Neutrino Area

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Revision History

Author	Description of Change	Revision No. & Date
Thomas R. Kobilarcik	Initial release of the Neutrino Area Chapter for the Fermi National Accelerator Safety Assessment Document (SAD).	Revision 0 February 14, 2012
Thomas R. Kobilarcik	Revision for E1039 running • Inclusion of Shielding Assessment Addendum • Updated target station information • Sleeve around buried beampipe between G2 and N01 enclosures Editorial & Organizational Change Edits	Revision 1 October 6, 2022

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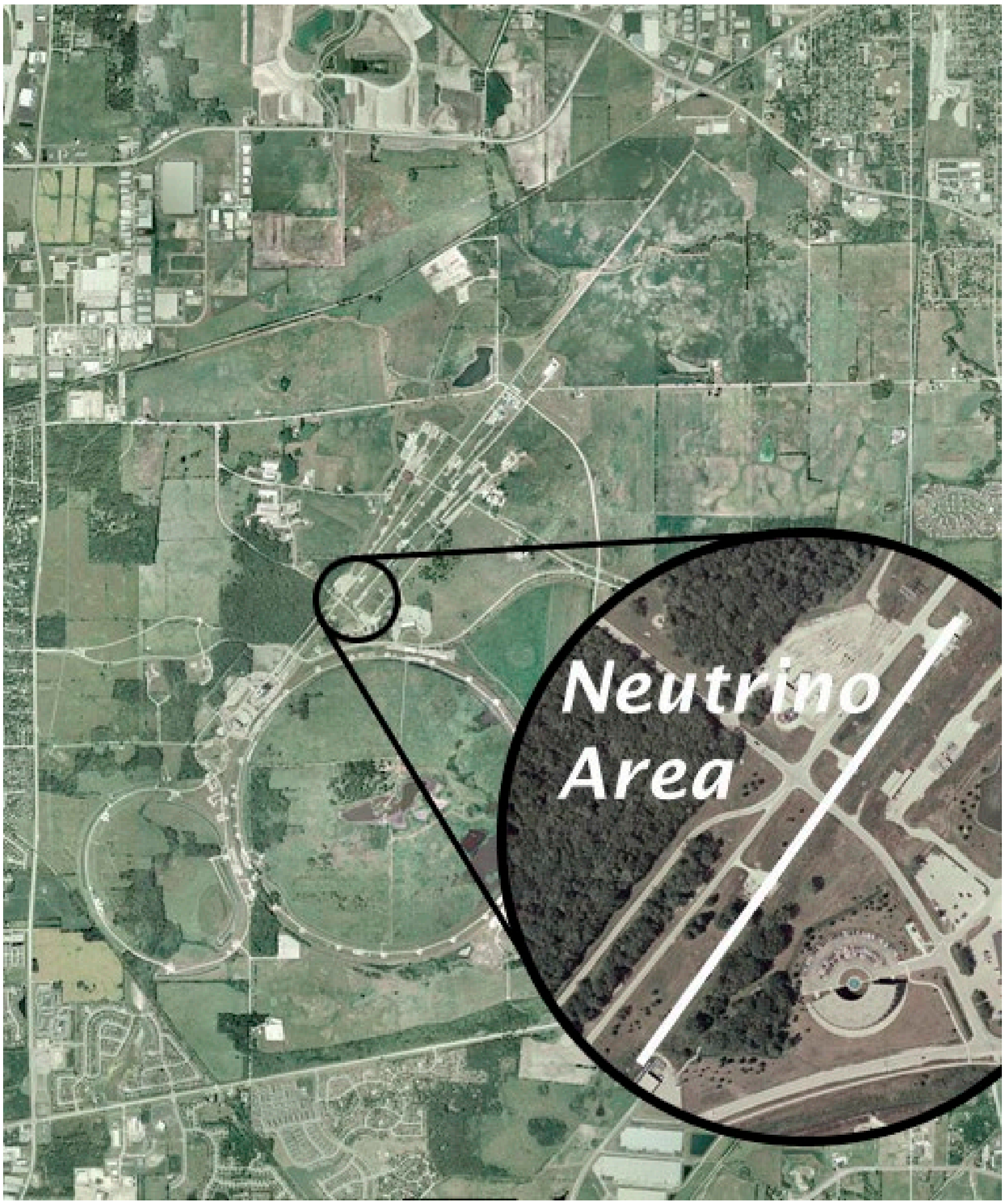
II - 16.1 Neutrino Area Beamline Location on Fermilab Site

The following aerial photograph shows the location of the Neutrino Area in relationship to the Fermilab site.



II - 16.2 Inventory of Hazards

The following table lists the identified hazards found in the Neutrino Area enclosures and support buildings. All hazards with an * have been adequately discussed in Chapters 1-10 of the Fermilab Safety Assessment Document (SAD) and are covered no further in this section.

Radiation Particle beams and prompt radiation Residual component activation Radioactive waste Surface water activation Groundwater activation Air activation Soil activation	**Kinetic Energy** Power tools* Pumps and motors*
Toxic Materials Lead shielding* Glycol*	**Potential Energy** Crane operations* Compressed gases* Vacuum / pressure vessels* Vacuum Pumps*
Flammable & Combustible Materials Cables*	**Magnetic Fields** Fringe fields*
Electrical Energy Stored energy exposure* High voltage exposure* Low voltage, high current exposure*	**Gaseous Hazards** Confined spaces*
Thermal Energy	**Access / Egress** Life Safety Egress*

II - 16.3 Introduction

This Section II, Chapter 16 of the Fermi National Accelerator Laboratory (Fermilab) SAD covers the Neutrino Beamline, target station, and beam absorber areas. The chapter has been prepared by the staff of the Fermilab Accelerator Division (AD) External Beam Delivery Department.

II - 16.3.1 Purpose of the Neutrino Area

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.

II - 16.3.2 Description of the Neutrino Area

The Neutrino Area, see figure 1, includes enclosures N01, NW2, NW3, NW4, NW5, NW6, and NW7; NM2, NM3 and NM4. Associated services buildings are NS0, NS1, NS2, NS3 and NS7. The Target Service Building (TSB) is also in the neutrino area.

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

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

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

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

Enclosure NW5 allows access to the NW beam line.

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

Enclosure NW7 allows access to the NW beam line.

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

Enclosure NM2 is to the east of, and at a lower elevation than, N01. This enclosure is accessed by the NS7 service building. Enclosures NM1 and NM2 are connected by buried vacuum pipe.

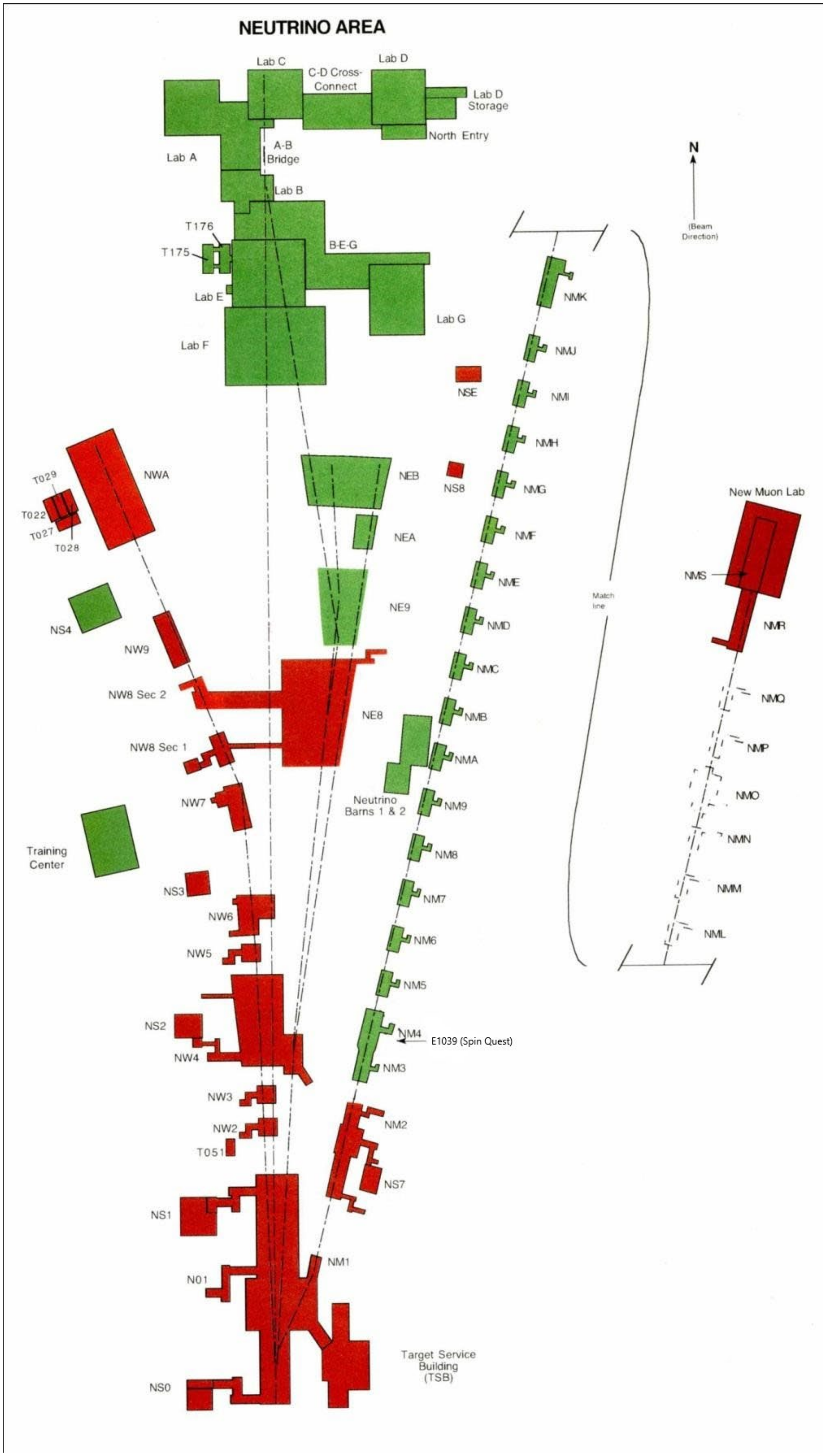

NEUTRINO AREA
Lab C
C-D Cross-Connect
Lab D
Lab D Storage
North Entry
Lab A
A-B Bridge
Lab B
T176
T175
B-E-G
Lab E
Lab G
Lab F
N
(Beam Direction)
NMK
NMJ
NMI
NMH
NMG
NMF
NME
NMD
NMC
NMB
NMA
NM9
NM8
NM7
NM6
NM5
NM4
E1039 (Spin Quest)
NM3
NM2
NS7
NM1
NSE
NS8
NWA
T029
T022
T027
T028
NEB
NEA
NE9
NS4
NW9
NW8 Sec 2
NE8
NW8 Sec 1
NW7
Neutrino Barns 1 & 2
Training Center
NS3
NW6
NW5
NS2
NW4
NW3
NW2
T051
NS1
N01
NS0
Target Service Building (TSB)
New Muon Lab
NMS
NMR
NMQ
NMP
NMO
NMN
NMM
NML
Match line

Figure 1

Enclosure NM3 is connected to NM2 by buried vacuum pipe. Enclosure NM3 extends into NM4 (which is used as the experimental hall).

II - 16.3.2.1 Description of the NE, NC, and NW Beamlines

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

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

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

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

II - 16.3.2.2 Description of the NM Beam Line

The NM Beamline extends through Enclosure NM1, into NM2, and terminates in Enclosure NM3.

Dipole magnets located in NM2 constitute the principle bend points in the beamline. Additional dipole magnets, referred to as "trim magnets" or "correctors", are found along the beam line. These magnets are used to make small corrections to the beam's trajectory.

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

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

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

II - 16.3.3 Operating Modes

The NM Beamline is capable of transporting 120 GeV/c protons from Enclosure NM1 to Enclosure NM3 at a variable spill rate and an intensity of $1\text{x}10^{13}$ 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.

II - 16.4 Safety Assessment

The unique beamline specific hazards for the NM beam line are analyzed in this section.

II - 16.4.1 Radiological Hazards

Radiation safety has been carefully considered in the design of the NM Beamline. The beamline presents radiological hazards in the form of prompt and residual ionizing radiation from particle beams, residual radiation due to activation of beamline components, and environmental radioactivity in the form of air, soil, and potential groundwater activation resulting from operating the beam transport and targeting systems.

A detailed shielding assessment and subsequent addendum[1,6] address these concerns. The assessments provide a detailed analysis of this facility, demonstrating the required overburden, use of signs, fences, and active interlocks to comply with the Fermilab Radiological Control Manual[2] (FRCM). Residual activation of components has a substantial impact on the ability to occupy the beamline enclosures where recurring access is required for routine maintenance. The 2012 shielding assessment for the Neutrino area extends from Enclosure C, where the first critical device is located, and continues through the G1, G2, NM1, NM2, and NM3 enclosures.

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

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.

II - 16.4.1.1 Ionizing Radiation

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

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

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

The 2019 Shielding Assessment requires that:

- *All penetrations be filled with shielding as specified.*
- *All movable shielding blocks be installed as specified.*
- *The average beam intensity shall not exceed 6.00×10^{14} protons per hour.*
- *Annual limit of $5.26x10^{18}$ protons.*
- *The instantaneous beam intensity shall not exceed 1.00×10^{13} protons over a 4-second spill.*

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

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

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

II - 16.4.1.2 Residual Activation

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

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

In most situations, general RWPs for access will suffice. A job-specific RWP and/or ALARA ("as-low-as-reasonably-achievable") plan will be required for work on any highly activated or potentially contaminated equipment with a potential individual exposure greater than 200 millirem (mrem) or potential exposures for all persons on the job greater than 1000 mrem. These tasks will be supervised by members of the Radiological Control Organization under the direction of the assigned Radiation Safety Officer (RSO).

II - 16.4.1.3 Radioactive Waste

Radioactive waste hazards and disposal will be managed within the program established throughout the Fermilab accelerator complex and as prescribed in the FRCM. Waste minimization is an objective of both the NM Beamline design and operational procedures. Although production of radioactive material is not an operational function of the NM Beamline, accidental beam loss and, in the case of some beam diagnostics devices, intentional interception of the beam will result in activation of beam line elements. Activated items that cannot be reused will be disposed eventually as radioactive waste in accordance with the FRCM requirements.

II - 16.4.1.4 Groundwater and Surface Water Activation

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

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

II - 16.4.1.5 Air Activation

Air activation is caused by the primary 120 GeV proton beam and secondary radiation interacting with the air surrounding the target station. The principal radionuclides of concern are ^{11}C (which has about a 20 minute half-life), ^{13}N (which has about a 10 minute half-life), ^{15}O (which has about a 2 minute half-life), ^{3}H, and ^{41}Ar (which are produced by thermal neutron capture on ^{40}Ar). ^{3}H and ^{41}Ar have half-lives of 12.3 years and 1.8 hours, respectively. The existing ventilation systems in NM beamlines slow transit time adequately to allow for radioactive decay of short-lived positron emitters. Access to these areas is tightly controlled, and will not be allowed without an adequate cool-off period. The cool-off period is determined by the assigned RSO, based on the shielding assessments. The shielding assessment addendum[6] specifies a 120-minute cool-off period prior to allowing access into the NM3 or NM4 enclosures to keep personnel exposure below 20% of the Derived Air Concentration (DAC) values. The shielding assessment[1] estimates that based on 5.26×10^{18} protons delivered per year, the annual air releases from operations will be 2 ± 0.6 Curies per year. This is a few percent of the laboratory annual air release budget.

II - 16.4.2 Oxygen Deficiency Hazards

The beamline does not use components that could produce oxygen deficiency hazards. The target, located in NM4 (the experimental hall), and NM3 are engineered ODH class 0[3]. Possible ODH hazards introduced by an experiment are addressed in Section 3 Chapter 3.Cryogenics

The beamline does not use cryogens. Possible cryogenic hazards introduced by an experiment are addressed in Section 3 Chapter 3.

II - 16.4.2.1 Hydrogen Target

Infrastructure exists at the downstream end of Enclosure NM3. The hazard assessment is specific to an individual experiment; refer to Section 3 Chapter 3.

II - 16.4.3 Unique Electrical or Magnetic Field Hazards

The electrical hazards for the Neutrino area fall within the scope described in the "Electrical Hazards" paragraph of Section 1, Chapter 4 of this document. There are no significant accelerator specific electrical or magnetic field hazards.

II - 16.5 Credited Controls

II - 16.5.1 Passive Controls

Passive controls are elements that are part of the physical design of the facility that require no action to function properly. These are fixed elements of the accelerator that take direct human intervention to remove. The NM Beam line uses a combination of permanent shielding, movable shielding, penetration shielding, and radiation area fences to protect personnel from radiological exposure during beam operations.

II - 16.5.1.1 Permanent Shielding Including Labyrinths

The permanent shielding encompasses the structural elements surrounding the beamline components and experimental hall. The permanent shielding for the enclosure is documented in the NM Beam Line SA[1] and addendum[6] and consists of sufficient earth overburden such that unacceptable levels of prompt radiation cannot occur based on the assessed beam conditions.

II - 16.5.1.2 Movable Shielding

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

The large shielding blocks range in weight from approximately 10,000 pounds to approximately 26,000 pounds, and cannot be moved without the use of the NM4 crane. The shielding for this area is defined in the shielding assessment[1] and addendum[6]. The AC power disconnect switch for the NM4 crane is locked out and configuration controlled by the assigned RSO.

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

II - 16.5.1.3 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.

II - 16.5.1.4 Radiation Fencing

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

II - 16.5.2 Active Controls

Active engineered controls are systems designed to reduce the risks from accelerator operations to acceptable levels. These are automatic systems that limit or terminate operations when operating parameters are exceeded. The active controls in place for the NM beam line is the radiation safety interlock system.

Enclosures N01/NM1, NM2, and NM3 are ODH Class 0; as such, in-place oxygen deficiency monitors and alarm systems are not needed.

II - 16.5.2.1 Radiation Safety Interlock System

Two critical devices, V100 and MuLam, are used to inhibit beam from entering the NM beam line. V100 consists of two vertically bending dipole magnets, wired in series, and energized by a single power supply. The critical device is the contactor which energizes the magnets. Similarly, MuLam consists of three horizontally bending dipole magnets, wired in series, and energized by a single power supply. The critical device is the contactor which energizes the magnets. Disabling either of these devices will preclude delivery of beam to the

NM beam line. Both V100 and MuLam are located 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.

II - 16.5.3 Administrative Controls

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

II - 16.5.3.1 Beam Permits and Run Conditions

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

II - 16.5.3.2 Summary of Beam Operating and Safety Envelope Parameters

The NM beam line is assessed to run at $1x10^{13}$ protons per pulse, at a rate of sixty pulses per hour, and a momentum of 120 GeV/c or any combination of spill rates not exceeding $1x10^{13}$ protons per minute. This results in an operating envelope of $6.0x10^{14}$ protons per hour, at 120 GeV/c.

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

II - 16.6 Summary & Conclusion

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

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

II - 16.7 Glossary, Acronyms

AD	Accelerator Division
BPM	Beam Position Monitor
CFM	Cubic feet per minute
DCS	Derived Concentration Standard
ES&H	Environment, Safety and Health
Fermilab	Fermi National Accelerator Laboratory
FESHM	Fermilab Environment, Safety, and Health Manual
FRCM	Fermilab Radiological Control Manual
GeV	Giga-electron volt
NC	Neutrino Center
NE	Neutrino East
NM	New Muon
NW	Neutrino West
ODH	Oxygen Deficiency Hazards
PPD	Particle Physics Division
RSO	Radiation Safety Officer
RWP	Radiation Work Permit
SA	Shielding Assessment
SAD	Safety Assessment Document
SCF	Standard Cubic Feet
SCFH	Standard Cubic Feet per Hour
SWIC	Segmented Wire Ionization Chambers
TSB	Target Service Building

II - 16.8 References

[1] Thomas R. Kobilarcik and Michael Geelhoed, Neutrino Muon Beam Line Shielding Assessment, February 2012. https://fermipoint.fnal.gov/org/eshq/sa/Shared%20Documents/Neutrino%20Muon%20Beamline%20Shielding%20Assessment/Neutrino%20Muon%20Beamline%20Shielding%20Assessment_v1.3.pdf

[2] Fermilab Radiological Control Manual. - The current web link is: http://esh.fnal.gov/xms/FRCM

[3] TeamCenter reference EN04847.

[4] G2 and NM1/N01 ODH Evaluation and Classification, B. DeGraff, January 2012.

[5] Fermilab Environment, Safety, and Health Manual. - The current web link is: http://esh.fnal.gov/xms/FESHM

[6] C. Johnstone and I. Rakhno, Neutrino Muon Beamline Shielding Assessment Addendum for E1039, December 18, 2019. https://fermipoint.fnal.gov/org/eshq/sa/Shared%20Documents/Neutrino%20Muon%20Beamline%20Shielding%20Assessment/Addendum%20for%20E1039%20('SpinQuest')/Neutrino%20Muon%20Beamline%20Shielding%20Assessment%20Addendum%20for%20E-1039%20v2.7.pdf