NEUTRINO AREA

SECTION III CHAPTER 14
OF THE FERMILAB SAD

Revision 2 March 14, 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) SAD, Neutrino Area was prepared and reviewed by the staff of the External Beam Delivery Department in conjunction with the Environment, Safety, and Health Division (ES&H) 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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SAD Review Subcommittee Chair

Revision History

Printed versions of this Chapter of the Fermilab SAD may not be the currently approved revision. The current revision of this Chapter can be found on ES&H 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 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 and Organizational Change Edits
S. McGimpsey and C. Johnstone	2	March 14, 2023	Updated for use with the new template and editorial changes. Includes the 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 *Safety of Accelerators*
^{7}Be	Beryllium-7
BLM	Beam Loss Monitor
BNB	Booster Neutrino Beam
BPM	Beam Position Monitor
BY	Boneyard
CA	Controlled Area
CA	Contamination Area
CAS	Contractor Assurance System
CC	Credited Control
CCL	Coupled Cavity Linac
CDC	Critical Device Controller
CERN	European Organization for Nuclear Research
CFM	Cubic Feet per Minute
CFR	Code of Federal Regulations (United States)
Ci	Curie
CLW	Co-Located Worker (the worker in the vicinity of the work but not actively participating)
cm	centimeter
CPB	Cryogenics Plant Building
CSO	Chief Safety Officer
CUB	Central Utility Building
CW	Continuous Wave
CX	Categorically Excluded
D&D	Decontamination and Decommissioning
DA	Diagnostic Absorber
DAE	Department of Atomic Energy India

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

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

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 *(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 Fermilab 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 beamlines 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 standby 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 and the NM4 experimental hall. 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) beamlines. 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 beamlines. 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 beamline.

Enclosure NW6 allows access to the NW and NC beamlines.

Enclosure NW7 allows access to the NW beamline.

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.

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

The NC beamline could be used to transport the 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, and 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 beamline would consist of a 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 beamlines share a common decay pipe.

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

The aperture in the Switchyard, which would allow the transport of beam to the NC and NE areas, has been blocked with a steel block that 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 the beam were to be inadvertently misdirected. The ES&H Division, Radiation Physics Operations (RPO) department manages all movable shielding though 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, the beam can no longer be transported to the NC, NW, or NE beamlines. 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) Beamline

The only beamline capable of currently transporting beam is the NM beamline and is the focus of this SAD chapter. The NM beamline 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 beamline in the Neutrino Area that is anticipated to have the beam re-established. 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 beamline. These magnets are used to make small corrections to the beam's trajectory.

One pair of quadrupole magnets, or doublet, focuses the beam onto the target, which is located in the NM4 enclosure.

Devices for monitoring the beam's position, known as beam Position Monitors (BPM), are located along the beamline, as are devices for showing the beam's profile, known as Segmented Wire Ionization

Chambers (SWIC). Ionization chambers, which measure the beam's intensity, are in NM2 and NM3. Loss monitors are also located along the beamline.

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

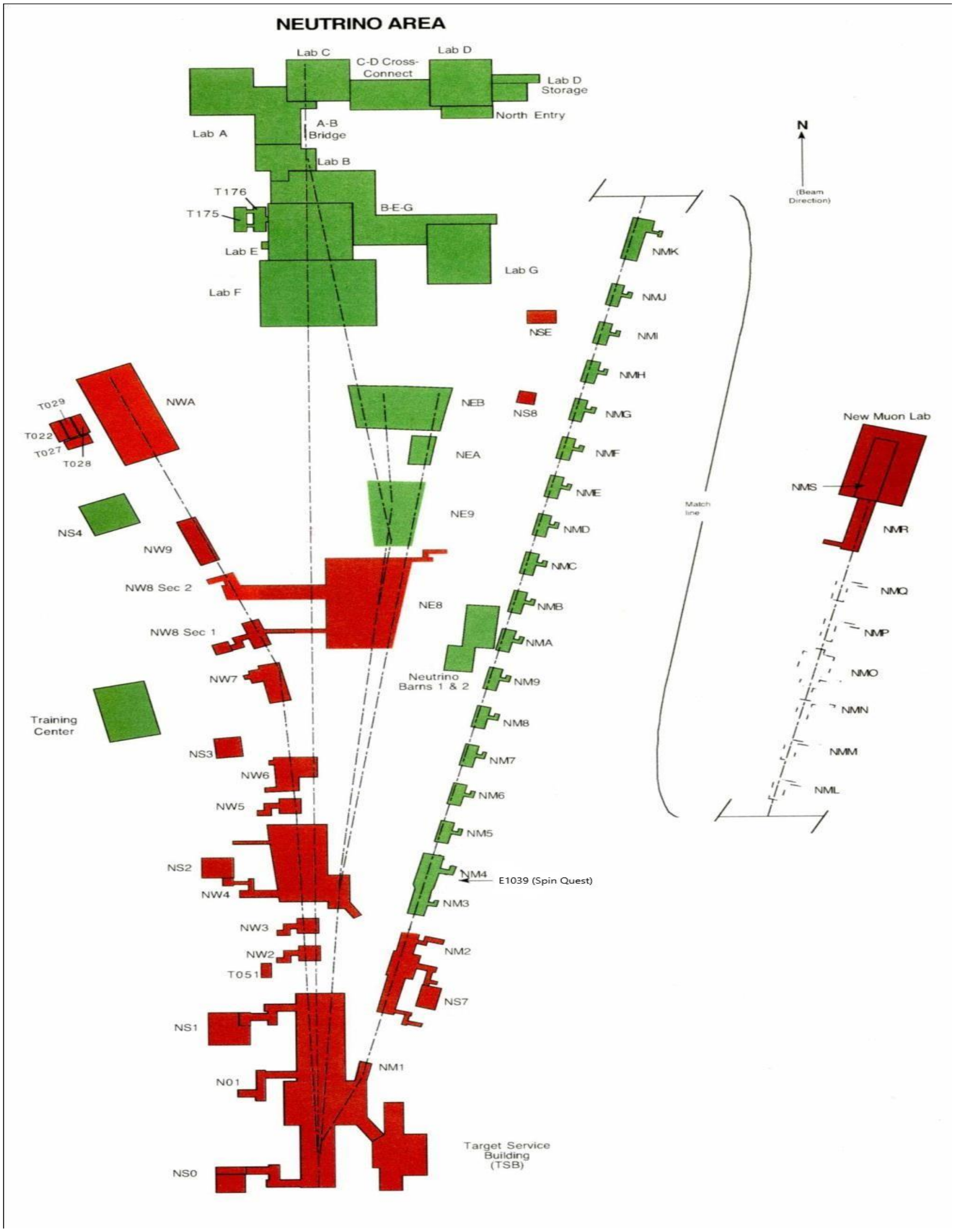

Figure 1. Layout of the Neutrino Beamline Area.

III-14-1.4 Location

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

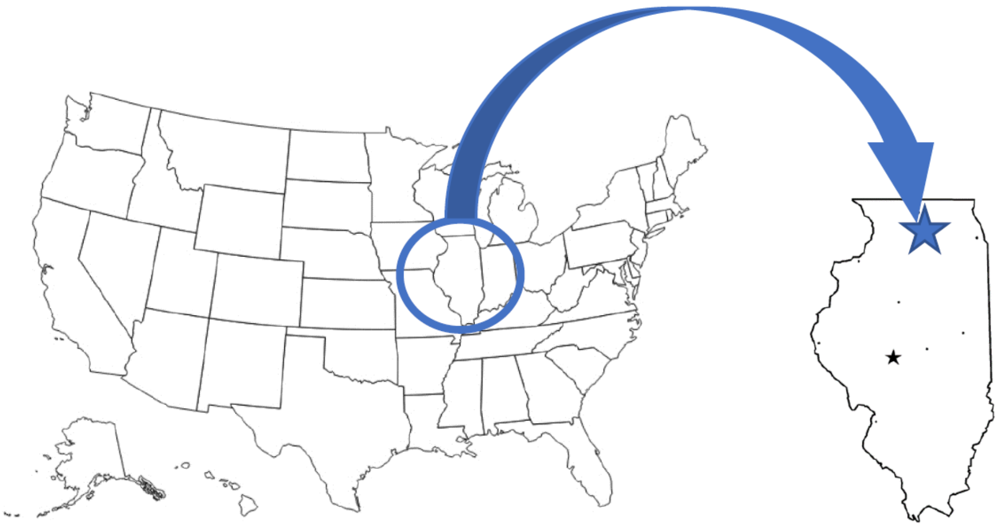

Figure 2. Regional view showing the location of the Fermilab site in Batavia, IL.

The Neutrino Area is located in the central campus on the Fermilab site. This area is located beyond Obvious Indicators, as shown in Figure 3 below.

Figure 3: Obvious Indicators

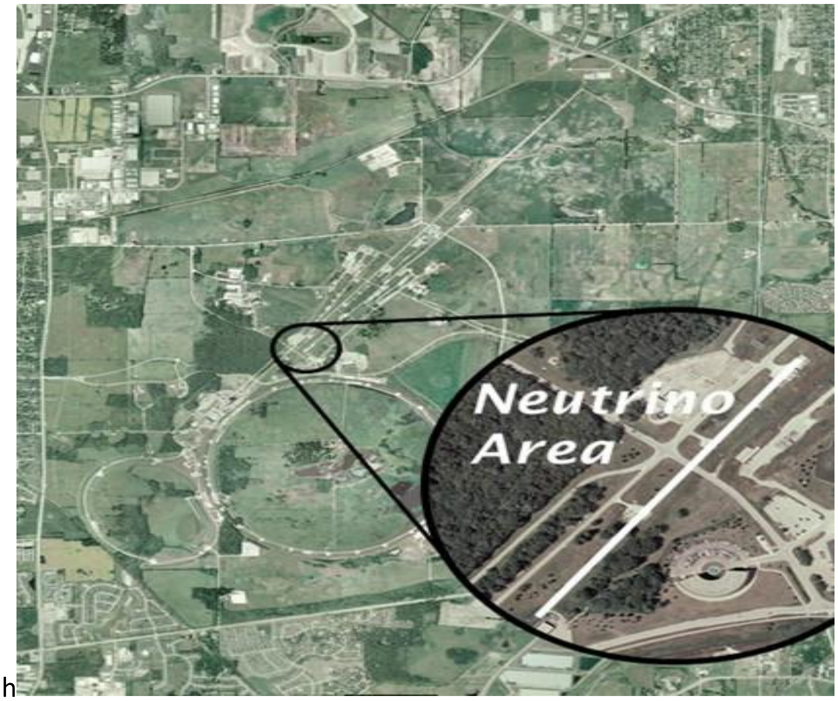

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Figure 4. Aerial view of the Fermilab site, indicating the location of the Neutrino Area.

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 $1x10^{13}$ 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. The 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 NM 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, and 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
☒	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 and 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][7] 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 beamline 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 that 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][7] has been compiled and reviewed to address these concerns. The assessment provides a detailed analysis of this facility, demonstrating the required overburden, and the 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 beamline areas from Switchyard and Enclosures C (G1 stub), G2, N01/NM1, NM2, and 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 an inadvertently steered beam, and radiological shielding have been added to the downstream end of NM3; these are assessed in the 2019 shielding assessment addendum [7].

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 beamline. 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 an 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 that 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 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 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 were 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][7], an evaluation has been performed to estimate the surface water and groundwater activation concentrations in the vicinity of soil surrounding a beam pipe. The shielding assessment demonstrates that the operation of the NM beamline 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 beamline is not operational for a full calendar year. The NM beamline 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 were 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 FMAG at the downstream end of NM3 is required to be classified as a RAW system [8]. 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 were 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 the NM beamline 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 [7] 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][7] estimates that based on $5.26x10^{18}$ 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 were 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 were 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). This includes incidental radioactive materials produced during the irradiation of target materials, as well as beamline components that 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 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 beamline 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 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 been 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 were 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. Since this material is inaccessible to workers, co-located workers, and the 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 is 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. 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. Baseline risk for this hazard was R II and, after control measures were evaluated, the residual risk level was R IV.

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. Baseline risk for this hazard was R II and, after control measures were evaluated, the residual risk level was R IV.

III-14.2.2.3 Fluorinert and 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. Baseline risk for this hazard was R I and, after control measures were evaluated, the residual risk level was R IV.

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. Baseline risk for this hazard was R I and, after control measures were evaluated, the residual risk level was R IV.

III-14.2.4.1 Stored-Energy Exposure

The Neutrino Area electrical hazards from the alternating current 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. Baseline risk for this hazard was R I and, after control measures were evaluated, the residual risk level was R IV.

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. Baseline risk for this hazard was R I and, after control measures were evaluated, the residual risk level was R IV.

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. Baseline risk for this hazard was R I and, after control measures were evaluated, the residual risk level was R IV.

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. Baseline risk for this hazard was R I and, after control measures were evaluated, the residual risk level was R IV.

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. Baseline risk for this hazard was R I and, after control measures were evaluated, the residual risk level was R IV.

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. Baseline risk for this hazard was R I and, after control measures were evaluated, the residual risk level was R III.

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. Baseline risk for this hazard was R I and, after control measures were evaluated, the residual risk level was R IV.

III-14.2.7.2 Compressed Gases

It is anticipated that compressed gases may need to be brought into the Neutrino Areas or enclosures, for experimental purposes. $ArCO_2$ is routinely used in beamline diagnostic components. These gas cylinders are securely stored in the G2 service building and outside of the NM4 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. Baseline risk for this hazard was R I and, after control measures were evaluated, the residual risk level was R IV.

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. Baseline risk for this hazard was R I and, after control measures were evaluated, the residual risk level was R III.

III-14.2.7.4 Vacuum Pumps

Roughing/turbo pumps are used throughout the NM beamline 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. Baseline risk for this hazard was R I and, after control measures were evaluated, the residual risk level was R III.

III-14.2.7.5 Material Handling

Trained personnel operate forklifts or handcarts 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. Baseline risk for this hazard was R I and, after control measures were evaluated, the residual risk level was R IV.

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 beamline comes from electromagnets. Fields are nominally only hazardous to people who have medical device implants. This hazard has been evaluated within the common risk matrix table included in SAD Section I Chapter 04 *Safety Analysis*. Work in the NM area involving this hazard implements the controls specified in the common risk matrix table. No unique controls are in use. Baseline risk for this hazard was R I and, after control measures were evaluated, the residual risk level was R III.

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. Baseline risk for this hazard was R I and, after control measures were evaluated, the residual risk level was R III.

III-14.2.9.2 Noise

Operational beamline systems or experimental setups 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. Baseline risk for this hazard was R III and, after control measures were evaluated, the residual risk level was R IV.

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. Baseline risk for this hazard was R I and, after control measures were evaluated, the residual risk level was R IV.

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. Baseline risk for this hazard was R I and, after control measures were evaluated, the residual risk level was R IV.

III-14.2.9.5 Asbestos

Access penetrations connecting the service buildings to the NM beamline enclosures may be asbestos-lined due to common fire prevention practices during the period when the building was constructed; 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. Baseline risk for this hazard was R I and, after control measures were evaluated, the residual risk level was R IV.

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.

Baseline risk for this hazard was R I and, after control measures were evaluated, the residual risk level was R III.

III-14.2.10 Access and Egress

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. Baseline risk for this hazard was R I and, after control measures were evaluated, the residual risk level was R IV.

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 MCI scenario that could happen in the NM beamline. Consideration and analysis of this MCI is focused on an onsite facility worker, onsite co-located worker, and an MOI.

III-14.3.1.1 Radiological Hazard

The NM beamline can provide 120 GeV protons from the Main Injector, through the Switchyard, down to a beam absorber downstream in NM3. An MCI 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 beamline resulting from the MCI for the 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 4.2E13 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 and described in detail in the Switchyard SAD chapter. 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 60-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 beamline 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 beamline, the power supply for V100 would need to be energized continuously, which would bend the beam vertically up, away from the Switchyard absorber and into the NM beamline. 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 [8] finds that a peak dose rate in excess of 200,000 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 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 and 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 5000 mrem for workers and co-located workers 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 NM enclosures is documented in the NM Beam Line SA and addendum [2][7] and listed here in Tables 2 through 5. Typically, this shielding is required to keep MCI doses to workers and co-located worker below 500 mrem in one hour. However, the entire NM berm from N01/NM1 to NM4 is surrounded by a locked fence and posted as a Radiation Area. As a result, the maximum dose to workers and co-located workers cannot exceed 5000 mrem in one hour. For this MCI analysis, the first step will be to determine if any locations exceed 500 mrem in one hour due to the MCI. If 500 mrem is exceeded, the maximum dose rate in those areas will be determined to see if 5000 mrem is exceeded in one hour behind the locked fence or 500 mrem is exceeded at the fence line in one hour.

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, 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 enclosures. 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. There is one longitudinal area (Z = 4357 to 4386) and one transverse area (4353-4367) where 500 mrem in one hour is exceeded. However, the dose at the longitudinal location is mitigated with an interlocked detector that is already present for 10CFR835 purposes. While an interlocked detector is located at this transverse location, the area around the target station, it does not mitigate the MCI dose due to 500 mrem being exceeded with one pulse of beam. It is this location that will constitute the highest dose rate due to the MCI and requires further evaluation.

Table 2: Longitudinal Shielding Spreadsheet from E906

Longitudinal Range	Location	Fixed Shielding (efd)	Movable Shielding (efd)	Current Shielding (efd)	Required (efd)
3179-3216	NM1	19.6		19.6	13.9
3216-3620	Beam Pipe	22.0		22.0	16.3
3620-3829	NM2	18.0		18.0	13.9
3829-3929	NM2	15.5		15.5	13.9
3929-4060	NM2	17.5		17.5	13.9
4060-4113	Beam Pipe	30.8		30.8	16.3
4113-4230	NM3	21.0		21.0	13.9
4230-4334	NM3	21.3		21.3	11.4
4334-4348	NM3	12.5		12.5	11.4
4348-4360	NM3	11.3		11.3	11.4

Table 3: Longitudinal Shielding Spreadsheet from E1039

Longitudinal Range	Location	Fixed Shielding (efd)	Movable Shielding (efd)	Current Shielding (efd)	Required (efd)
4353-4357	NM3 collimator	11.4	6.1	17.5	13.9
4357-4360	NM3	11.4		11.4	11.4
4360-4368	Target Cave		11.7	11.7	13.9
4368-4373	Target Wall		29.9	29.9	16.3
4373-4374	Pre-FMAG		31.4	31.4	16.3
4374-4378	FMAG US		31.0	31.0	16.3
4378-4381	FMAG US		28.8	28.8	16.3
4382-4388	FMAG DS		26.0	26.0	16.3
4388-4389	FMAG DS		22.4	22.4	16.3
4389-4390	FMAG DS		28.5	28.5	16.3
4390-4391	Post-FMAG		3.5	3.5	3.0
4391-4392	Post-FMAG		8.9	8.9	3.0
4392-4394	Post-FMAG		3.5	3.5	3.0

Longitudinal Range	Location	Fixed Shielding (efd)	Movable Shielding (efd)	Current Shielding (efd)	Required (efd)
4394-4454	NM4		0.0	0.0	3.0
4454-4490	NM4		7.1	7.1	3.0
4490-4503	NM4		8.9	8.9	3.0

Table 4: Transverse Shielding Spreadsheet from E906

Transverse Station (ft)	Location	Fixed Shielding (efd)	Movable Shielding (efd)	Current Shielding (efd)	Required (efd)
NC13176	N01	26.6		26.6	16.3
NC13208	N01	21.8		21.8	16.3
NM23673	NM2	19.0		19.0	16.3
NM23827	NM2	19.5		19.5	16.3
NM23882	NM2	19.0		19.0	16.3
NM24009	NM2	25.5		25.5	16.3
NM24028	NM2	17.9		17.9	16.3
NM24100	Beam Pipe	31.4		31.4	18.7
NM34120	NM3	18.4		18.4	16.3
NM34125	NM3	21.7		21.7	16.3
NM34150	NM3	21.7		21.7	13.9
NM34168	NM3	21.2		21.2	13.9
NM34245	NM3	21.3		21.3	13.9

Table 5: Transverse Shielding Spreadsheet from E1039

Transverse Station (ft)	Location	Fixed Shielding (efd)	Movable Shielding (efd)	Current Shielding (efd)	Required (efd)
4354-W	NM3 Collimator	11.4	6.1	17.5	16.3
4354-E	NM3 Collimator	11.4	6.1	17.5	16.3
4357-W	NM3	16.9	0.0	16.9	13.8
4357-E	NM3	16.9	0.0	16.9	13.8
4360-W	Target Cave		4.0	4.0	13.9
4360-E(dn)	Target Cave		19.8	19.8	13.9
4360-E(up)	Target Cave		5.0	5.0	13.9

Transverse Station (ft)	Location	Fixed Shielding (efd)	Movable Shielding (efd)	Current Shielding (efd)	Required (efd)
4361-W	Target Cave		8.4	8.4	13.9
4361-E(dn)	Target Cave		23.6	23.6	13.9
4361-E(up)	Target Cave		11.4	11.4	13.9
4364-W	Cryo Line		11.0	11.0	13.9
4364-E(dn)	Cryo Line		23.6	23.6	13.9
4364-E(up)	Cryo Line		11.4	11.4	13.9
4367-W	Target Cave		6.7	6.7	13.9
4367-E(dn)	Target Cave		32.6	32.6	13.9
4367-E(up)	Target Cave		11.4	11.4	13.9
4368-W	Target Cave		18.5	18.5	13.9
4368-E(dn)	Target Cave		33.5	33.5	13.9
4368-E(up)	Target Cave		20.3	20.3	13,9
4370-W	Target Wall		22.9	22.9	13.9
4370-E(dn)	Target Wall		32.8	32.8	13.9
4370-E(up)	Target Wall		20.5	20.5	13.9
4373-W	Pre-FMAG		25.9	25.9	16.3
4373-E(dn)	Pre-FMAG		29.4	29.4	16.3
4373-E(up)	Pre-FMAG		24.3	24.3	16.3
4376-W	FMAG Face		31.0	31.0	16.3
4376-E(dn)	FMAG Face		37.4	37.4	16.3
4376-E(up)	FMAG Face		31.0	31.0	16.3
4378-W	FMAG		28.8	28.8	16.3
4378-E(dn)	FMAG		39.9	39.9	16.3
4378-E(up)	FMAG		28.8	28.8	16.3
4380-W	FMAG		26.0	26.0	16.3
4380-E(dn)	FMAG		39.9	39.9	16.3
4380-E(up)	FMAG		26.0	26.0	16.3
4382-W	FMAG		26.0	26.0	16.3
4382-E(dn)	FMAG		33.9	33.9	16.3
4382-E(up)	FMAG		26.0	26.0	16.3
4388-W	FMAG		22.4	22.4	16.3
4388-E(dn)	FMAG		37.7	37.7	16.3
4388-E(up)	FMAG		22.4	22.4	16.3
4389-W	FMAG		26.1	26.1	16.3
4389-E(dn)	FMAG		37.0	37.0	16.3
4389-E(up)	FMAG		26.1	26.1	16.3
4390-W	Post-FMAG		2.5	2.5	3.0
4390-E(dn)	Post-FMAG		16.9	16.9	3.0
4390-E(up)	Post-FMAG		2.2	2.2	3.0
4392-W	Post-FMAG		10.4	10.4	3.0

Transverse Station (ft)	Location	Fixed Shielding (efd)	Movable Shielding (efd)	Current Shielding (efd)	Required (efd)
4392-E(dn)	Post-FMAG		24.6	24.6	3.0
4392-E(up)	Post-FMAG		10.1	10.1	3.0
4394-W	Post-FMAG		2.2	2.2	3.0
4394-E(dn)	Post-FMAG		16.9	16.9	3.0
4394-E(up)	Post-FMAG		2.2	2.2	3.0
4411-E(dn)	Post-FMAG		12.4	12.4	3.0
4411-E(up)	Post-FMAG		0.0	0.0	3.0
4411-W	Post-FMAG		0.0	0.0	3.0
4482-E(dn)	Post-FMAG		16.4	16.4	3.0
4482-E(up)	Post-FMAG		6.6	6.6	3.0
4482-W	Post-FMAG		6.6	6.6	3.0
4502-E(dn)	Post-FMAG		14.8	14.8	3.0
4502-E(up)	Post-FMAG		7.7	7.7	3.0
4502-W	Post-FMAG		7.7	7.7	3.0

MARS simulations were performed previously for the NM shielding assessment and addendum, and the results were used to scale up to the MCI intensity to determine the unmitigated dose rates. The results are shown in Figure 4. Then the dose rates were determined at the target cave, and then scaling the dose rates out to locations accessible by workers and co-located workers is shown in Figure 5.

Table 6: Unmitigated Doses for the MCI

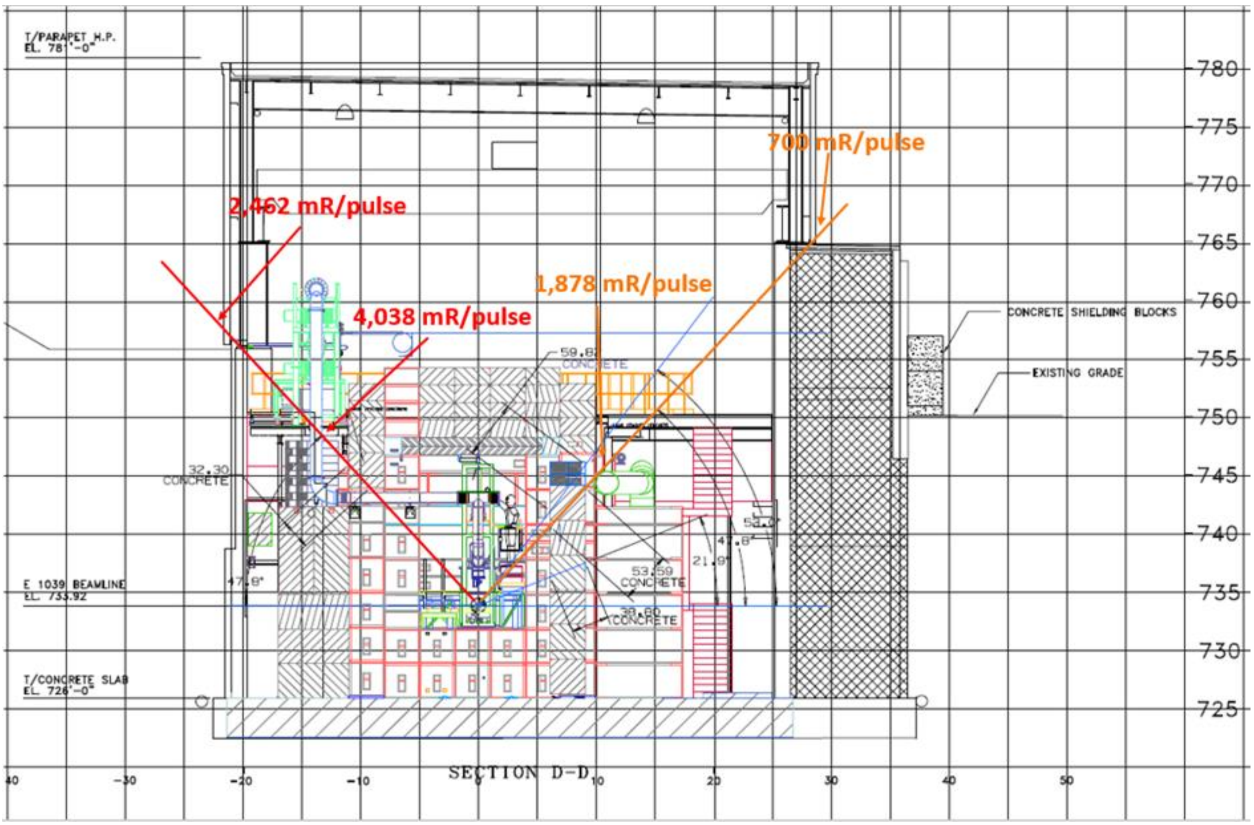
Enclosure	Z Location	ISA spreadsheet	Shielding efd	MCI peak dose (mrem/hr)
NM1	3179-3216' 3208'	Longitudinal Transverse	19.6 21.8	7 <2
Berm pipe	3216-3620'	Longitudinal	22	7
NM2	3829-3929 4028'	Longitudinal Transverse	15.5 17.9	117 2
Berm Pipe	4060-4113 4100'	Longitudinal Transverse	30.8 31.4	<1 <1
NM3	4353-4364' 4360-4367'	Longitudinal Transverse	11.7 4	1,615 262,500
NM4	4394-4454'	longitudinal	0	<45.7 LPH2-NMS001
NM4	4390 – 4394'	transverse	2.2	<45.7

Enclosure	Z Location	ISA spreadsheet	Shielding efd	MCI peak dose (mrem/hr)
				XPH2-NMS001-2
NM4	4411'	transverse	0	<45.7 XPH2-NMS004-5

Figure 5 shows a "slice" at the interaction point at the NM3 target cave and the highest resulting doses. The largest calculated doses are on the east side of the NM4 experimental hall roof and the southwest corner of the NM4 experimental hall at grade level. The due east and west side locations were evaluated, due to these areas potentially being accessible to personnel on the other side of the locked fence. The dose on the roof is 700 mrem and the dose at the southwest corner is 2462 mrem. Both of these locations are only accessible to workers and co-located workers and are less than 5000 mrem. However, these doses result from one pulse of MCI beam intensity. So, the two chipmunks, on the NM3 berm and the southwest corner of the NM4 experimental hall, will be credited controls with trip limits set to less than 5000 mrem/hr.

The roof is not accessible to personnel. The fence on the west side is 143 feet away from NM4 and is the closest accessible location. Keeping the berm dose rate to less than 5000 mrem/hr, 1/r would reduce this dose at the fence line to 35 mrem in one hour. Although this is conservative since the NC berm is present between NM4 and the fence, and the highest dose that is not mitigated by any shielding outside of NM4 experimental hall emanates from grade level at approximately a 45-degree angle.

Figure 5: Scaled dose rates for the MCI



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 5000 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][7]. 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-14.3.2.1.4 Fencing

Locked 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-14.3.3 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 beamline 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, and the NM4 experimental area. The interlock system inhibits transport of beam into the NM beamline except when the NM beamline is properly secured and locked.

The RSIS inhibits beam by controlling redundant critical devices. For this beamline, the two critical devices, V100 and MuLam, are used to inhibit beam from entering the NM beamline. 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. MuLam consists of one horizontally bending dipole magnet 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 beamline. Both V100 and MuLam are in the Switchyard Area upstream of the Neutrino Area beamlines. Compromising the RSIS 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, NM3, and NM4. 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. It should be noted that the G2 enclosure is protected by critical devices V100 and HP3US/HP3DS. More information on that can also be found in the Switchyard SAD chapter.

The RSIS includes 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.

All but two locations on the NM berm have more than the required amount of shielding to keep doses to workers and co-located workers to less than 5000 mrem in one hour. The locations with enough shielding minus 0.5 efd, listed in Tables 2 through 5, is a credited control. For the two locations that do not have enough shielding, the shielding that is present is a credited control, along with an interlocked detector. The trip setting for the interlocked detector will be set to account for this lesser amount of shielding taken as a credited control. As a result, 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 5000 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 into the NM beamline.

Interlocked radiation detectors are placed on the NM3 berm along the beamline and the southwest corner of the NM4 experimental hall. The interlocked radiation detectors protect personnel by disabling the beam should prompt radiation from operations exceed specific dose rate limits. The credited control trip limits for these interlocked radiation detectors are set to levels that prevent any individual from receiving a dose rate beyond what is defined in Section III-14.3.2.1.1, even with an unforeseen reduction of the permanent shielding between the interior of the enclosure walls and the surface of the berm by 0.5 e.f.d., at the time of the maximum credible incident. The analysis to determine the credited control trip limits is provided as a reference in the “Analysis of the Maximum Credible Incident Analysis for Neutrino Muon Beam Line.” [6] This analysis evaluates the consequence of the maximum credible beam intensity being lost at the target cave. The specific detector type, their locations, and their credited control trip limit values are presented in Table 7 below. Operationally, the trip levels are set lower than this value to satisfy occupancy requirements per 10 CFR Part 835 through the direction of the Radiation Physics Operation Department (RPO).

Interlocked radiation detectors are capable of disabling beam within a maximum of three seconds to the NM berm, allowing only one 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 4.2×10^{13}.

Table 7: Credited Radiation Detectors

Credited Control Device	Longitudinal and Transverse Location Protected	Location	Credited Control Limit (mrem/hour)
Chipmunk	4353 – 4368 (Long.)	NM3 Berm	< 5000
Chipmunk	4360 – 4367 (Trans.)	SW Corner of NM4 Exp. Hall.	< 5000

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 NM beamline 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 that 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 beamline is located in an area in which members of the public are not invited, so that only badged 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 beamline berms.

III-14.4.1 Interlocked Detectors

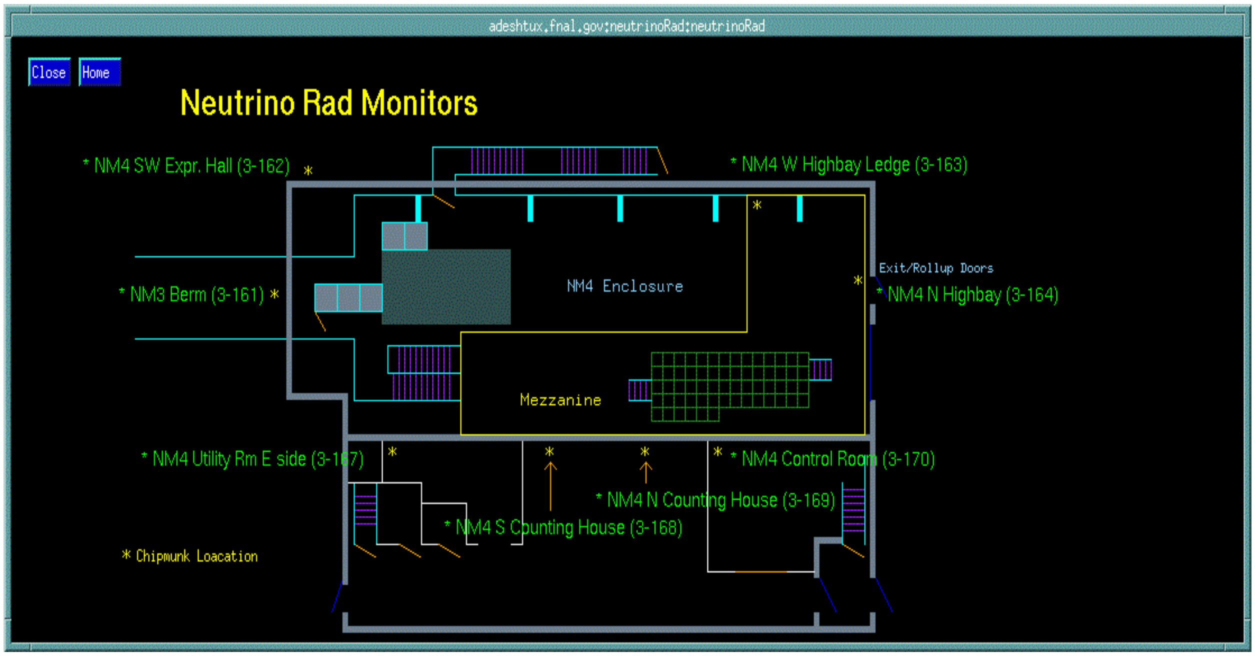
The NM4 experimental area currently employs an additional six interlocked detector radiation detectors to limit prompt dose to ensure compliance with 10CFR835 and the Fermilab ALARA Program requirements. Interlocked detectors 3-161and 3-162 are credited controls as described in Section III-

14.3.3.1. Interlocked radiation detector trip limits, for the radiation detectors on the berm and in the experimental hall, should be set to less than 5000 mrem/hr. Chipmunk locations and trip level settings of radiation detectors interlocked to the RSIS must have concurrence from the assigned RSO.

Interlocked radiation detectors are capable of disabling beam within a maximum of three seconds to the NM beamline, thus only allowing only one pulse into the NM beamline in the event of a trip setting being exceeded. These detector locations are shown in Figure 6.

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 the minimum three feet 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.

Figure 6: Interlocked Detectors



III-14.4.1 Training

All personnel engaged in the commissioning, operation, and emergency management of the NM beamline shall have, at a minimum, Fermilab's Radiological Worker 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 (LOTO) procedures shall be required to perform troubleshooting and maintenance as applicable.

III-14.4.2 Procedures

As applicable, either Fermilab's general Lock Out-Tag Out or written Departmental LOTO procedures shall be used. As per Fermilab's FESHM Chapter 2100, written departmental LOTO procedures shall be reviewed and re-approved every 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 12 months to remain current.

III-14.4.3 Machine Protection Controls

Beam Loss Monitors routinely determine when beam is being lost at unacceptable regions and/or rates. Beam Position Monitors and 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 beamline 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 S. McGimpsey, Maximum Credible Incident Analysis for the Neutrino Muon Beamline, March 2024.
[7] C. Johnstone and I. Rakhno, Neutrino Muon Beamline Shielding Assessment Addendum for E1039, December 18, 2019.
[8] 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*.