Neutrino Area

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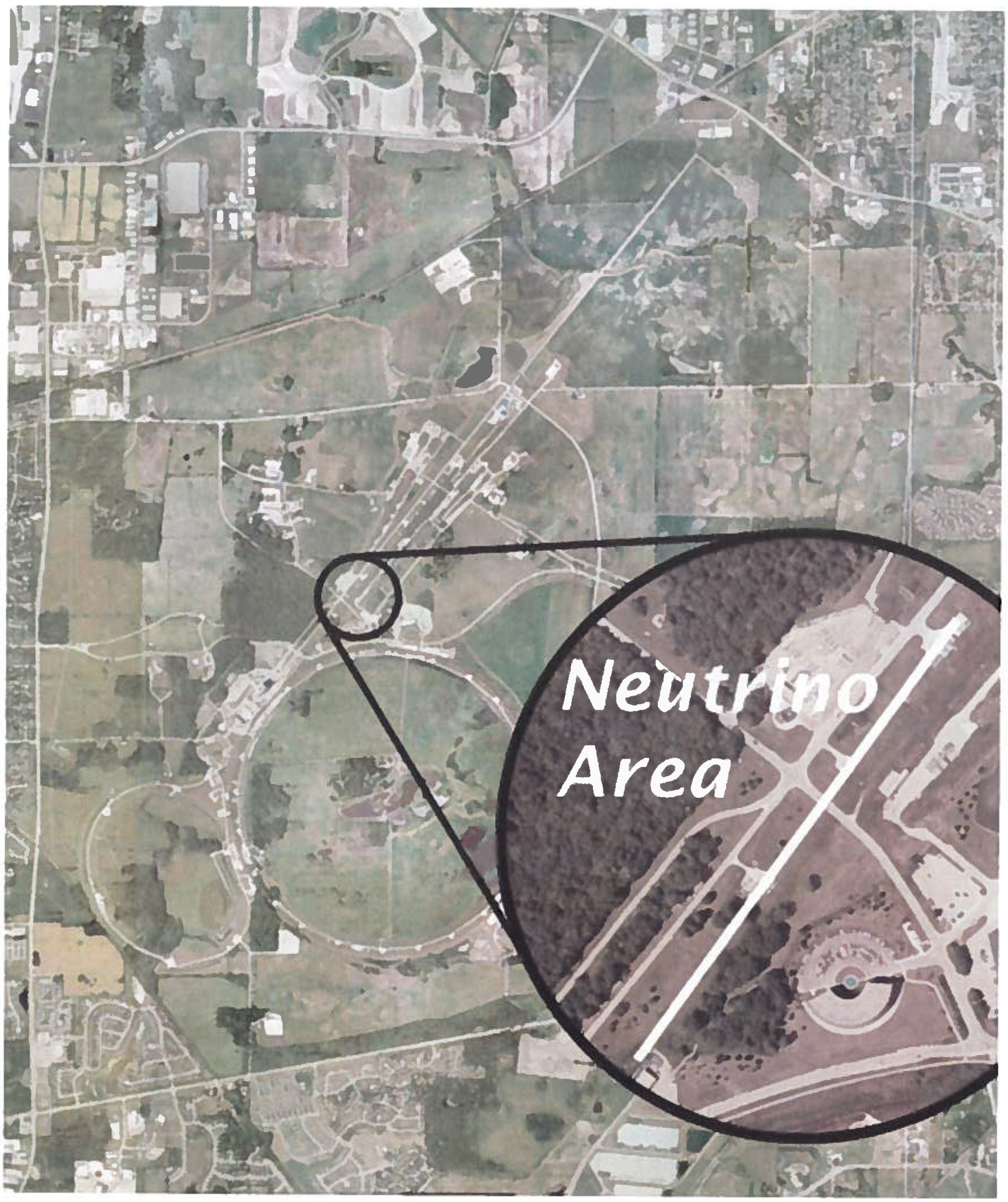
II - 16.1 Neutrino Area Beamline Location on Fermilab Site

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*	**Potential Energy** Crane operations* Compressed gases* Vacuum / pressure vessels* Vacuum Pumps*
Flammable & Combustible Materials Cables* Flammable Gasses	**Magnetic Fields** Fringe fields*
Electrical Energy Stored energy exposure* High voltage exposure* Low voltage, high current exposure*	**Gaseous Hazards** Confined spaces* Oxygen Deficiency Hazards Cryogen spills Cryogenic gas leaks
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 Beams 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.

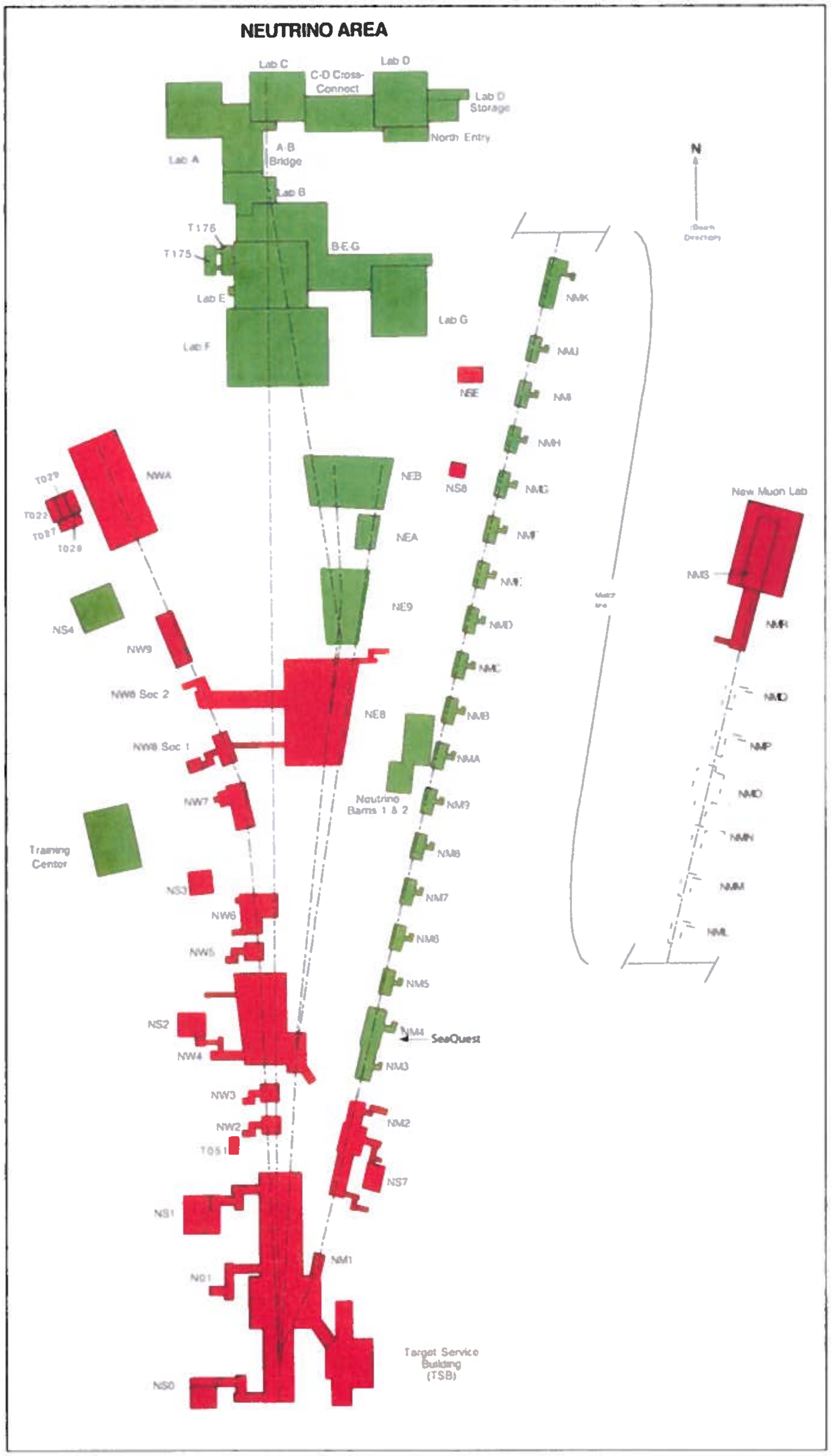

NEUTRINO AREA
Lab C
C-D Cross-Connect
Lab D
Lab D Storage
North Entry
Lab A
A-B Bridge
Lab B
T176
T175
B-E-G
Lab E
Lab G
Lab F
N
NWA
NEB
NS8
NEA
NE9
NS4
NW9
NE8
Neutrino Barns 1 & 2
Training Center
New Muon Lab
NS3
NW7
NW6
NW5
NS2
NW4
NW3
NW2
SeaQuest
NM3
NM2
NS7
NS1
NM1
NS0
Target Service Building (TSB)

Figure 1

Enclosure NM3 is connected to NM2 by buried vacuum pipe. Enclosure NM3 extends into NM4 (which is actually 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 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 the downstream end of NM3 at the NM3/NM4 interface.

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.

Finally, a target station is located at the downstream end of Enclosure NM3. The target station consists of a target wheel, capable of supporting several solid targets, and the hydrogen target enclosure, which houses liquid hydrogen and liquid deuterium targets. Un-interacted protons are absorbed by a large magnetized steel pile, which constitutes the downstream wall of NM3.

Enclosure NM3 extends into the experimental hall, also referred to as "NM4". Only general features of NM4 are addressed in this document.

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 1×10^{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.

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[1] addresses these concerns. The assessment provides a detailed analysis of this facility, demonstrating the required overburden, use of signs, fences, and active interlocks to comply with the Fermilab Radiological Control Manual[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 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 NM1 are unchanged from the previous operation of the beamline. Corrosion-induced vacuum leaks in the 760-foot-long buried beam pipe between G2 and N01 and modifications to enclosures NM2 through NM4 are assessed in a revised Neutrino Muon (NM) Beam Line Shielding Assessment[1] (SA). The assessment assumes 60 pulses of 120 GeV/c protons per hour at an intensity of 1×10^{13} protons per pulse (for a rate of 6×10^{14} protons per hour).

The assessment considered 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.

To address these concerns a detailed shielding assessment has been compiled and reviewed by the Fermilab Shielding Review Subcommittee. The assessment provides a detailed analysis of this region, demonstrating the required overburden, use of signs, fences, and active interlocks to maintain acceptable radiation levels. The shielding assessment for the NM Beam Line has analyzed the beam line areas from the Switchyard Enclosure C, V100-1 dipole through Enclosure NM4.

The 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.*
- *The instantaneous beam intensity shall not exceed 1.00×10^{13} protons over a 4-second spill.*

Section 15 of the NM Beam Line SA stipulates the required controls and monitoring:

- *The radiation safety interlock system will be certified as working.*
- *The interlocked repetition rate monitor, used to limit beam spill frequency and spill duration, will be in place and certified for use.*
- *Radiation detectors around the NM4 enclosure will be installed and interlocked to the radiation safety interlock system.*

The shielding assessment then concludes:

We have analyzed the NM beam line shielding under normal and accident conditions. We have determined that, with the controls listed in Section 15 of the shielding assessment, the facility is in conformance with all FRCM requirements and can be operated safely with the following parameters.

- *Maximum average beam intensity is 6.00×10^{14} protons per hour.*
- *Maximum instantaneous beam intensity is 1.00×10^{13} protons over a 4 second spill.*
- *Annual limit of 5.26×10^{18} protons.*

II - 16.4.1.2 Residual Activation

Residual radiation in the NM Beamline except at the target station 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. The shielding assessment estimates dose rates of 10 – 100 mrem/hr in the vicinity of the target station after 30 days of running and one day of cool off.

When the NM Beamline is not in operation, the target station will remain radioactive; therefore access to these components is tightly controlled. These controls include training verification, centralized authorization, and key entry. The level of control depends on the level of residual radiation. The controls required for different radiation levels are specified in the FRCM, and are detailed in the Radiation Work Permit (RWP) for the work to be performed. In most cases, the general RWP for accesses will suffice. A job-specific RWP will be required for work on any highly activated equipment. These tasks will be supervised by members of the Accelerator Division Radiation Protection Group under the direction of an Accelerator Division 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

Radioactivity induced by the interaction of high-energy particles with the soil that surrounds the buried beam pipe between G2 and N01 and the NM3 target station are addressed in this section. The production of ^{3}H and ^{22}Na is the greatest concern due to production rate and leachability into the groundwater as well as the long half-lives of the radionuclides. Fermilab standards pertaining to groundwater activation are provided in the FRCM, and the methodologies used for making groundwater activation estimates, are given in Environmental Protection Notes No. 8 and 17. The methodology is designed to achieve a conservative estimate of groundwater activation. Additionally the annual integrated intensity used in the calculations is estimated well above the practical beam delivery limits.

Estimating groundwater activation must account for the possible operating scenarios with the small corrosion-induced vacuum leaks in the buried beam pipe between the G2 and N01 enclosures. Long-term plans to address the vacuum leaks are, at the time of this writing, still evolving. Ideas being considered include the possibility of excavating and replacing the leaking sections of beam pipe or inserting a sleeve into the existing beam pipe. How the vacuum leaks are addressed will determine one of three possible operating scenarios for this section of the beamline: operation with a new high vacuum quality beam pipe; operation with a reduced quality of vacuum; or operation with the beam pipe filled and purged with one atmosphere of helium if it is determined that the vacuum may continue to degrade at an unacceptable rate.

Of the three possible operating scenarios, operation with one atmosphere of helium is the least desirable from the radiological perspective, because it involves material intercepting the beam particles, and is summarized here. The analysis indicates that with continuous operation at 1×10^{13} protons per minute or 4.39×10^{17} protons per month, 0.34 micro-Curies of ^{3}H would be produced in the helium. Conservatively assuming all of this ^{3}H gets into the soil, plus the ^{3}H and ^{22}Na created due to the beam scattered from helium into the soil, the contribution to the surface water concentration, conservatively assuming the sump pumps run once per week, is listed in Table 1A. This assumption is conservative because the ^{3}H produced by the beam will be initially in the form of gaseous HT or with much lessor probability T_2 molecules. Some of this gas will escape as gas rather than become HTO molecules. This equates to roughly 3% of the Derived Concentration Standard (DCS) set forth in DOE Order 458.1. The contamination of the groundwater due to this level of activation is well below the regulatory limits. Other beam transport pipe choices will have lower radiological consequences.

Protons Transmitted per Month	Projected Concentrations pCi/ml	Regulatory Limit Surface Water* pCi/ml
4.39×10^{17}	3.00 ^{3}H	1900 ^{3}H
	0.29 ^{22}Na	10 ^{22}Na

Table 1A – G2/N01 Beam Pipe Surface Water

The results shown in Tables 1B and 1C indicate for 5.26×10^{18} protons delivered per year to the target station, an accumulation of ^{3}H and ^{22}Na in the groundwater or surface water is significantly less than the regulatory limits defined in the DCS set forth in DOE Order 458.1.

Protons Delivered to Target	Projected Concentrations pCi/ml-y	Regulatory Limit Groundwater* pCi/ml-y
5.26×10^{18}	3.1×10^{-9} ^{3}H	20 ^{3}H
	4.1×10^{-12} ^{22}Na	0.4 ^{22}Na

Table 1B – Target Station Groundwater

Protons Delivered to Target	Projected Concentrations pCi/ml-y	Regulatory Limit Surface Water* pCi/ml-y
5.26×10^{18}	3.1×10^{-1} ^{3}H	1900 ^{3}H
	2.8×10^{-2} ^{22}Na	10 ^{22}Na

Table 1C – Target Station Surface Water

*Source: The value for ^{3}H in groundwater is taken from the Federal drinking water standards set forth in 40 CFR 141. That for ^{22}Na is 4% of the Derived Concentration Standards of DOE STD-1196-2011 as recommended by DOE O458.1. The values for surface water are taken from DOE-STD-1196-2011.

Neutrino area sump and retention pit concentrations are regularly sampled as part of the AD Routine Monitoring Program, procedure ADDP-SH-1003.

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. The shielding assessment estimates that after 1 month of irradiation, a30 minute cool off period will reduce dose rates to below 0.25 mrem/hr. Access to the enclosures is not allowed during the cool off period determined by the AD RSO.

The shielding assessment estimates that based on 5.26×10^{18} protons delivered per year, the annual air releases from operations will be 2 $\pm$ 0.6 Curies per year. This is a few percent of the laboratory annual air release budget.

Air activation caused by beam passing through the G2-N01 buried beam pipe when filled with helium has been assessed. As stated earlier, the purge rate of the helium is approximately 2 SCFH or approximately 1440 SCF per month. After one month of operations, at 4.39×10^{17} protons per month, 0.34 micro-Curies of tritium would be produced in the helium. The purge rate of the helium is approximately equal to the volume of the pipe per month. The helium purge will release approximately 0.34 micro-Curies of tritium per month adding insignificantly to the laboratory annual air release budget.

II - 16.4.2 Oxygen Deficiency Hazards

Although the beamline does not use components that could produce oxygen deficiency hazards, one of the operating scenarios for the buried beam pipe between G2 and N01 would involve filling the beam pipe with helium along with a continuous helium purge. The other area is the E906 Target System that uses small quantities of deuterium, hydrogen, and nitrogen in the experimental targets.

When the beam pipe between G2 and N01 is operating with a helium backfill, there is a continuous purge of approximately 2 SCFH that originates in the G2 service building and is vented into the N01 enclosure. Two 250 SCF helium gas bottles are located inside the G2 service building. The pressure is regulated down to a few inches of water and piped to a flange on the buried beam pipe in the G2 enclosure. The buried pipe windows are constructed such that a window failure will vent to the beam pipe and not directly vent into either the G2 or N01 enclosures. The ODH classification of an enclosure, as defined in the FESHM, is determined by calculating an ODH fatality rate Ø and is based on probability of failure on demand. The ODH analysis[3] concludes that both the G2 and N01 areas are ODH class 0 areas that require constant ventilation, but do not require on-demand ventilation or electronically monitored ventilation. Both the G2 and N01 enclosures are equipped with directional circulating fans to ensure continuous mixing of the exhausted helium or any helium that might leak from the pipe flanges or supply pipe fittings.

The ODH analysis[4], contained in the E906 Target Safety Report, concludes that the release of the deuterium or hydrogen cylinder into the NM4 experimental hall would cause a negligible reduction in oxygen. Similarly, the release of the entire nitrogen cylinder into the hall would reduce the oxygen concentration by less than 1% assuming an oxygen concentration of 21% prior to the release. Based on this analysis, the building is ODH class 0 and does not require any constant active ventilation, on-demand ventilation, or electronically monitored ventilation.

The target station will be enclosed in a target tent. The tent has a 1300 CFM explosion proof exhaust fan. A single flask failure would release 2.2 liters of liquid hydrogen or approximately 60 SCF of gas. The tent exhaust ventilation rate is significantly higher than the worst case scenario gas release rate. The ODH analysis[4] concludes the tent is also ODH class 0 and requires a monitoring of the exhaust ventilation.

II - 16.4.3 Cryogenics

Two cryogenic targets, one with liquid deuterium and the other with liquid hydrogen are located at the downstream end of Enclosure NM3 inside the target station tent. Cryogenic refrigerators, located in the upstream east side of NM4, will cool the targets. The ODH analysis[4] considered the potential for a spill or leak of these cryogenic fluids resulting in a classification of the NM4 building as ODH class 0.

II - 16.4.4 Flammable Gasses

II - 16.4.4.1 Hydrogen Target

A hydrogen target system is located at the downstream end of Enclosure NM3. The E906 target system is composed of three stainless steel flasks. The stainless steel flasks are 2.2 liters each in volume with dimensions of 20 inches long by 3 inches in diameter. One flask holds liquid deuterium; one holds liquid hydrogen and one is evacuated for a control. The two liquid flasks are in different vacuum spaces to reduce the potential of releasing 4.4 liters of Hydrogen/Deuterium (instead of a single flask failure of releasing only 2.2 liters). Any release from the target flask or its vacuum shell is expected to be vented through the tent ventilation system and exhausted outdoors.

The following precautions are taken:

- Warning signs are posted alerting personnel of hydrogen gas in the area and that ignition sources are not allowed.
- No ignition sources are allowed in the target tent while flammable gasses are present.

- A flow switch monitors and alarms for a loss of air flow through the tent exhaust ventilation duct alerting the shift crew of the ventilation failure.
- The phone number and pager number of the hydrogen target operations crew are posted allowing the shift crew to contact an expert as necessary.
- No combustibles or ignition sources will be allowed in the area of the hydrogen cylinders. No welding will be allowed within 33 feet of the cylinders without the Particle Physics Division (PPD) and AD Office approvals.
- Cylinders will be properly secured. Only hydrogen cylinders in use will be kept at the entryway to the NM4 building. Full or empty bottles not in use will be promptly removed and stored in a designated storage area. Concrete bumpers are installed to keep automobiles at a safe distance from the cylinders.
- The hydrogen supply lines have an excess flow valve installed outdoors. Each cylinder uses an appropriate pressure regulator. Each supply line also includes a relief valve set for 50 psig in order to protect the cold traps.
- Hydrogen supply lines will be leak checked at 90% of the circuit relief pressure.
- The hydrogen lines and ventilation exhaust ducting will be identified with labels.
- Hydrogen lines will be metallic and will be appropriately installed and supported.

The documented analyses[4] of the target system along with pertinent review panel correspondence are maintained in accordance with Fermilab Environment, Safety, and Health Manual[5] (FESHM). In summary, hydrogen target hazards are mitigated so that potential impacts to personnel are minor on-site or negligible off-site.

II - 16.4.5 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 passive controls are fixed elements of the beam line 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 consists of sufficient earth overburden such that unacceptable levels of prompt radiation cannot occur based on the assessed beam conditions.

For normal operating conditions, the assessment finds that the permanent shielding as designed is adequate to limit maximum dose rates to:

- less than 0.25 mrem/hr outside the enclosures in areas without radiological postings;
- less than 1 mrem/hr at the labyrinth entrances outside of fenced areas;
- and less than 100 mrem/hr at the fenced areas by the target station.

For accident conditions, the assessment finds that the permanent shielding will limit the maximum accidental dose to:

- Less than 1 mrem/hr for areas with no radiological postings;
- less than 5 mrem/hr for posted controlled areas with no occupancy limits;
- and less than 500 mrem/hr for egresses behind radiation fences.

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. The AC power disconnect switch for the NM4 crane is locked out and configuration controlled by the AD RSO. The steel shielding cart blocking the access to the target station is locked in-place and access to the target station is controlled by the AD RSO..

II - 16.5.1.3 Penetration Shielding

Penetrations along the NM beam line have been analyzed in the shielding assessment. The locations of all the beam line penetrations are inside of fenced radiation areas and the dose measured at the terminus of any penetration, under accident conditions, is allowed to be up to 500 mrem/hr. An analysis shows that the maximum expected dose under accident conditions is less than 50 mrem/hr. All penetrations have been found to be in compliance with FRCM, or have been adequately shielded to bring them into compliance.

II - 16.5.1.4 Radiation Fencing

The NM Beam Line SA concluded that the radiation levels along the beamline require radiation 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. These fences are posted as radiation areas and access is controlled by the AD RSO.

II - 16.5.2 Active Controls

The radiation safety interlock system is the only active control system used in the NM beam line. Flammable gasses and cryogenic liquids are only used in the NM Beam Line at the target station. The volumes of these gasses are small enough that no active controls are needed. All enclosures in the Neutrino Area 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

II - 16.5.3.1 Beam Permits and Run Conditions

Beam will not be transported to the NM beam line without an approved Beam Permit and Run Condition. The Beam Permit specifies beam power limits as determined and approved by the AD Head in consultation with the AD ES&H Department Head, AD RSO, AD Operations Department Head, and External Beams Department Head. The run conditions list the operating modes and safety envelope for the NM beam line. Run conditions are issued by the AD ES&H department, and are signed by the AD Operations Department Head, AD RSO, and AD Division Head.

In order to run beam to the NM beam line, the radiation safety interlock system for N01/NM1, NM2, NM3 and NM4 must be searched and secured; the critical devices V100 and MuLam must be energized; and the upstream area (Switchyard) must be ready for beam.

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, Run Conditions, and Startup administered by the AD ES&H Department and AD Head. Beam Permit and Run 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 Head in consultation with the AD ES&H Department Head, AD RSO, AD Operations Department Head, and AD External Beams Department Head. The Run Condition for the NM Beam Line describes the operating configuration as reviewed by the AD RSO, AD Operations Department Head, and as approved by the AD 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. The designs, controls, and procedures to mitigate NM Beam Line specific hazards are identified and described. In addition to these specific safety considerations, 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.

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

[4] E906 Target Safety Document Version 1, December 8, 2010

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