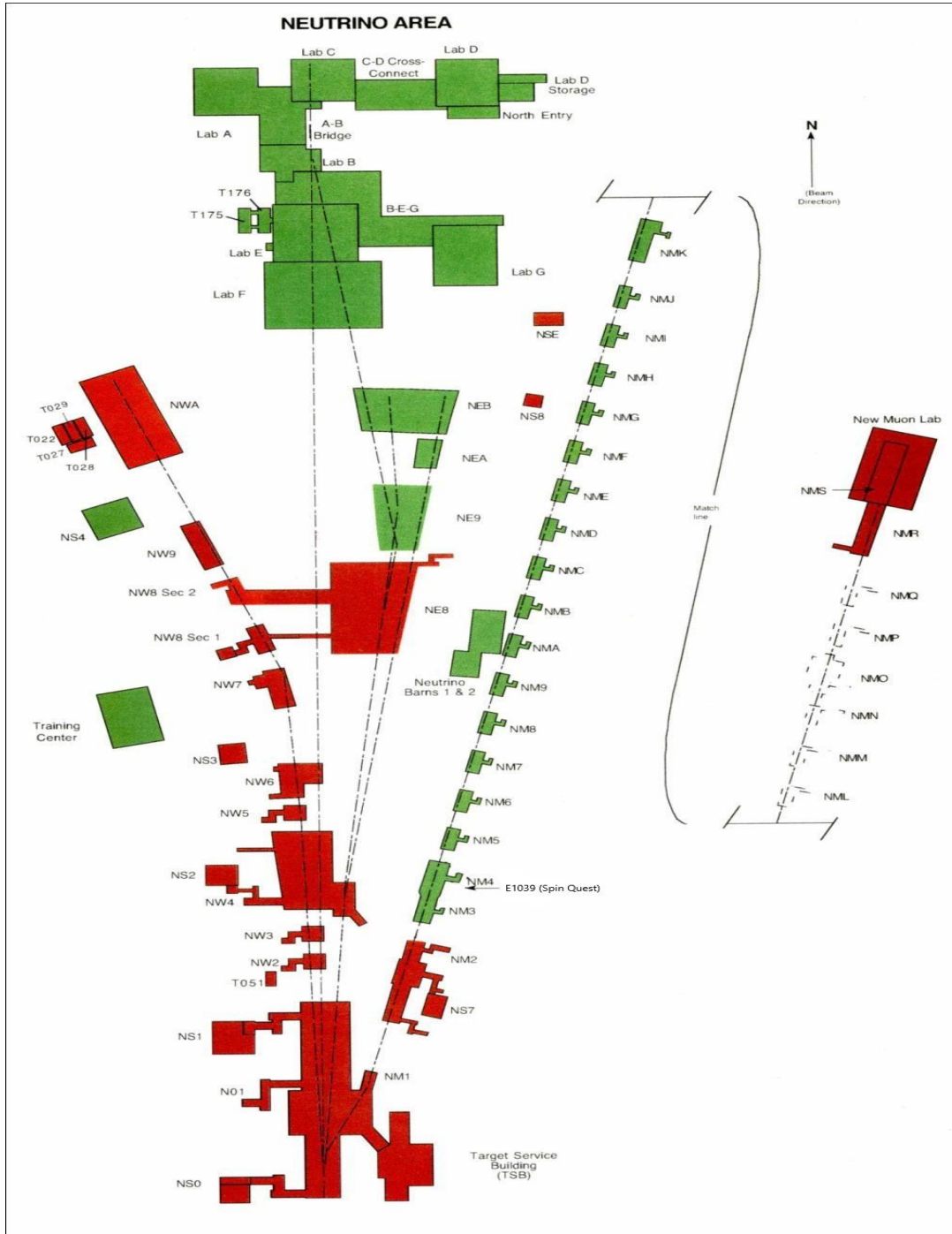


Figure 1. Layout of the Neutrino Beamline Area.

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. The NM4 experimental hall is managed by the Particle Physics Directorate.

### III-14.1.6 Operating Modes

The NM Beamline is capable of transporting 120 GeV/c protons from Enclosure NM1 to a magnetized beam absorber (FMAG) located at the upstream end of Enclosure NM4, at a variable spill rate and an intensity of  $1 \times 10^{13}$  protons per minute or  $6.00 \times 10^{14}$  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. The beam absorber (FMAG) removes all primary particles and their secondary products except for muons, neutrons and neutrinos. A magnetic field sweeps lower energy muons horizontally, leaving only high energy muons in the forward direction for experimental purposes.

It should be noted that the Neutrino Muon beamline physically extends from Switchyard enclosure C (G1 stub), through enclosures G2, N01/NM1, NM2 and NM3. This SAD Chapter only covers enclosures N01/NM1, NM2, NM3 to the upstream portion of NM4 where the experimental “target station”, including FMAG are located. Switchyard enclosures C and G2 are covered in the Switchyard SAD Chapter.

### 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-14.8 *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 and Oxygen Deficiency Hazards due to cryogenic systems within accelerator enclosures have been identified as accelerator specific hazards, and as such their controls are identified as Credited Controls. The analysis of these hazards and their Credited Controls will be discussed within this SAD Chapter, and their Credited Controls summarized in the Accelerator Safety Envelope for the Fermilab Main Accelerator. Accelerator specific controls are identified as **purple/bold** throughout this Chapter.

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

Table 1. Hazard Inventory for Neutrino Area.

Radiological		Toxic Materials	
<input checked="" type="checkbox"/>	Prompt Ionizing Radiation	<input checked="" type="checkbox"/>	Lead
<input checked="" type="checkbox"/>	Residual Activation	<input checked="" type="checkbox"/>	Beryllium
<input checked="" type="checkbox"/>	Groundwater Activation	<input type="checkbox"/>	Fluorinert & Its Byproducts
<input checked="" type="checkbox"/>	Surface Water Activation	<input type="checkbox"/>	Liquid Scintillator Oil
<input checked="" type="checkbox"/>	Radioactive Water (RAW) Systems	<input type="checkbox"/>	Ammonia
<input checked="" type="checkbox"/>	Air Activation	<input type="checkbox"/>	Nanoparticle Exposures
<input type="checkbox"/>	Closed Loop Air Cooling	<b>Flammables and Combustibles</b>	
<input checked="" type="checkbox"/>	Soil Interactions	<input checked="" type="checkbox"/>	Combustible Materials (e.g., cables, wood cribbing, etc.)
<input checked="" type="checkbox"/>	Radioactive Waste	<input type="checkbox"/>	Flammable Materials (e.g., flammable gas, cleaning materials, etc.)
<input checked="" type="checkbox"/>	Contamination	<b>Electrical Energy</b>	
<input checked="" type="checkbox"/>	Beryllium-7	<input checked="" type="checkbox"/>	Stored Energy Exposure
<input checked="" type="checkbox"/>	Radioactive Sources	<input checked="" type="checkbox"/>	High Voltage Exposure
<input type="checkbox"/>	Nuclear Material	<input checked="" type="checkbox"/>	Low Voltage, High Current Exposure
<input type="checkbox"/>	Radiation Generating Devices (RGDs)	<b>Kinetic Energy</b>	
<input type="checkbox"/>	Non-Ionizing Radiation Hazards	<input checked="" type="checkbox"/>	Power Tools
<b>Thermal Energy</b>		<input checked="" type="checkbox"/>	Pumps and Motors
<input type="checkbox"/>	Bakeout	<input type="checkbox"/>	Motion Tables
<input checked="" type="checkbox"/>	Hot Work	<input type="checkbox"/>	Mobile Shielding
<input type="checkbox"/>	Cryogenics	<b>Magnetic Fields</b>	
<b>Potential Energy</b>		<input type="checkbox"/>	Fringe Fields
<input checked="" type="checkbox"/>	Crane Operations	<b>Other Hazards</b>	
<input checked="" type="checkbox"/>	Compressed Gasses	<input checked="" type="checkbox"/>	Confined Spaces
<input checked="" type="checkbox"/>	Vacuum/Pressure Vessels/Piping	<input type="checkbox"/>	Noise
<input checked="" type="checkbox"/>	Vacuum Pumps	<input checked="" type="checkbox"/>	Silica
<input checked="" type="checkbox"/>	Material Handling	<input checked="" type="checkbox"/>	Ergonomics
<b>Access &amp; Egress</b>		<input checked="" type="checkbox"/>	Asbestos
<input checked="" type="checkbox"/>	Life Safety Egress	<input checked="" type="checkbox"/>	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. There are two predominant radiation hazards. The first hazard is due to the interaction of beam particles in the materials surrounding the beam pipes and beam line elements. The second is caused by the interaction of beam particles in the experimental components and the subsequent interactions of the secondaries with their surrounding material.

There are three categories of beam-induced radiation hazards:

1. Prompt radiation levels inside and surrounding the enclosure that are present during beam transport. These include protons, neutrons, muons, and other energetic particles.
2. Residual radiation due to activation of beamline components, and experimental devices which can give rise to radiation exposure to personnel during accesses to the beam enclosure and experimental facility for repair, maintenance, inspection, and operation activities; and
3. Environmental radioactivity due to the operation of the beam transport system, such as the activation of air, soil, and groundwater.

A detailed shielding assessment [2] has been compiled and reviewed to address these concerns. The assessment provides 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)[1]. Residual activation of components makes a substantial impact on the ability to occupy the experimental hall where recurring access is required for routine experimental equipment changes. The shielding assessment has analyzed the beam line areas from Switchyard, Enclosure C (G1 stub), G2, N01/NM1, NM2, NM3 to the end of the experimental area in NM4. This includes the buried beam pipe connecting these areas.

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[6].

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. Operation of the area conforms to the FRCM to maintain exposures for operating personnel as low as reasonably achievable (ALARA).

This hazard has been evaluated via a Maximum Credible Incident (MCI) analysis that is described in Section III-14.3. This analysis specifies that Fermilab uses Credited Controls that flow down to the Accelerator Safety Envelope (ASE) to mitigate the consequences of the MCI to at or below the acceptable dose levels described in SAD Section I Chapter 4. A detailed description of each of the Credited Controls and their function is provided in Section III-14.4. The conclusion of these analyses is that the mitigated dose level associated with prompt ionizing radiation due to beam loss is acceptable.

#### 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 cave area and upstream face of the absorber magnet (FMAG), 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 Division Radiation Physics Operations Department under the direction of the assigned Radiation Safety Officer (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 200 millirem (mrem) or potential exposures for all persons on the job greater than 1000 person-mrem. These tasks will be supervised by members of the Radiological Control Organization under the direction of the assigned RSO.

Additionally, the baseline, qualitative risks due to this hazard were assessed in Section III-14.9 Appendix – Risk Matrices Tables 18.1 – 18.3, 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 IV, 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. Radioactivity induced by the interaction of high-energy particles with the soil that surrounds a proton beam line or target is addressed in this section. The production of tritium and sodium-22 poses the greatest concern, since the product of



the production rate, leachability into the water flowing through the soil, and decay half-lives of these nuclides may be large. Fermilab standards pertaining to groundwater activation are provided in FRCM Chapters 3 and 11[1], and methodologies for estimating groundwater activation are given in Environmental Protection Notes Numbers 8 and 17. Additionally, the annual integrated intensity used in the calculations is estimated well above the practical beam delivery limits.

As discussed in the shielding assessment and addendum [2][6], an evaluation has been performed to estimate the surface water and groundwater activation concentrations in the vicinity of soil surrounding beam pipe. The shielding assessment demonstrates that the operation of the NM beam line will be well within annual limits set by surface or ground water activity.

The beam line is assessed at a 100% duty factor of  $5.26E18$  protons/year. However, Fermilab has a mandatory shutdown every summer, typically lasting 12-15 weeks, so the NM beam line is not operational for a full calendar year. The NM beam line is typically operational for about 40 weeks/year. Results of baseline risk has been reduced from a value of I to a residual risk of III or IV when preventive and mitigative measures are considered.

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

As a result, the baseline, qualitative risks due to this hazard were assessed in Section III-14.9 Appendix – Risk Matrices Tables 18.1 – 18.3, 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

See ground water section above.

#### III-14.2.1.5 Radioactive Water (RAW) Systems

The cooling system for the beam absorber (FMAG) at the downstream end of NM3 is required to be classified as a RAW system[7]. The RAW skid placement, approximately 50 ft upstream of the beam absorber, was chosen to minimize residual dose rates to workers. The RAW system is part of the radiation safety interlock system and monitors temperature, and flow rate.

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 in Section III-14.9 Appendix – Risk Matrices Tables 18.1 – 18.3, 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 IV, meaning the risk is a minor concern, not subject to additional evaluation.

#### III-14.2.1.6 Air Activation

Illinois state regulations and the Fermilab registration in Registration of Smaller Sources (ROSS) program, administered by the Illinois Environmental Protection Agency (IEPA), govern releases of airborne radionuclides. The regulations limit the effective dose equivalent delivered to a member of the public to 10 mrem/year [1]. Fermilab has established a secondary goal of keeping the maximum effective dose equivalent at the site boundary due to air emissions under 0.1 mrem/yr.

The existing ventilation systems in NM beam line 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  $5.26 \times 10^{18}$  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 in Section III-14.9 Appendix – Risk Matrices Tables 18.1 – 18.3, 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 in Section III-14.9 Appendix – Risk Matrices Tables 18.1 – 18.3, 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). This includes incidental radioactive materials produced during the irradiation of target materials, as well as beamline components that have been hit by the beam.

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. Results of risk assessment in Section III-14.9 Appendix – Risk Matrices Tables 18.1 – 18.3 have demonstrated that baseline risk has reduced from a value of I to a residual risk of IV when preventive and mitigative measures are considered.

#### III-14.2.1.10 Contamination

The hazards due to contamination were 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 in Section III-14.9 Appendix – Risk Matrices Tables 18.1 – 18.3, and determined to be risk level I (major concern) for workers and co-located workers and risk level IV (minimal 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 VI, meaning the risk is a minimal 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 be 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 in Section III-14.9 Appendix – Risk Matrices Tables 18.1 – 18.3 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](#)

The Neutrino Area presents toxic material hazards identified in Table 1. 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](#)

The primary lead hazard is in the form of lead solder from older electronics that are still in use. 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](#)

While not expected, this SAD considers that Beryllium may need to be brought into the NM3/NM4 enclosure, for experimental purposes. 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 Combustible Materials

Common industrial lubricants, solvents, and paints are used by technicians to maintain equipment and are stored in flammable materials lockers. This hazard has been evaluated within the common Risk Matrix table included in SAD Section I Chapter 04 *Safety Analysis*. Work in the 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

Electrical hazards are present in the form of low and high voltage power supplies that power magnets, roughing/turbo pumps and diagnostic equipment. 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

The Neutrino Area electrical hazards from the alternating current (AC) power distribution systems and the power supplies mentioned in the previous section have 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

See previous sections III-14.2.4 and III-14.2.4.1. 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

See previous sections III-14.2.4 and III-14.2.4.1. 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](#)

Qualified welders could occasionally need to work in the enclosures to repair waterlines and other metalwork. This hazard has been evaluated within the common Risk Matrix table included in SAD Section I Chapter 04 *Safety Analysis*. Work in the 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](#)

Power tools are commonly used when working on Neutrino Area equipment in all of the enclosures or service buildings. This hazard has been evaluated within the common Risk Matrix table included in SAD Section I Chapter 04 *Safety Analysis*. Work in the 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](#)

Standard industrial pumps and motors are utilized in the Neutrino area for water cooling and vacuum systems. This hazard has been evaluated within the common Risk Matrix table included in SAD Section I Chapter 04 *Safety Analysis*. Work in the 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](#)

Trained technicians utilize various hoists lifts, and cranes to move, maintain, and install equipment in the beamline enclosures and experimental hall. 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](#)

It is anticipated that compressed gases may need to be brought into the Neutrino Areas or enclosures, for experimental purposes. ArCO<sub>2</sub> is routinely used in beam line diagnostic components. These gas cylinders are securely stored in the G2 service building and outside of the NM4 service building. 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](#)

Vacuum vessels are present in the NM beamline in the form of beam pipes or other beamline components. This hazard has been evaluated within the common Risk Matrix table included in SAD Section I Chapter 04 *Safety Analysis*. Work in the 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](#)

Roughing/Turbo pumps are used throughout the NM beam line to maintain vacuum in the beamline and other components. 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](#)

Trained personnel operate forklifts or hand carts to move materials throughout the Neutrino area. 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

The fringe field hazard in the NM beam lines comes from electromagnets. 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](#)

##### III-14.2.9.1 Confined Spaces

Confined spaces in the area are in the form of sump pump vaults and experimental cryomodule equipment that is no longer used. 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

Operational beamline systems or experimental set-ups, have the potential to create a noise hazard. 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

Silica dust may be created when drilling into concrete floors or walls. This hazard has been evaluated within the common Risk Matrix table included in SAD Section I Chapter 04 *Safety Analysis*. Work in the 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

Both office and technical work involve sitting or standing for long periods of time, repetitive motion, cramped conditions, and other ergonomic concerns. This hazard has been evaluated within the common Risk Matrix table included in SAD Section I Chapter 04 *Safety Analysis*. Work in the 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

Access penetrations connecting the service buildings to the NM beam line enclosures may be asbestos lined due to common fire prevention practices during the period when the building was constructed. Due to the age of the building, asbestos may be present in other areas as well. 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

Technicians utilize ladders, step stools, and mobile work platforms to conduct maintenance in the Neutrino areas. Utilizing fall protection equipment, trained personnel may work on top of equipment where there is a chance of falling. This hazard has been evaluated within the common Risk Matrix table included in SAD Section I Chapter 04 *Safety Analysis*. Work in the 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

All enclosures in the NM beamline (Enclosure C to NM4) have at least two access and egress points. 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](#)

##### III-14.2.11.1 Hazard to Air

N/A.

##### III-14.2.11.2 Hazard to Water

N/A.

##### III-14.2.11.3 Hazard to Soil

N/A.

### III-14.3. Maximum Credible Incident Scenario(s) for the Accelerator Specific Hazards

#### III-14.3.1 [Definition of Maximum Credible Incident](#)

This section of the Neutrino Area SAD evaluates the maximum credible incident (MCI) scenario that could happen in the NM beam line. 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-14.3.1.1 Radiological Hazard

The Neutrino Muon beam line can provide 120 GeV protons from the Main Injector, through Switchyard, down to a beam absorber downstream in NM3. A maximum credible incident would be one that produces

the greatest beam loss for the longest period of time. The NM MCI is dependent on the intensity of the Switchyard beam line resulting from the MCI for Switchyard. After careful evaluation, it has been determined that the Switchyard MCI, with respect to beam intensity, has the following beam parameters. At 120 GeV, Switchyard can achieve a maximum of 4.2 protons/pulse, with a 55 second cycle time that is limited by the repetition rate limiter located in Switchyard on the VH94 power supply. A repetition rate limiter is used to protect against the delivery of 120GeV beam more than once a minute. This device has been used for many years and has been refined by the AD Power Electronics Systems Department (PESD) and the ES&H Interlocks Group. This device is a Credited Control. The following scenarios will disable the Switchyard CDC by turning off S:HP3US & S:HP3DS, inhibiting beam transport:

- If the magnet power supply S:VH94 is excited for more than seven seconds in a sixty second period.
- If the magnet power supply S:VH94 is excited more than once in a 60 second period.
- If a fault occurs with the Repetition Rate Limiter Hardware Input Module, Output Module, or Analog monitoring Module.

See the Switchyard SAD chapter on maximum credible incident scenario(s) for the accelerator specific hazard(s) for more information. A change to the NM MCI will be evaluated for its effect on the NM beam line through the USI process.

As a result, the maximum beam intensity output that can be achieved from the NM beamline is  $2.75E15$  protons/hour, with  $4.2E13$  protons/pulse at a 55 second cycle time. For this MCI intensity to be delivered to the NM beam line, the power supply for V100 would need to be energized continuously, which would bend the beam vertically down, away from the Switchyard absorber and into the Neutrino Muon beam line. Additionally, no beam would be delivered to the Meson area. This could be achieved by having the Meson Critical device (S:MLAM) locked off. A maximum credible incident would be one that produces the greatest beam loss for the longest period of time. The NM MCI occurs when  $2.75E15$  protons/hour is lost and continuously incident on the beam pipe or a beamline component that is both the closest to the thinnest section of permanent shielding and the farthest away from interlocked radiation detectors in the NM beamline for one hour. This MCI in NM can be a result of the misdirection of the beam so that it impacts the beam pipe and surrounding structures inside the accelerator enclosure, which can occur from a single failure of one or more devices or power supplies, or erroneous operation of them.

Prompt radiation causes hazardous radiation fields directly and indirectly through material effects. 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. Previous MARS simulations [2] finds that a peak dose rate in excess of 10,000 mrem/hr would occur in areas on the NM berm adjacent to the NM beamline and experimental area in this accident condition. Without any preventative or mitigative measures, the prompt radiation dose level associated with this accident is not acceptable.

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 5 rem in one hour in any area accessible by facility workers or co-located workers.

- 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 (which includes Batavia Road, Prairie Path, parking lots open to the public, and general access areas including Wilson Hall, Ramsey Auditorium).

These credited controls are discussed in Section III-14.4.

The accumulated dose outside of the shielding on the NM 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 NM enclosures is the public road and bicycle trail. 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-14.4 Summary of Credited Controls

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

#### III-14.3.2 Credited Engineering Controls

The purpose of this section is to provide the information necessary to understand the engineered controls, which can be active or passive, and administrative controls that are used to prevent or mitigate the consequences of the MCI. This analysis then verifies that the risk associated with the NM beam line MCI is reduced to a negligible level.

##### III-14.3.2.1 Passive Credited Controls

Passive controls are elements that are part of the physical design of the facility that require no action to function properly. These are fixed elements of the beamline that take direct human intervention to remove. The NM beam line is designed and constructed as a permanent concrete and earth-covered radiation shield that uses a combination of permanent shielding, movable shielding, and penetration shielding, to protect personnel from radiological exposure due to an MCI.

###### III-14.3.2.1.1 Permanent Shielding Including Labyrinths

The permanent shielding encompasses the structural elements surrounding the beamline components and experimental hall. The amount of permanent shielding for the enclosure is documented in the NM Beam Line SA and addendum [2][6].

There are three categories of beam-material interactions that are considered for the NM shielding requirements for the MCI. The first is beam hitting a magnet in an enclosure, and the second is beam hitting the beam pipe in the enclosure and the third is beam hitting buried beam pipe. These scenarios require 13.9 effective feet of dirt (e.f.d.), 11.4 e.f.d. and 16.3 e.f.d., respectively, to limit the radiation dose rate to less than 500 mrem-per-hour for a person outside of the beamline areas. If these amounts of shielding exist, then a person outside of the beamline areas and right next to the shielding will receive at most a dose of 500 mrem within one hour from the assumed one hour of maximum beam power operations. In locations where there is more than the required amount of shielding, that shielding is a

credited control. Any areas along the NM beamline with less than the required amount of shielding, will require active controls as described below in addition to the existing shielding. In the locations with less than the required amount of shielding, 0.5 ft less than the values in table 2 will be taken as the credited control along with the interlocked detector. The trip setting for the interlocked detector will be set to account for this lessor amount of shielding taken as a credited control. There are currently eight locations in the NM3 and NM4 areas that already required the use of interlocked detectors for normal operating conditions and compliance with 10CFR835 and the Fermilab ALARA program. For the MCI described above, only one of these interlocked detectors is needed. This is the detector on the NM3 berm at the longitudinal location covering the Z (ft) range from 4353-4368. This interlocked detector also protects the transverse locations 4354-4370. See Tables 2 and 3. It should be noted that longitudinal and transverse areas downstream of FMAG (Z=4390) are secondary particles and not subject to the ISA shielding spreadsheet requirements, specifically 3 ft of shielding. Previous beam on studies have been performed to address the secondary particles and the use of the additional interlocked radiation detectors, along with their corresponding trip settings, to comply with the requirements of 10CFR835. This requirement automatically satisfies MCI dose limits of this SAD.

Table 2: Longitudinal Shielding Spreadsheet

Long. Range Z (ft)	Location	Category	Current shielding e.f.d.	Required Shielding e.f.d.	Interlocked detector Needed?
4353-4357	NM3 collimator	4A	17.5	13.9	Y – already in place
4357-4360	NM3	4B	11.4	11.4	Y – already in place
4360-4368	Target Cave	4A	11.7	13.9	Y – already in place
4368-4373	Target Wall	4A	29.9	13.9	
4373-4374	Pre-FMAG	4A	31.4	13.9	
4374-4378	FMAG US	4C	31	16.3	
4378-4381	FMAG US	4C	28.8	16.3	
4382-4388	FMAG DS	4C	26	16.3	
4388-4389	FMAG DS	4C	22.4	16.3	
4389-4390	FMAG DS	4C	28.5	16.3	
4390-4391	Post-FMAG	4A	3.54	3.0	
4391-4392	Post-FMAG	4A	8.9	3.0	
4392-4394	Post-FMAG	4A	3.54	3.0	
4394-4454	NM4	4A	0	3.0	
4454-4490	NM4	4A	7.08	3.0	
4490-4503	NM4	4A	8.85	3.0	

Table 3: Transverse Shielding Spreadsheet

Transverse Location (ft)	Location	Category	Current Shielding e.f.d.	Required Shielding e.f.d.	Interlocked detector Needed
4354-W	NM3 Collimator	4A	17.5	13.9	Y – already in place
4354-E	NM3 Collimator	8A	17.5	4.7	Y – already in place
4357-W	NM3	8B	16.9	3.0	Y – already in place
4357-E	NM3	8B	16.9	3.0	Y – already in place
4360-W	Target Cave	9A	4.0	3.0	Y – already in place
4360-E(dn)	Target Cave	4A	19.8	13.9	Y – already in place
4360-E(up)	Target Cave	8A	5.0	4.7	Y – already in place
4361-W	Target Cave	8A	8.4	4.7	Y – already in place
4361-E(dn)	Target Cave	4A	23.6	13.9	Y – already in place
4361-E(up)	Target Cave	8A	11.4	4.7	Y – already in place
4364-W	Cryo Line	8A	11.0	4.7	Y – already in place
4364-E(dn)	Cryo Line	4A	23.6	13.9	Y – already in place
4364-E(up)	Cryo Line	8A	11.4	4.7	Y – already in place
4367-W	Target Cave	8A	6.7	4.7	Y – already in place
4367-E(dn)	Target Cave	4A	32.6	13.9	Y – already in place
4367-E(up)	Target Cave	8A	11.4	4.7	Y – already in place
4368-W	Target Cave	8A	18.5	4.7	Y – already in place
4368-E(dn)	Target Cave	8A	33.5	4.7	Y – already in place
4368-E(up)	Target Cave	8A	20.3	4.7	Y – already in place
4370-W	Target Wall	8A	22.9	4.7	Y – already in place
4370-E(dn)	Target Wall	4A	32.8	13.9	
4370-E(up)	Target Wall	4A	20.5	13.9	
4373-W	Pre-FMAG	8C	25.9	7.0	
4373-E(dn)	Pre-FMAG	4C	29.4	16.3	
4373-E(up)	Pre-FMAG	4C	24.3	16.3	
4376-W	FMAG Face	4C	31.0	16.3	
4376-E(dn)	FMAG Face	4C	37.4	16.3	
4376-E(up)	FMAG Face	4C	31.0	16.3	
4378-W	FMAG	4C	28.8	16.3	
4378-E(dn)	FMAG	4C	39.9	16.3	
4378-E(up)	FMAG	4C	28.8	16.3	
4380-W	FMAG	4C	26.0	16.3	
4380-E(dn)	FMAG	4C	39.9	16.3	
4380-E(up)	FMAG	4C	26.0	16.3	

Transverse Location (ft)	Location	Category	Current Shielding e.f.d.	Required Shielding e.f.d.	Interlocked detector Needed
4382-W	FMAG	4C	26.0	16.3	
4382-E(dn)	FMAG	4C	33.9	16.3	
4382-E(up)	FMAG	4C	26.0	16.3	
4388-W	FMAG	4C	22.4	16.3	
4388-E(dn)	FMAG	4C	37.7	16.3	
4388-E(up)	FMAG	4C	22.4	16.3	
4389-W	FMAG	4C	26.1	16.3	
4389-E(dn)	FMAG	4C	37.0	16.3	
4389-E(up)	FMAG	4C	26.1	16.3	
4390-W	Post-FMAG	4A	2.5	3.0	
4390-E(dn)	Post-FMAG	4A	16.9	3.0	
4390-E(up)	Post-FMAG	4A	2.2	3.0	
4392-W	Post-FMAG	4A	10.4	3.0	
4392-E(dn)	Post-FMAG	7A	24.6	3.0	
4392-E(up)	Post-FMAG	4A	10.1	3.0	
4394-W	Post-FMAG	4A	2.2	3.0	
4394-E(dn)	Post-FMAG	4A	16.9	3.0	
4394-E(up)	Post-FMAG	4A	2.2	3.0	
4411-E(dn)	Post-FMAG	4A	12.4	3.8	
4411-E(up)	Post-FMAG	4A	0.0	3.0	
4411-W	Post-FMAG	4A	0.0	3.0	
4482-E(dn)	Post-FMAG	4A	16.4	3.8	
4482-E(up)	Post-FMAG	4A	6.6	3.0	
4482-W	Post-FMAG	4A	6.6	3.0	
4502-E(dn)	Post-FMAG	4A	14.8	3.8	
4502-E(up)	Post-FMAG	4A	7.7	3.0	
4502-W	Post-FMAG	4A	7.7	3.0	

### III-14.3.2.1.2 Movable Shielding

The downstream portion of Enclosure NM3 extends into the experimental hall NM4. The NM4 experimental hall contains the target cave and the additional shielding that surrounds it. This target cave area, or “target station”, consists of a combination of steel and concrete shielding blocks and the primary beam absorber. The steel and concrete shielding blocks and absorber (Z=4362-4387), mitigate the prompt radiation dose from targeting beam to below 500 mrem/hr and are also credited controls.

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.

#### *III-14.3.2.1.3 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. This situation remains unchanged under the new MCI analysis and dose rate limits stated above.

### III-14.3.3 Active Engineered Credited Controls

Active engineered controls are systems designed to reduce the risks from the MCI to an acceptable level. The active controls in place for the operation of the NM beam line are discussed below.

#### III-14.3.3.1 Radiation Safety Interlock System

The NM enclosures employ a Radiation Safety Interlock System (RSIS). The characteristics of the system are described in Section I of the Fermilab SAD. There are interlocked doors at all entrance points to N01/NM1, NM2 and NM3 enclosures. The interlock system inhibits transport of beam into the NM beam line except when the NM beam line is properly secured and locked.

The RSIS inhibits beam by controlling redundant critical devices. For this beam line, the 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 controller 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 controller 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. An interlocked repetition rate monitor, used to limit beam spill frequency and spill duration, will be in used during beam transport to the NM area. This repetition rate limiter is a credited control. For additional information on the repetition rate monitor, see the Switchyard SAD chapter.

The RSIS including requirements for hardware and system testing, inventory of interlock keys and procedures for maintenance of interlock systems. The RSIS hardware enforces the Search and Secure and Controlled Access processes. The RSIS is designed, installed, and configuration managed in conformance with the requirements stated in the FRCM. The “search and secure” process consists of a thorough exploration of the enclosure to ensure that the NM RSIS area is not occupied. This process is completed by resetting the interlock boxes and a prescribed order in preparation for beam delivery. 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.

As mentioned above, with the NM MCI having an intensity of 2.52E15 protons/hr, the amount of permanent shielding needed to keep an individual exposure below 500 mrem in an hour is 13.9, 11.4 and 16.3 e.f.d. depending on the beam line location and category. This is the shielding between the interior surface of the enclosure walls or buried beam pipe and the nearest areas accessible by any individual.

However, for the MCI, if there are areas along the NM beamline that do not have the required amounts of shielding, Interlocked radiation detectors are employed at those areas so that the same level of protection is provided and a dose to an individual standing in these areas will not receive a dose greater than 500 mrem in one hour. These radiation detectors are interlocked to the critical device controller (CDC), and if any one of them is absent from the CDC loop in the RSIS, beam cannot be transported to the NM beam line.

Interlocked radiation detectors are placed on the berm along the primary beamline and the experimental hall in those areas that are the most likely to be occupied at locations capable of detecting all accident conditions and are credited controls. They also serve to limit prompt dose to ensure compliance with FRCM requirements. Interlocked radiation detector trip limits, for the radiation detectors on the berm, should be set at 500 mrem/hr or less. Chipmunk locations and trip level settings of radiation detectors interlocked to the RSIS must have concurrence from the assigned Radiation Safety Officer.

Interlocked radiation detectors are capable of disabling beam within a maximum of 3 seconds to the NM beam line, allowing only 1 pulse into the NM beamline in the event of an accident condition including initial detection of the event. This therefore limits the total number of protons delivered in an accident condition to  $4.2 \times 10^{13}$ . These interlocked radiation detectors will also protect transverse shielding loss points. Based on the MCI analysis the following interlocked radiation detector is a credited control[6]. While the NM3 and NM4 areas currently employ a total of 8 interlocked detectors, only the detector, shown in Table 4, on the NM3 berm is a credited control and needed to keep the dose to an individual below 500 mrem/hr. The others seven detector are in place to ensure compliance with the occupancy and posting requirements outlined in the FRCM.

Table 4: Credited Radiation Detectors

Credited Control Device	Longitudinal and Transverse Location Protected	Location	Credited Control Limit (mrem/hour)
Chipmunk	4353 - 4368	NM3 Berm	500



### III-14.3.4 [Administrative Credited Controls](#)

All NM administrative credited controls are discussed below.

#### III-14.3.4.1 [Operation Authorization Document](#)

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 beam power limits as determined and approved by the AD Associate Laboratory Director, in consultation with the ES&H Radiation Physics Operations Department Head, ES&H Accelerator Safety Department Head, assigned RSO, AD Operations Department Head, and AD External Beam Delivery Department Head. The Running Condition for the NM beam line describes the operating configuration as reviewed by the assigned RSO, AD Operations Department Head, and AD External Beam Delivery Department Head and as approved by the AD Associate Laboratory Director.

#### III-14.3.4.2 [Staffing](#)

MCR must be appropriately staffed to ensure that a valid search and secure is performed for all enclosures, that all interlocked radiation detector trip limits are below the ASE limit and all beam losses stay under one hour in duration.

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-14.3.4.3 [Accelerator Operating Parameters](#)

To ensure operations within bounding conditions used in the MCI analysis, the following intensity shall not be exceeded:  $2.75E15$  protons/hr.

## III-14.4. [Defense-in-Depth Controls](#)

Fermilab employs additional Defense in Depth (DD) controls to further reduce the possibility of an individual being exposed during an MCI. The NM beam line is located in an area in which members of the public are not invited, so that only badges employees have access to this area. Other DD controls in place are locked service buildings and radiological fences to keep individuals off the outside of the beam line berms.

### III-14.4.1 [Fencing and Posting](#)

Fences are used and posted to designate potential Radiation Areas during machine operations. The NM Shielding Assessment concluded that the radiation levels that can be expected along the NM beam line

require fences with a radiation area posting. The entire NM berm is fenced and posted consistent with its identification as a Radiation Area in accordance with the FRCM.

#### III-14.4.2 [Training](#)

All personnel engaged in the commissioning, operation, and emergency management of the NM beam line shall have at a minimum, Fermilab's Radiological Worker Training, Radiological Worker Just In Time Training and Radiological Worker Practical Factors Training. Furthermore, personnel approved for access into the NM interlocked enclosures shall have Fermilab's Controlled Access training current as well.

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

#### III-14.4.3 [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 LOTO 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-14.4.4 [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. SEMs can provide information regarding the beam intensity per spill. And the Beam Budget Monitor continually monitors the integrated beam delivered to the NM beam lines on an hourly basis.

#### III-14.5. [Decommissioning](#)

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

#### III-14.6. [Summary and Conclusion](#)

Specific hazards associated with commissioning and operation of the Neutrino Areas and 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 Neutrino Areas and 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-14.7. 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.
- [7] D. Christian, M Geelhoed, N. Mohkov, E906/SeaQuest MARS Simulation, Fermilab-TM-2479.

### III-14.8. 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 14.4 of this Chapter as well as SAD Chapter VII-A.1 *Accelerator Safety Envelope – Fermi Main Accelerator*.