Neutrinos at the Main Injector (NuMI) Beam Line

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Author	Description of Change	Revision No. & Date
John E. Anderson Jr. Craig Moore	Initial release of the NuMI Beam Line Chapter for the Fermi National Accelerator Laboratory Safety Assessment Document (SAD)	Revision 0 June 3, 2013

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II-9 NuMI Beam Line

II – 9.1 NuMI Beam Line Location on the Fermi National Accelerator Laboratory (Fermilab) Site

The following aerial photograph shows the location of the NuMI Beam Line in relationship to the Fermilab site.

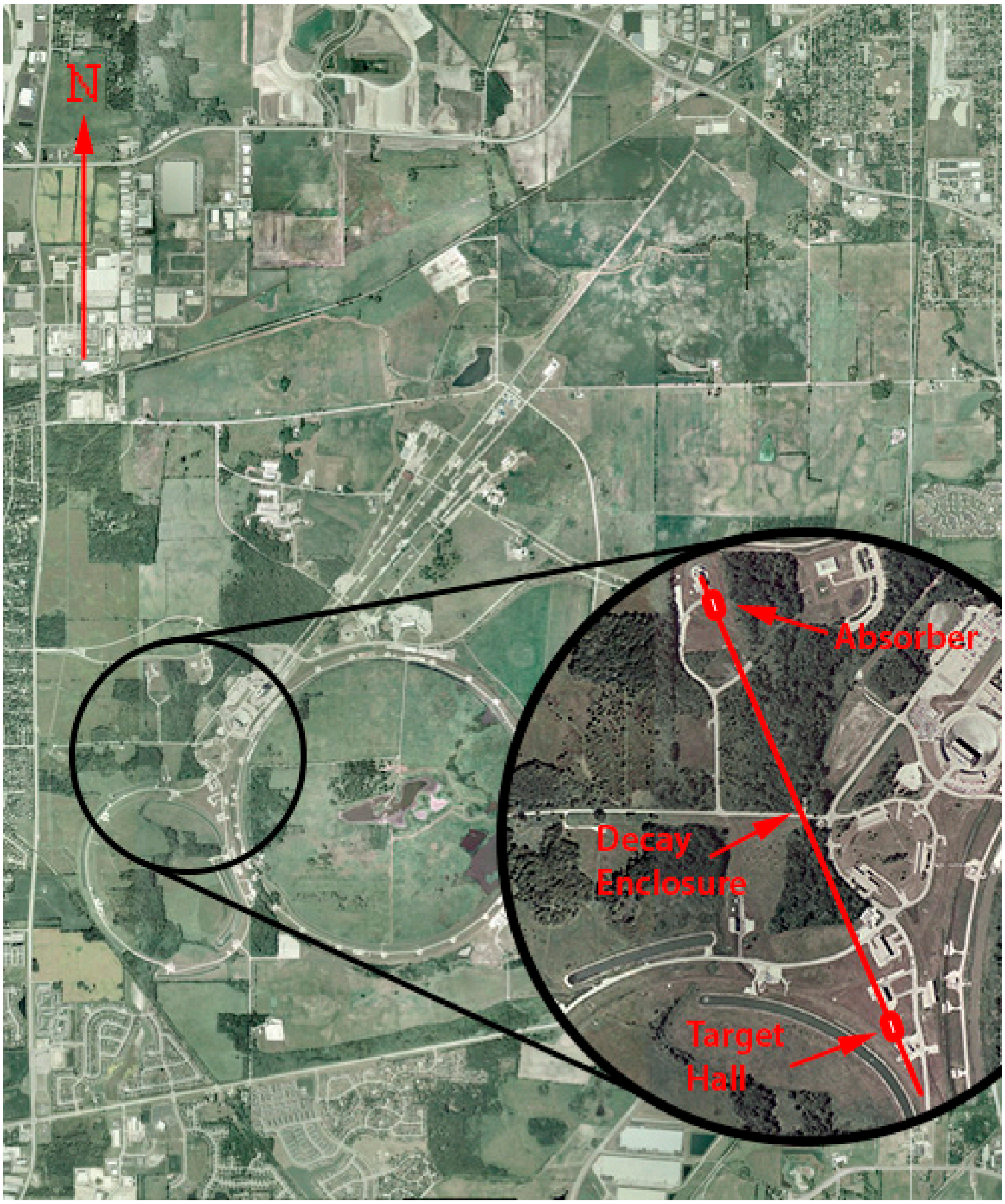

Figure 1 View of the Fermilab site showing the NuMI Beam Line location.

II – 9.2 Inventory of Hazards

The following table lists the identified hazards found in the NuMI Beam Line and support buildings. All hazards with an asterisk (*) have been discussed in Chapters 1-10 of the Fermilab Safety Assessment Document (SAD) and are not covered further in this section.

Radiation Ionizing radiation Residual activation Ground water activation Air activation Radioactive waste	**Kinetic Energy** Power tools * Pumps and motors *
Toxic Materials Lead shielding * Beryllium components *	**Potential Energy** Crane operations * Compressed gases * 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 *
Thermal Energy	**Access / Egress** Life safety/emergency egress

II – 9.3 Introduction

This Section II, Chapter 9 of the Fermilab SAD addresses the NuMI Beam Line. The NuMI Beam line runs from a lined and unlined Carrier Tunnel that begins at the NuMI stub in the Main Injector and includes the target hall, decay tunnel, hadron absorber enclosures, access tunnel, and muon alcoves as well as the respective surface and underground service buildings.

II – 9.3.1 Purpose of the NuMI Beam Line

The purpose of the NuMI Beam Line is to produce an intense beam of neutrinos for physics experiments designed to detect and study neutrino oscillations. The NuMI Beam Line extracts a 120 Giga-electron volt (GeV) beam of protons from the Main Injector (MI) and directs a high intensity beam of neutrinos to near-detectors at Fermilab and far-detectors at Soudan, Minnesota and Ash River, Minnesota.

II – 9.3.2 Description of the NuMI Beam Line

The NuMI Beam Line receives an extracted beam of 120 GeV protons from the MI. The extracted beam strikes a target to produce short-lived hadrons. Neutrino horns focus the hadrons before the hadrons enter the NuMI decay pipe. A fraction of the hadrons in the decay pipe decay to neutrinos and muons as they travel through the decay pipe. At the end of the decay pipe, the remaining hadrons are absorbed in the hadron absorber.

The native rock in place downstream of the hadron absorber absorbs the muons produced with the neutrinos in the decay region. Muon monitors along the beam line monitor the direction of the beam by measuring muon distributions. Figure 2 depicts the process for production of the neutrino beam.

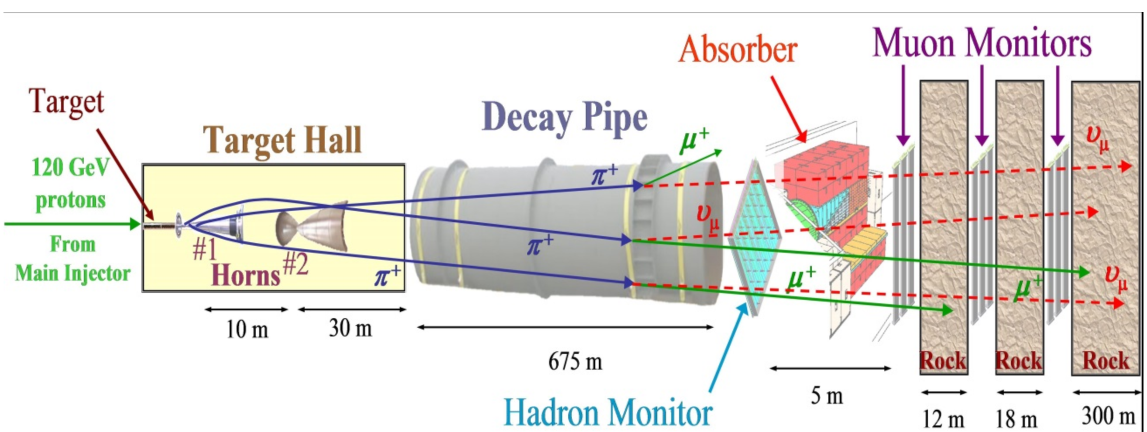

Figure 2. Process for production of the NuMI neutrino beam

Research and support facilities constructed for the NuMI Project also include access shafts, support rooms, and a bypass tunnel for the rock region downstream of the absorber. The main components of the NuMI Beam Line include:

- An underground lined Carrier Tunnel starting at the NuMI stub in the MI;
- An underground unlined Carrier Tunnel;
- Underground Pre-Target/Target enclosure;
- An underground Decay Tunnel;
- An underground Hadron Absorber Enclosure and Access Tunnel with Muon Alcoves; and
- Surface MI-65 and Main Injector Neutrino Oscillation Search (MINOS) Service Buildings

The NuMI Beam Line instrumentation assures that the beam is on target and directed to the near and far detectors by maintaining beam losses to a minimum level. This outcome is accomplished through the use of position information to assure that the beam is in the center of its vacuum chamber with profiles to allow unexpected beam tails and halo to be observed, sensitive loss measurements to allow beam problems to be immediately addressed, and intensity measurements to monitor large beam losses.

The NuMI Profile Monitors are secondary emission monitors designed to place minimal material in the beam. Toroids or beam current transformers are used in the NuMI Beam Line for intensity measurements. Total Loss Monitors used in the NuMI Beam Line provide continuous coverage from the NuMI extraction enclosure through the final targeting elements.

II – 9.3.3 Operating Modes

The NuMI Beam Line transports 120 GeV MI protons at a maximum intensity of 5.4×10^{13} protons every 1.333 seconds. This transport rate amounts to 1.46×10^{17} protons/hr.

Figure 3 depicts the major elements of the NuMI Beam Line:

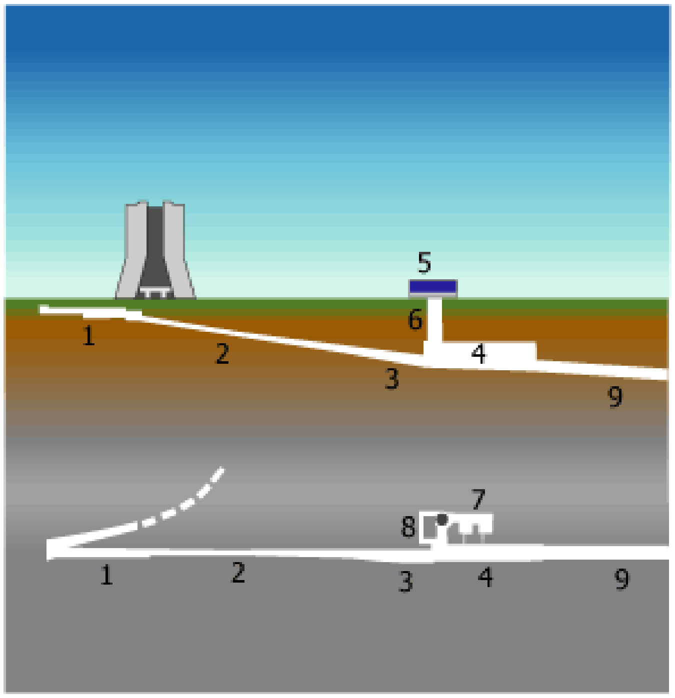

Figure 3 Major elements of the NuMI Beam Line.

II – 9.4 Safety Assessment

The unique beam line specific hazards for the NuMI area are analyzed in this section. The radiological hazards include ionizing radiation, residual activation, groundwater and surface water activation, air activation, and radioactive waste. In addition to the radiological hazards, the NuMI Beam Line has a unique electrical hazard, life safety emergency egress, and flooding hazards that are addressed.

II – 9.4.1 Radiological Hazards

The NuMI Beam Line presents radiological hazards in the form of prompt and residual ionizing radiation from particle beams, residual radiation due to activation of beam line components, and environmental radioactivity in the form of potential groundwater, surface water, and air activation resulting from the operation of the beam transport systems.

A detailed shielding assessment and post assessment documents address these hazards [1]. The assessments provide a detailed analysis of the NuMI Beam Line facility demonstrating the required shielding, controls and interlocks to comply with the Fermilab Radiological Control Manual (FRCM) [2].

The NuMI Beam Line begins at the location of the first NuMI extraction kicker magnet in the MI at cell 602. The assessment continues through the MI ring to the NuMI Stub, the Carrier Tunnel, the Target Hall, the decay pipe, the hadron absorber, and the muon alcoves. The assessment includes the MI-65 and MINOS access shaft areas and the Target Hall support rooms.

The assessment considers groundwater and surface water activation, lists surface water discharge points and monitoring locations; calculates air activation, estimates annual release, and release points; considers muon production; considers longitudinal and transverse shielding requirements; summarizes labyrinth and penetration calculations; calculates residual dose rates; and specifies active shielding controls and monitoring.

II – 9.4.1.1 Ionizing Radiation

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

A detailed shielding assessment has been compiled and reviewed by the Fermilab Shielding Review Subcommittee to address these concerns. The assessment provides a detailed analysis of the beam line, demonstrating the required overburden or soil shielding, use of signs, fences, and active interlocks to maintain any prompt radiation within acceptable levels.

The shielding assessment for the NuMI Beam Line has included analyses of injection, targeting, decay, and absorption areas. The assessment covers prompt dose rates associated with the secondary beam line, labyrinths and penetrations, the Hadron Absorber labyrinth, the radioactive water system (RAW) room, and muons in the bypass tunnel. Since the majority of the NuMI Beam Line is deep underground, there are only a few areas where the issue of prompt radiation from NuMI operations is a concern. These areas include the MI/NuMI Stub, the power supply room/upstream shaft area and the bypass tunnel. The NuMI Beam Line shielding assessment requires that:

- *Certain penetrations are filled with shielding as specified;*
- *All movable shielding blocks are installed as specified;*
- *All interlocked detectors are installed as specified;*

- *The radiation safety interlock system is certified as working.*

The NuMI Shielding Assessment concludes:

- *The facility is in conformance with all FRCM requirements and can be operated safely with the following beam parameters:*
  - *Maximum operating intensity is 1.46 x 10^{17} protons per hour;*
  - *Maximum energy is 120 GeV.*

II – 9.4.1.2 Residual Activation

The shielding assessment estimates residual activation of NuMI Beam Line components. The beam line is designed to keep residual dose rates in the primary beam region below100 milli-rem per hour (mrem/hr) and below 30 mrem/hr in the Hadron Absorber Hall where personnel have access. Radiological surveys taken over the past six years of operation with 120 GeV protons show dose rates in the primary beamline region and in the accessible areas of the Hadron Absorber Hall of less than 15 mrem/hr.

The shielding assessment estimates residual activation of NuMI Target Chase components. The standard residual dose rate values quoted are for a 30-day irradiation and a 1 day cool down, designated (30d, 1d). Estimated values for (30d, 1d) at operations of 700 kilowatt (kW) beam power are 6 rem/hr for the Target, 400 rem/hr for Horn 1, and 33 rem/hr for Horn 2.

When the NuMI Beam Line is not in operation, the enclosure area will remain radioactive and access to these components will be tightly controlled with the level of 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.

In most situations, general RWPs for accesses will suffice. A job-specific RWP and an as-low-as-reasonably-achievable (ALARA) plan will be required for work on any highly activated equipment with a potential individual exposure greater than 200 mrem or potential job exposure greater than 1000 person-mrem. These tasks will be supervised by members of the Accelerator Division (AD) Environment, Safety, and Health (ES&H) Radiation Safety Group under the direction of the AD Radiation Safety Officer (RSO).

II – 9.4.1.3 Groundwater and Surface Water Activation

Operation of the NuMI Beam Line will activate water in the vicinity of the NuMI Beam Line tunnel. The majority of the activation occurs within a few meters of the beam line tunnel wall. Groundwater modeling of the subsurface hydrologic systems suggests that the NuMI tunnel functions as a well that captures nearby groundwater [1].

Water flowing into the NuMI tunnel is pumped to the surface from the sump at the base of the MINOS Access Shaft. The shielding assessment estimates that with $6x10^{20}$ protons on target each year, the ^{3}H (tritium) and ^{22}Na (sodium-22) concentrations of the sump water will be 35 pico Curie (pCi)/milliliter (ml) for ^{3}H with no detectable ^{22}Na, approximately 2% of the surface water discharge limits. At the surface, the water is discharged to a holding tank for use in the Fermilab Industrial Cooling Water (ICW) system, which confines the tritiated water to the Fermilab site.

The NuMI horns, decay pipe, and the hadron absorber are cooled by water. The water in these cooling systems will become activated with ^{3}H, and to a lesser extent ^{7}Be (beryllium-7). The controls, interlocks and alarms designed for these systems prevent catastrophic losses and damage to the equipment [1]. The release of RAW from any of the NuMI cooling systems does not cause any significant increase to the concentration of radionuclides in the discharge to the ICW system [1].

AD ES&H Radiation Safety Group monitors beam line losses to maintain water activation and residual dose rates in the tunnel below limits defined in the FRCM as part of the Fermilab environmental monitoring program. Water is sampled periodically at monitoring well S-1274 located down-gradient of the lined section of the Carrier Tunnel and a holding tank located near the MINOS Service Building. The NuMI Beam Line sumps are sampled periodically in accordance with Fermilab monitoring procedures and tested for radionuclides.

Releases of ^{3}H and ^{22}Na constitute the radionuclides of most significant concern from the standpoint of groundwater and surface water activation. Table 1 presents documented and monitored levels of radionuclides associated with the NuMI beamline and associated regulatory limits.

10.75×10^{20} protons on target	Monitoring Well Measured Concentrations	Regulatory Limits*
^{3}H	< 0.2 pCi/ml	20 pCi/ml Groundwater 1900 pCi/ml Surface Water
^{22}Na	< 0.03 pCi/ml	0.4 pCi/ml Groundwater 10 pCi/ml Surface Water
* ^{3}H Regulatory Limit from 40CFR141 Federal Drinking Water Standards. ^{22}Na Regulatory Limits from the DOE STD-1196-2011 Derived Concentration Standards.		

Table 1: Release Concentrations and Regulatory Limits associated with NuMI Beam Line-produced radionuclides in groundwater and surface water.

II – 9.4.1.4 Air Activation

Federal regulations and the Fermilab Lifetime Operating Air Pollution permit issued by the Illinois Environmental Protection Agency (IEPA) govern releases of airborne radionuclides. The regulations limit the equivalent dose delivered to a member of the public to 10 mrem/year [3, 4]. Fermilab has established a secondary goal of keeping the maximum equivalent dose at the site boundary due to air emissions under 0.1 mrem/yr.

The methodology used to assess NuMI air activation concerns has been documented in the shielding assessment [1]. Delayed ventilation is used at NuMI to reduce radioactive air emissions. The vast majority of the radioactivity produced is short-lived. A delay time of one hour from production of the radionuclides to release will reduce the levels of radioactivity by roughly one order of magnitude at the stack release point.

There are six NuMI Beam Line exhaust air vents (EAV). EAV1 is the vent for the Carrier Tunnel and Pre-Target area. EAV2, Target Pile Evaporator Stack (TPES), and Survey Riser (SR) SR3 are the exhaust vents for the Target Hall area and upstream decay region. EAV3 is the exhaust vent for the Hadron Absorber area and downstream decay region. The highest levels of air activation are from the Target Hall/upstream decay region (EAV2, TPES, and SR3) and the Hadron Absorber/downstream decay region (EAV3). The air from EAV1, EAV2, TPES, SR3 and

EAV3 is routinely monitored by the Environment, Safety, Health, & Quality (ESH&Q) Section to insure air emissions stay well below 0.1 mrem/yr level at the site boundary.

During the early operation of the NuMI Beam Line, increases in tritium concentration were observed in the water discharged from the NuMI sumps to the Fermilab ICW system. The increase in tritium concentrations in the water discharged from the NuMI sumps has been directly correlated to humidity levels inside the NuMI Target Hall and target chase. Dehumidification systems have been installed to reduce the humidity levels in air within the Target Hall and target chase.

A condensate collection system has been installed to collect tritiated water condensed on the cooling coils of the NuMI target chase air cooling and desiccant re-circulation systems. The water is pumped from a holding tank in the NuMI Beam Line tunnel to a holding tank located in the southwest corner of the MI-65 service building. The water from the holding tank is gravity fed to an evaporation unit where the evaporated water is exhausted out the TPES through the roof of the MI-65 service building.

A high velocity fan on the roof of MI-65 mixes outside air with the exhausted moist air from the evaporator. This mixing prevents condensation of the evaporated water on the MI-65 service building roof and area surrounding the building. Tritium released through the MI-65 exhaust stacks contributes less than 1 micro-rem /year to Fermilab site boundary dose [1].

Secondary particles and un-interacted protons within the beam line will also interact with helium in the NuMI decay pipe to produce tritium and other radionuclides. Monte Carlo Shielding Computer Code (MARS) [5] simulations predict that about 0.12 Ci of tritium will be produced in the helium and 9 Ci of tritium will be produced in the decay pipe steel for every 1 $x10^{20}$ protons on target. Approximately half of the tritium in the decay pipe steel or 5 Ci of tritium are expected to leak from the steel into the helium. However, measurements of the decay pipe tritium contents showed no evidence of tritium migration from the decay pipe steel into the helium. This is attributed to the lack of air and moisture inside the decay pipe.

After ten years of running with helium in the decay pipe, irradiation of 5×10^{21} protons on target, the airborne activation in the Target Hall from a decay pipe window failure would result in a dose rate of 12 mrem/hr, well below the FRCM limit of 100 mrem in one hour. The release of all the tritium accumulated in the decay pipe helium into the air will contribute less than 0.1 micro-rem to the Fermilab site boundary dose.

The NuMI Beam Line shielding assessment calculates the annual maximum anticipated equivalent dose to an individual located at the Fermilab site boundary to be 0.025 mrem from all emission sources.

II – 9.4.1.5 Radioactive Waste

Tritiated water from the Target Chase and Absorber Hall air chiller condensate is evaporated. Fermilab reports the amount of ^3H evaporated in Fermilab Radionuclide Air Emissions Annual Reports [6] provided to the DOE Fermi Site Office for transmission to State and Federal regulatory agencies in accordance with 40 CFR Part 61 Subpart H, National Emission Standards for Emissions of Radionuclides Other Than Radon from Department of Energy Facilities. Tritiated RAW is solidified and disposed of as solid low level radioactive waste.

Some used components will be stored in the Target Hall storage area until preparations are made for safe storage at the C0 assembly building, another location on site, or for disposal. Other items that can be taken up the access shaft are characterized and disposed of as solid low-level radioactive waste.

NuMI radioactive waste hazards and waste disposal are managed within the program established for the Fermilab accelerator complex 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 NuMI area, beam loss and, in the case of some beam diagnostics devices, intentional interception of the beam will result in activation of beam line elements. Reuse of activated items will be carried out when feasible. Activated items that cannot be reused will be disposed of as radioactive waste in accordance with the FRCM requirements.

II – 9.4.2 Electrical Stored Energy Exposure

Operation of the neutrino focusing horns poses electrical hazards from the stripline connections between power supply capacitor bank and the horns and the 60 kilo Jules of stored energy in the power supply capacitor bank. The Target Hall Power Supply Room horn stripline is an electromagnetic transmission line constructed of a series of aluminum conductors that carry the very high current needed to pulse the focusing horns in the target chase. Access to the stripline is controlled by the NuMI radiation safety interlock system and the stripline is located behind a fence.

The power supply capacitor bank is designed, installed, operated and maintained in accordance with Fermilab Environment, Safety, and Health Manual (FESHM) requirements. Performing Lock out Tag out (LOTO) is required before performing maintenance on devices connected to hazardous energy sources.

II – 9.4.3 Life Safety Emergency Egress

Life safety considerations have been used to set the Target area occupancy limit to 50 persons with a subsidiary limitation of four occupants in the downstream area of the Carrier Tunnel region during installation and maintenance activities. There is an 8-person limit at the Target underground area during normal operations.

Occupancy limits and tracking of those in the underground area are maintained through a badging process that requires a NuMI underground access badge when entering the underground areas. The individual entering the underground leaves their Fermilab badge at the entrance to the respective NuMI access shaft. A NuMI underground badge is then assigned to each individual. Upon completing their time underground, the individual returns the NuMI underground badge and retrieves their Fermilab badge providing for an accurate head count of those underground.

Methods of emergency egress have been established for each of the NuMI Beam Line areas:

- Exiting from the NuMI stub is through the usual MI emergency egress system. A secondary route is through the Carrier Tunnel to the Target Access Shaft staircase;
- Exiting from the Carrier Tunnel is either upstream via the MI, or downstream via the Target Access Shaft staircase;
- Primary exiting from the Target Hall and support rooms is through the Target Access Shaft staircase;
- Secondary Target Hall exiting is through the decay tunnel walkway to the MINOS Access Shaft and up the enclosed MINOS elevator;
- Tertiary exiting route from the Target Hall is through the Carrier Tunnel and the MI;

- The primary exit from the Absorber areas is through the isolated MINOS Access Shaft elevator; and
- The secondary exit from the Absorber area is through the Decay Tunnel walkway upstream to the Target area and out the Target Hall Access Shaft staircase.

National Institute of Occupational Safety and Health approved escape packs are provided adjacent to the shaft elevators to provide 10 minutes of breathing air to personnel during emergency egress. All personnel working in the underground facilities are required to take Fermilab Underground Safety Training as well as appropriate radiation training, and LOTO II training.

Egress through the MINOS area is addressed in MINOS Hall Detectors Section III, Chapter 5.

II – 9.4.4 Flooding

Incoming groundwater from the length of the NuMI tunnels collects in the MINOS Access Shaft sump pit. The water is pumped to the surface. If the pumping system is non-operational, approximately one hour can pass before the water will reach the MINOS Access Shaft floor level defining the beginning of a flooding condition. This hazard is addressed in the MINOS Hall Detectors Section III, Chapter 5.

II – 9.5 Credited Controls

II – 9.5.1 Passive Controls

Passive controls are accelerator 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 NuMI Beam Line is designed to optimize the effect of these passive controls with permanent concrete and earth-covered radiation shields that use a combination of permanent shielding, movable shielding, and penetration shielding to protect personnel from radiological exposure during beam line operations.

II – 9.5.1.1 Permanent Shielding including Labyrinths and Penetrations

The permanent shielding encompasses the structural elements surrounding the beam line components. The NuMI concrete structure is contiguous with the MI beam line. Labyrinths and penetrations in the NuMI tunnels and halls have been assessed for radiation dose rates under normal operating and accident conditions. The areas assessed in the Shielding Assessment include the following:

- Survey Risers 1, 2, and 3;
- Exhaust Stacks EAV1, EAV2 and EAV3;
- Target Hall Labyrinth;
- Target Hall Equipment Door;
- Horn Stripline Penetration;
- RAW System Penetration;
- Hadron Absorber Access Labyrinth;
- Muon Alcoves 2, 3 and 4 gates;
- RAW Room Door;
- Target Chase Air Cooling Labyrinth;
- MINOS Access Shaft and EAV4; and
- Muon Alcove Bypass Tunnel.

The largest potential NuMI Beam Line radiological losses under both normal operating and accident conditions are at Survey Risers SR1 and SR2. Permanent shielding at these locations reduces the potential dose rate to 0.1 mrem/hr under both normal and accident conditions.

II – 9.5.1.2 Movable Shielding

Assessments of movable Target Hall shielding components have been made foremost for access to the Target Hall and the handling of irradiated components within the Target Hall. A movable concrete door is put in place during beam operations to preclude access to the Target Hall from the NuMI access shaft area. MARS calculations predict a dose rate on the Target Hall side which corresponds to less than 1 micro-rem/hr penetrating through the gaps in the shield door [1]. Measurements of the dose rate immediately outside the door would be less than 1 mrem/hr due to leaking air through the penetrations and combination of other small sources. These areas are considered Controlled Areas.

Measurements of NuMI residual radiation dose rates for Target Hall components have been made whenever a Target Hall component was taken from the NuMI Target Chase. NuMI Target Hall component shielding is housed within a permanent concrete liner. The movable shielding components include steel blocks, T- blocks and R-blocks. Movable shielding components are placed by crane operation in the Target Hall as a step in accessing, repairing or replacing NuMI Target Chase components. Figure 3 shows the movable components of Target Hall component shielding.

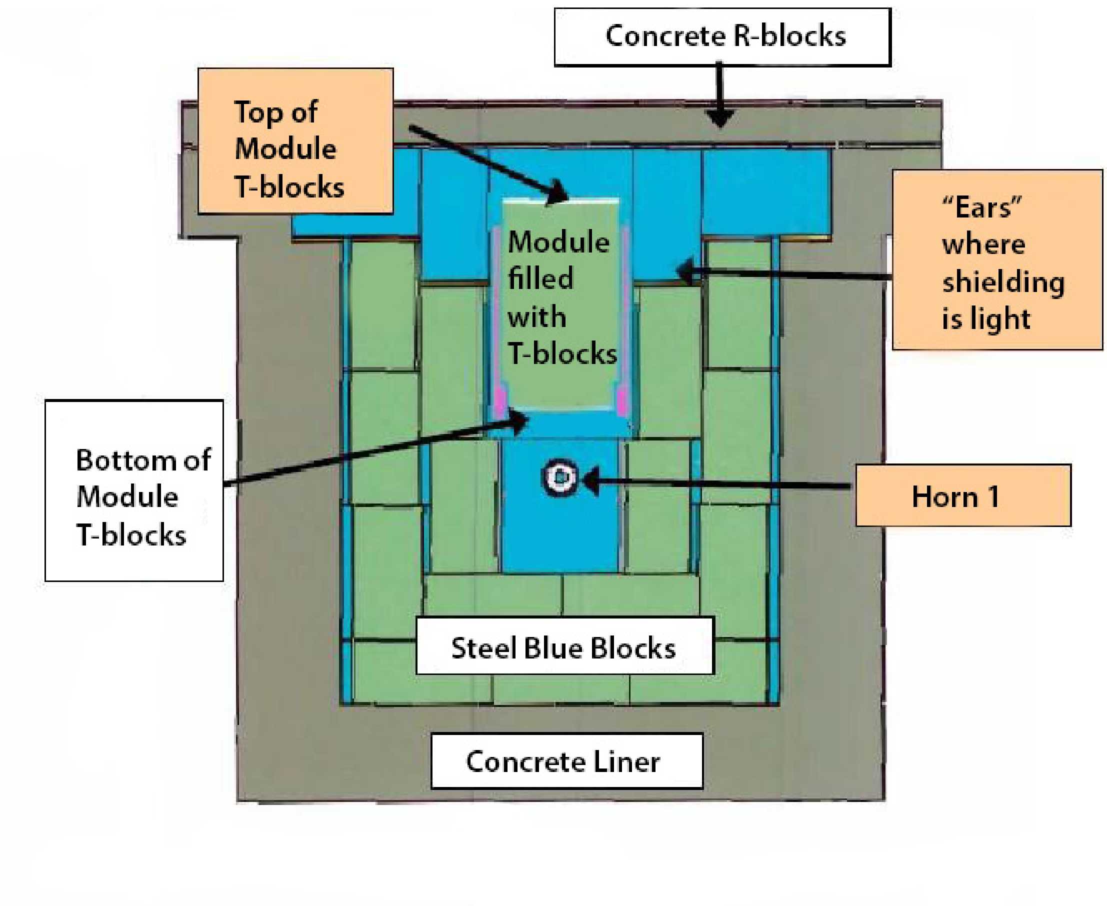

Figure 9. Cross Section of the NuMI Target Hall component region.

NuMI component handling is done remotely. Resultant radiation fields following relocation of the movable Target Hall shielding does not pose a hazard to workers. Continual attention is devoted to ensure that component access, repair, or replacement activity dose rate levels are maintained within FRCM acceptable limits.

II – 9.5.2 Active Controls

Active engineered controls are systems designed to reduce the risks from accelerator operations to an acceptable level. These are automatic systems that limit operations, shut down operations, or provide warning alarms when operating parameters are exceeded. The active controls in place for the NuMI Beam Line are discussed below.

II – 9.5.2.1 Radiation Safety Interlock System

The NuMI Beam Line employs a Radiation Safety Interlock System (RSIS). The characteristics of the system are described in Chapter I of the Fermilab SAD.

The NuMI Beam Line connects the MI RSIS and the NuMI RSIS. The boundary between the two systems is the door located at the mid-point of the NuMI Carrier Tunnel. The lined section of the Carrier Tunnel is a separately interlocked area to avoid the necessity of routine search and secure of this area. This lined section of the Carrier Tunnel is not accessible when the MI is operating.

The downstream end of the Carrier Tunnel is part of the NuMI RSIS and access to this region disables the NuMI critical devices. The primary critical devices are the NuMI Extraction Lambertson string (ACNET designation I:LAM60 & I:LAM61), and the Horizontal/Vertical Bend Magnet string (ACNET designation I:HV101A, B, & C). In the event of a critical device failure, the system has a failure mode function that will reach back and disable the upstream Booster RSIS. The NuMI RSIS prevents personnel access to Pre-Target, the Target Hall area, Decay Pipe tunnel, Hadron Absorber area and Muon Alcoves with beam enabled Access is not allowed to these areas unless the critical devices are disabled.

There are interlocked detectors in the Carrier Tunnel region to minimize losses along the primary beam, and power supply room. These detectors disable the critical devices when set points are exceeded.

The RSIS for the NuMI Beam Line includes the underground enclosures with the exception of the following areas that are accessible during routine operations:

- MI-65 Target Access Shaft Including Stairwell and Elevator;
- MI-65 Below Ground Elevator and Landing Area;
- Target Hall Power Supply Room;

- Absorber Access Tunnel up to the Absorber Area Door; and
- MINOS Access Shaft including elevators.

These areas are designated Controlled Areas.

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. The RSIS requirements including requirements for hardware and system testing, inventory of interlock keys, search and secure procedures for the beam line enclosure, controlled access procedures, personnel training requirements, and procedures for maintenance of interlock systems are in conformance with the FRCM.

II – 9.5.3 Administrative Controls

All NuMI Beam Line 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 – 9.5.3.1 Beam Permits and Run Conditions

In accordance with AD Administrative Procedure on Beam Permits, Run Conditions, and Startup (ADAP-11-0001), beam will not be transported to the NuMI 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 AD External Beams Department Head. The run conditions list the operating modes and safety envelope for the NuMI 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 NuMI Beam Line, the Pre-Target, Target Hall, Decay Pipe tunnel, Hadron Absorber area and Muon Alcoves must be secure. The radiation monitors in the Carrier Tunnel and power supply room must be active.

II – 9.5.3.2 Summary of Beam Operating and Safety Envelope Parameters

The NuMI Beam Line has been assessed from the standpoint of beam operating and safety envelope parameters. The beam operating parameter assessment was performed for 120 GeV MI protons transported to the NuMI target at a maximum intensity of 5.4×10^{13} protons every 1.333 seconds (1.46×10^{17} protons/hr).

II – 9.6 Summary & Conclusion

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

The preceding discussion of the hazards associated with NuMI Beam Line operations and the credited controls established to mitigate those hazards demonstrate that the NuMI Beam Line can be operated in a manner that will produce minimal risk to the health and safety of Fermilab workers, researchers, the public, as well as to the environment.

II – 9.7 Glossary, Acronyms

AD	Accelerator Division
ALARA	As Low As Reasonably Achievable
^{7}Be	Beryllium-7
EAV	Exhaust Air Vent
ES&H	Environment, Safety and Health
ESH&Q	Environment, Safety, Health and Quality
Fermilab	Fermi National Accelerator Laboratory
FESHM	Fermilab Environment, Safety, and Health Manual
FRCM	Fermilab Radiological Control Manual
GeV	Giga electron volts
^{3}H	Tritium
ICW	Industrial Cooling Water
LOTO	Lock out Tag out
MARS	Monte Carlo Shielding Computer Code
MI	Main Injector
MINOS	Main Injector Neutrino Oscillations Search
micro-rem/hr	micro-rem per hour
mrem/hr	milli-rem per hour
^{22}Na	Sodium-22
NuMI	Neutrinos at the Main Injector
pCi/ml	picoCurie/milliliter
RAW	Radioactive Water System
RSIS	Radiation Safety Interlock System
RSO	Radiation Safety Officer
RWP	Radiation Work Permit
SAD	Safety Assessment Document
SR	Survey Riser
TPES	Target Pile Evaporator Stack

II – 9.8 References

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