Booster Neutrino Beam

Revision 0
January 23, 2013

Author(s)
John E. Anderson Jr.
Craig Moore

Revision History

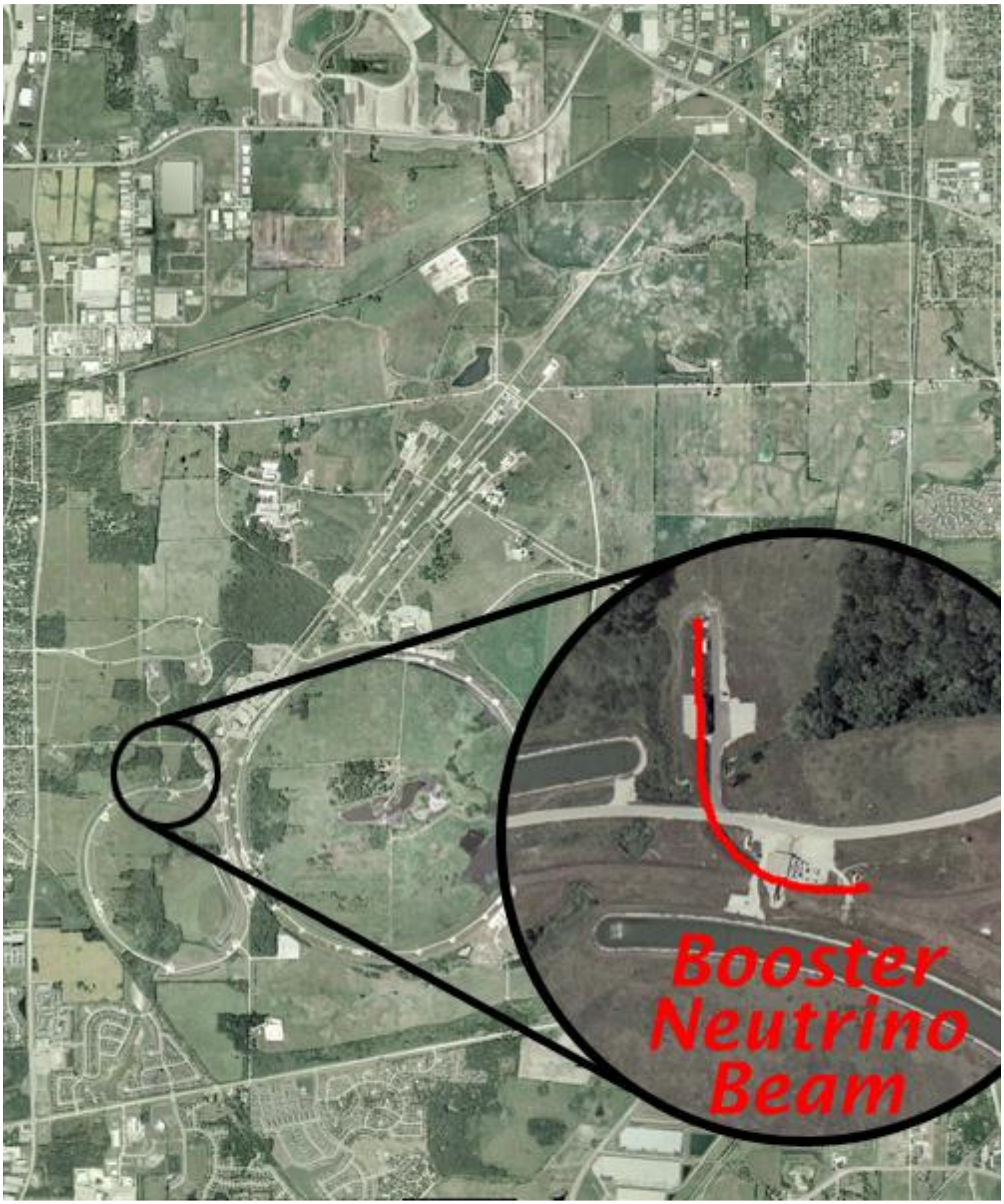
Author	Description of Change	Revision No. & Date
John E. Anderson Jr. Craig Moore	Initial release of the Booster Neutrino Beam Chapter for the Fermi National Accelerator Safety Assessment Document (SAD)	Revision 0 January 23, 2013

Table of Contents

II - 5 Booster Neutrino Beam

II - 5.1 Booster Neutrino Beam Area Location on Fermilab Site

The following aerial photograph shows the location of the Booster Neutrino Beam area in relationship to the Fermilab site.



II - 5.2 Inventory of Hazards

The following table lists the identified hazards found in the Booster Neutrino Beam enclosures and support building. All hazards with an * have been discussed in Chapters 1-10 of the Fermilab Safety Assessment Document and are not covered further in this section.

Radiation Particle beams and prompt radiation Residual component activation Ground water activation Surface water activation Radioactive waste Air Activation Soil activation	**Kinetic Energy** Power tools * Pumps and motors *
Toxic Materials Beryllium * Lead shielding *	**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 - 5.3 Introduction

This Section II, Chapter 5 of the Fermi National Accelerator Laboratory (Fermilab) Safety Assessment Document (SAD) covers the Booster Neutrino Beam area enclosures located north of the Main Injector accelerator.

II - 5.3.1 Purpose of the Booster Neutrino Beam

The original purpose of the Booster Neutrino Beam area was to provide an intense source of neutrinos to definitively explore the neutrino oscillation signal reported by the Los Alamos

Liquid Scintillator Neutrino Detector (LSND) experiment which took data from 1993-1998. The LSND experiment found evidence that muon neutrinos oscillate into electron neutrinos.

The Booster Neutrino Beam beamline was originally constructed for the first phase experiment called MiniBooNE for the Booster Neutrino Beam (BooNE) collaboration. Since the original construction, an additional experimental area SciBooNE was constructed and successfully ran. Construction is underway for the next phase experiment MicroBooNE. MicroBooNE will utilize a liquid argon Time Projection Chamber (TPC) to verify the usefulness of the technique and to check out the low energy excess seen by MiniBooNE. The facility is capable of being configured for a variety of 8 GeV neutrino physics.

II - 5.3.2 Description of the Booster Neutrino Beam areas

The Booster Neutrino Beam area is a multi-purpose neutrino experimental facility located north of the Main Injector near the MI-10 Service Building (see figure 1). The beamline begins near the downstream end of the 8 GeV Line enclosure at cell 851, where the first element is a switching magnet. Bending and focusing magnets in the Main Injector transport the extracted beam from the switching magnet to a buried beam pipe that connects the Main Injector and the 8 GeV Fixed Target beamline enclosure. The beamline continues through the 8 GeV Fixed Target beamline enclosure to the MiniBooNE target station under the MI-12 Service Building. Following the target station are the decay region, 25-m and 50-m beam absorbers, the MI-13 enclosure, and electronics shed.

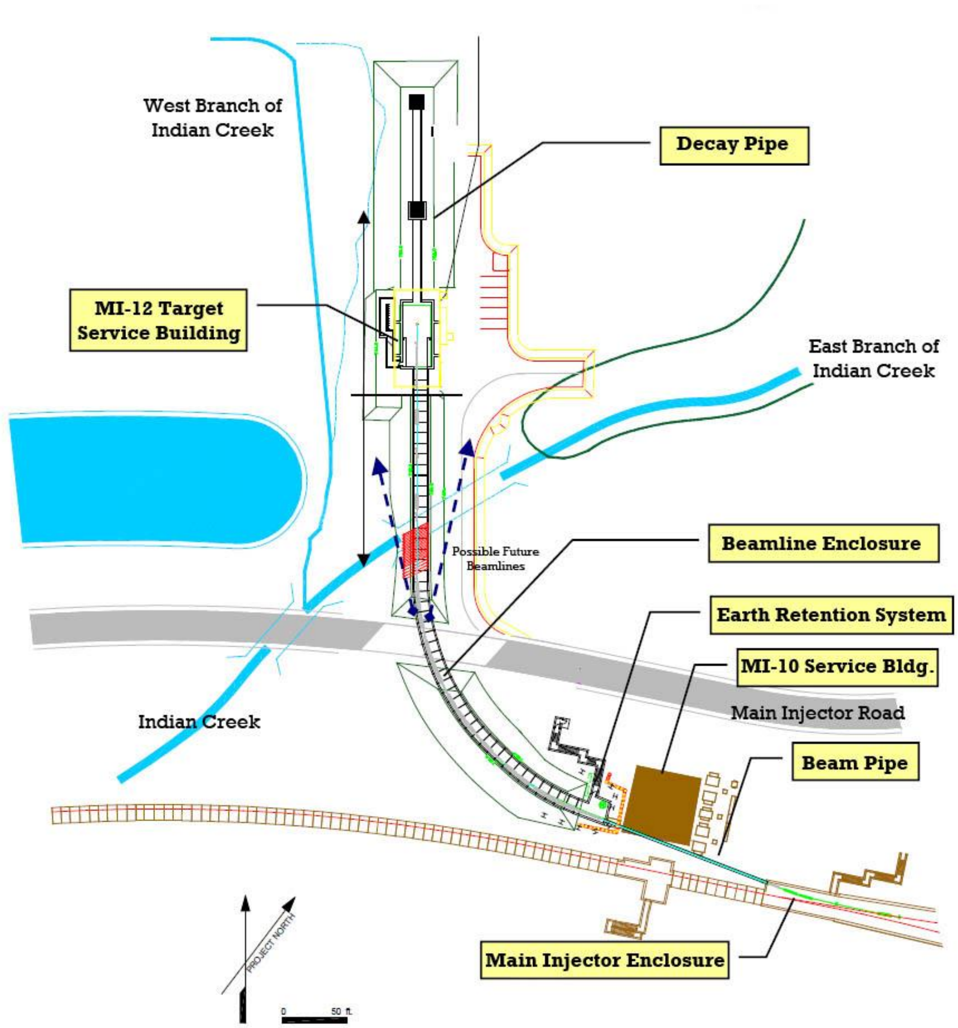


Figure 1 – Booster Neutrino Beam Layout

II - 5.3.3 Operating Modes

The Booster Neutrino Beam area accepts 8 GeV proton beam from the Booster. The 8 GeV beam leaves the Booster enclosure as it would for the Main Injector, down the MI-8 Line. It travels in the MI-8 Line through Q851. A switch magnet, MBEX (E:H851), located downstream of Q851, deflects selected Booster batches into the 8 GeV Fixed Target beamline. The next three quadrupoles, Q860, Q861 and Q862, capture the beam and focus it for transport through the 42-m drift tube (also known as the Jack Pipe) under the MI-10 service building. Before the drift tube is also where Booster Neutrino beam leaves the Main Injector enclosure near the 101 location. After the drift tube, quadrupoles Q864, Q865 and Q866 match the beam to the Focus-Defocus (FODO) cells of the arc that provides the major bend to direct the beam toward the MiniBooNE experimental area.

Protons from the primary beam strikes a beryllium target. The target is located within and concentric with the magnetic focusing horn, but is physically separated from the horn. Pions produced in the beryllium target by the 8 GeV protons make a large range of angles with respect to the incident beam direction. The neutrinos produced by the pion decays move nearly collinear with the parent pion direction. Unless the pions are focused toward the detector, many of the neutrinos would miss the detector and be lost to the experiment. The pions coming off of that target are focused by the solenoidal magnetic field generated from a high-current-carrying horn. The horn was designed to preferentially select pions with beam energies from 0.5 to 1 GeV, which are of interest to the MiniBooNE experiment. The horn operates at up to a 7.5 Hz repetition rate.

The horn focuses pions into a 50-m steel decay pipe, 1.8 meters in diameter. At the end of the decay pipe is a beam absorber, which stops all secondary particles except the neutrinos. Located 25 m from the target is an intermediate absorber that can be lowered into the beam. This feature was introduced to provide a test signal versus the background.

The neutrinos will travel 440 m through the ground to the MiniBooNE Detector (covered under a separate SAD chapter). These neutrinos will range in energies from 300 MeV to 1.5 GeV.

II - 5.4 Safety Assessment

This section contains an analysis of the unique accelerator-specific hazards of the Booster Neutrino Beam area. The unique accelerator-specific hazards found in the Booster Neutrino Beam area are radiological in the forms of ionizing radiation, residual activation, ground water and surface water activation, activation of closed loop cooling systems, and disposal of radioactive waste.

II - 5.4.1 Radiological Hazards

The Booster Neutrino Beam area presents radiation hazards in the form of prompt and residual ionizing radiation from particle beams and residual radiation due to activation of beamline components. Operating the Booster Neutrino Beam transport and targeting system also results in environmental radioactivity in the form of air, soil, and potential groundwater activation.

Two detailed shielding assessments and post assessment documents address these hazards. The assessments provide a detailed analysis of the Booster Neutrino Beam area and demonstrate the required overburden for shielding, use of signs, fences, and active interlocks comply with the Fermilab Radiological Control Manual[1] (FRCM). Residual activation of beamline components has a substantial impact on the ability to occupy the beamline enclosures where recurring access is required for routine maintenance. The 8 GeV Fixed Target Shielding Assessment[2] region extends from cell 803 in the 8 GeV Line to the front face of the MiniBooNE Target Station. The MiniBooNE Target Station Shielding Assessment[3] region begins at the front face of the target station in the MI-12B enclosure and continues through the decay and absorber regions to the point where the muons range out in the soil 70' downstream of the 50 meter absorber. The assessments assume an average pulse rate of 7.5 Hz pulses of 8 GeV/c protons at an intensity of $6x10^{12}$ protons per pulse (for a rate of $1.62x10^{17}$ protons per hour).

The assessments 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 - 5.4.1.1 Ionizing Radiation

Prompt ionizing radiation is the principle radiation hazard when beam is transported through the Booster Neutrino Beam area. Sufficient amounts of shielding (earth, concrete or iron) and/or networks of interlocked detectors surround the enclosures and beam pipes to keep any prompt radiation within acceptable levels and to protect workers and the general public from ionizing radiation.

The shielding provided by the enclosure and earthen overburden has been specifically and quantitatively analyzed for both normal and accidental loss conditions and documented in the 8 GeV Fixed Target Shielding Assessment, MiniBooNE Target Station Shielding Assessment, and post assessment documents.

The assessments require that:

- *All penetrations be filled with shielding as specified.*
- *All movable shielding blocks be installed as specified.*
- *The average beam intensity shall not exceed 1.62×10^{17} protons per hour.*
- *The radiation safety interlock system will be certified as working.*
- *Radiation detectors around the beamline enclosure will be installed and interlocked to the radiation safety interlock system.*
- *The 1000 CFM enclosure intake and exhaust ventilation fans must be off.*

- *The target cooling system fans must be on.*
- *An annual limit of 7.5×10^{20} protons is specified.*

These documents demonstrate that that facility can safely operate within the guidelines of the FRCM at a beam energy of 8 GeV and intensities up to 1.62 x 10^{17} protons per hour with an annual intensity limit of 7.5x10^{20} protons.

II - 5.4.1.2 Residual Activation

By design, residual radiation in the Booster Neutrino Beam area except at the target station is expected to be low. Beam interaction which would cause a high level of residual radiation would compromise the efficient transport of primaries to the target. Operational losses along the 8 GeV fixed target beamline will result in activation of instrumentation devices and other beam line components that intercept the beam. The activation level and quantity of activated material will not be unique relative to other modules of the of the Fermilab accelerator.

Residual activation hazards will be managed within the As Low As Reasonably Achievable (ALARA) program established throughout the Fermilab accelerator complex and as prescribed in the FRCM. All potential residual activation hazards are handled operationally as in all other primary beam enclosures. These controls include verification of training, centralized authorization, and key entry. The level of control depends on the level of residual radiation. In most cases, the typical Radiation Work Permit (RWP) for accesses will suffice. A job-specific RWP and an ALARA plan will be required for work on any highly activated equipment.

The target and focusing horn, referred to collectively as the "target station", have become highly radioactive during operation. The shielding assessment estimates the dose on target station components of up to 150 rem/hr and dose rates outside the target station shielding of less than 100 mrem/hr after 10 years of running and one day of cool off. No personnel access is allowed into the target station area. Job-specific ALARA plans have been developed to install a new horn and remove a failed horn. Members of the Accelerator Division Radiation Protection Group will supervise these tasks under the direction of an Accelerator Division Radiation Safety Officer (RSO).

There is no personnel access to the inside of the decay region. The 25-m absorber can be raised and lowered into the beam by accessing the 25-m absorber silo without exposing personnel to the front face or interior steel absorber plates.

II - 5.4.1.3 Ground Water and Surface Water Activation

This sections addresses radioactivity induced by the interaction of high-energy particles with the soil that surrounds the beamline, target station, decay region and beam absorbers. The greatest concern is the production of ^{3}H and ^{22}Na radionuclides due to production rate and leachability into the groundwater as well as the long half-lives of the radionuclides. The FRCM provides Fermilab standards pertaining to groundwater activation, and Environmental Protection Notes No. 8 and 17 provide the methodologies used for estimating groundwater activation. The methodology is designed to achieve a conservative estimate of groundwater activation.

Groundwater activation is a concern both in the target area and in the decay pipe area. The target pile was designed for the specified beam elevation, to provide adequate protection of the groundwater below the target pile.

A containment region consisting of crushed aggregate (CA-6) surrounds the 1.8 meter diameter decay pipe. The containment region extends at least ten feet from the beam centerline, i.e. seven feet from the decay pipe wall.

A design excluding water from the containment region was developed to keep groundwater activation outside this volume below the regulatory limits for radionuclides. The intent was to isolate water from the containment region using a double-walled geotextile liner system similar to those used in landfills (Figure 2). Six monitoring wells were installed for dewatering and sampling the three different liner zones. Three monitoring wells, one for each liner zone, are located at the upstream and downstream ends of the decay region on the east side.

The lower half of the liner system was tested in June, 2001, before final backfilling took place, and no leaks were detected[4]. A second set of tests in January, 2002[5] indicated a failure of both layers, and that the failure is near the bottom of the liner system.

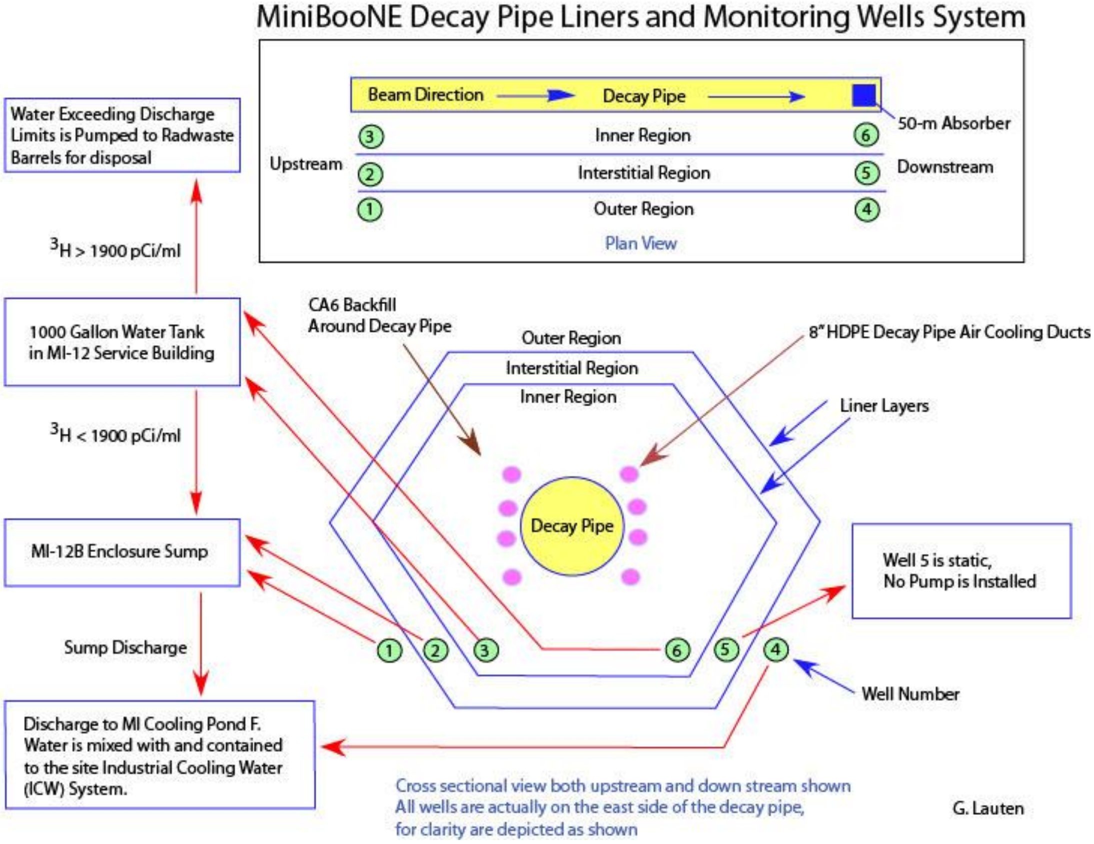


Figure 2 MiniBooNE Decay Pipe Liners and Monitoring Wells System

These tests could not identify the location of the failure, but they suggest that it is near the MI-12 end of the decay region. The failure likely cannot be repaired at reasonable cost; however, the leak prevention functionality of the liner system can be restored by continuously pumping and dewatering the entire volume. A detailed plan for dewatering and monitoring the decay region system has been developed[6].

The liner tests and the plans for mitigation have been reviewed by the MiniBooNE Safety Committee[7]. The details regarding installation of the equipment, measurement of performance, and documentation of the results are addressed in the Plan for Dewatering and Monitoring the MI-12 Decay Region[6]. Following the dewatering plan keeps groundwater activation outside the liner region below the regulatory limits for radionuclides; however dewatering also creates a waste stream of tritiated water requiring disposal.

In accordance with the dewatering plan, water from the exterior monitoring wells #1 and #4 is pumped to the Main Injector cooling pond F either directly or via the MI-12B enclosure sump. The MI cooling pond F is part of the site-wide Industrial Cooling Water (ICW) system, thus containing any tritiated water to the Fermilab site. The water levels in the remaining wells are monitored with level indicators, and pumped into a holding tank in the MI-12 Service Building for activation analysis prior to either release to the MI Cooling Pond or appropriate waste disposal. All discharges to surface waters conform to the requirements of DOE Order 458.1. Specifically, water having concentrations in excess of the Derived Concentration Standards (DCSs) of DOE Order 458.1 is disposed of as radioactive waste.

The AD External Beams Department in conjunction with the AD ES&H Department continues ALARA efforts to understand and reduce the amount of tritiated water collected from the system. Well and liner tests conducted between July and November 2012 were part of this effort to reduce the amount of tritiated water collected from the liner dewatering systems. These tests indicated that there are new well casing failures between the outer and interstitial regions of the liner at the upstream monitoring locations at an elevation below the liner. The tests further indicate that there are new well casing failures between all three downstream monitoring wells below the liner region and a likely breech in the liner at the location where the Little Muon Counter (LMC) pipe passes through the liner near the MI-13 enclosure. The suspected breach in the liner at the LMC s likely the source for the slow increase in tritiated water collected from the downstream monitoring wells over the past few years. These failures between the well casings and suspected liner breach at the LMC do not change the current dewatering plans, but rather provides additional information for the development of strategies to reduce the amount of tritiated water collected requiring disposal.

The MiniBooNE horn will be cooled by a "Closed Loop" water system, with its own pumps and purification system, filled from the Low Conductivity Water system. The system will reside in the MI-12B enclosure, just upstream of the target pile. The design and construction of this system is similar to many other "radioactive water (RAW) systems" at Fermilab. Water level, flow, and temperature interlocks are an input to the beam permit system. The system will be monitored for tritium build-up in accordance with the FRCM. Routine analysis of the RAW system concentration levels, the HEP program schedule, operational impact to other parts of the accelerator complex, and ALARA principles will all be considered when determining the appropriate timing of water replacement. The system incorporates a spill pan of sufficient volume to contain the activated water in case of leaks. Any water collected is disposed of in accordance with the FRCM.

The sump discharge locations along the 8 GeV beamline discharge to the MI cooling ponds that are part of the site-wide ICW system. The sump discharges are routinely sampled as part of the Accelerator Division (AD) Routine Monitoring Program ADDP-SH-1003.

II - 5.4.1.4 Air Activation

Air activation is caused by the primary 8 GeV proton beam and secondary radiation interacting with the air in the interior of the MiniBooNE target pile and decay pipe. 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 is 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.

Estimates for air activation from beamline target and decay areas were developed by members of the NuMI collaboration, and their work has been modified for the MiniBooNE target pile geometry[8]. The results from this analysis show that the amount of activated air released to the atmosphere depends upon three factors, (i) how much beam is lost in the 8 GeV Fixed Target beamline enclosure, (ii) how much air from the target pile and decay pipe is mixed with the air in the enclosure, and (iii) how rapidly the air flows through the enclosure, i.e. the ventilation rate.

The primary solution to controlling radioactive air emissions is to apply reasonable engineering controls to seal the activated region, i.e., the target pile in this case to maximize the decay of the airborne radionuclides in place. Concrete caps the target pile steel on the top, sides and front in order to contain the air inside the target pile. Voids on the sides, between the steel and concrete, have been filled with Styrofoam sheets. The top and front of the target pile have been made air tight to the extent possible by covering them with aluminum sheeting and caulking between sheets and where the sheets meet the concrete walls of the enclosure. The steel lid covering the 25-m absorber has been sealed with caulk where it meets the concrete side walls to make it as air tight as possible.

The shielding assessment for the MiniBooNE configuration estimates that operation of the facility will release no more than 15 Ci per year. The 15 Ci/yr will result in a dose at the site boundary of less than 0.015 mrem/yr, well below the Environmental Protection Agency (EPA) standard of 10 mrem/year and also much less than the EPA's continuous monitoring threshold of 0.1 mrem/year.

A fan installed at the exhaust stack near the MI-12A entrance establishes airflow from the target pile end towards the upstream end at ventilation rate of 100 cfm. This rate corresponds to more than a four-hour transit time through the enclosure. Air release data from 2008 through 2011 shows an average annual release of 2.4 Ci/yr from the target pile region, well below the assessed estimated release of 15 Ci/yr. The dose at the site boundary is based on separate calculations discussed in MiniBooNE Air Activation Analysis[8] and scaled to 1.62 x 10^{17} protons/hr in the Addendum to the MiniBooNE Target Station Shielding Assessment[3] using historical meteorological data.

The AD ES&H Department and the ESH&Q Section routinely monitors a permanent stack monitor installed for purposes of data-logging air emissions. This monitor is an input to the MUX system, and through the connection from MUX to the accelerator control system, can be connected to the beam permit system to shut off the beam in cases of off-normal operation. Following a period of operation and a cool-down period, the AD RSO determines when it is safe to turn back on the 1000-cfm ventilation systems that release air from the enclosure to the external atmosphere.

The design and construction of the target pile will reduce leakage except from around the horn region itself. Locations where there is a potential for the release of airborne radionuclides in measurable concentrations are identified and are routinely monitored in accordance with standard Fermilab procedures to ensure compliance with applicable standards.

II - 5.4.1.5 Closed Loop Air Cooling

The MiniBooNE target will be cooled by drawing air from the horn box, through the tube surrounding the beryllium target. The air will pass through a very efficient filter before reaching the blowers, to contain any particulates. Beryllium flakes from the target are the primary material that might be collected. Disposal of this filter will be done in accordance with FESHM. The filter is housed inside of a 0.75" thick steel shield. The steel shielding reduces the dose equivalent, on contact, to 36 mrem/hr per 0.1% of total target activity captured by the filter.

II - 5.4.1.6 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 Booster Neutrino Beam area design and operational procedures. Although production of radioactive material is not an operational function of the Booster Neutrino Beam area, 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.

Radioactive water from the target and horn cooling systems and any water from the decay region dewatering wells having concentrations in excess of the Derived Concentration Standards (DCSs) of DOE Order 458.1 is disposed of as radioactive waste in accordance with the FRCM requirements.

II - 5.5 Credited Controls

II - 5.5.1 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 beamline that take direct human intervention to remove. The Booster Neutrino Beamline area enclosures are designed and constructed as a permanent concrete and earth-covered radiation shield to protect personnel from radiological exposure during beam operations.

II - 5.5.1.1 Permanent Shielding Including Labyrinths

The permanent shielding encompasses the structural elements surrounding the beamline components. A buried beam transport pipe separates the concrete structure from the Main Injector enclosures. The permanent shielding includes the beamline enclosure with one personnel exit labyrinth, one major equipment hatch and personnel access labyrinth at the MI-12 Service Building, utility penetrations, and earthen berms and overburden.

The permanent shielding for the enclosure is documented in the 8 GeV Fixed Target Shielding Assessment, MiniBooNE Target Station Shielding Assessment, and post assessment documents. The shielding consists of sufficient earth overburden such that unacceptable levels of prompt radiation cannot occur under the assessed beam conditions.

II - 5.5.1.2 Penetration Shielding

The beamline has several utility penetrations routing between the exclusion areas and occupied areas which were analyzed for required shielding. These penetrations were designed to eliminate the need for additional penetration shielding. In summary, the prompt dose rates at the exits of the penetrations are within the limits established in the FRCM.

II - 5.5.1.3 Moveable Shielding

Within the MI-12 service building is an access shaft to the below grade enclosure to allow for rigging beamline elements and target station components into or out of the 8 GeV Fixed Target beamline enclosures. The access shaft is filled with a combination of steel and concrete shielding blocks to mitigate the prompt radiation from targeting to acceptable levels in the MI-12 service building.

The 25-meter absorber is constructed with an access shaft to the surface in the center of the decay region. The access shaft is filled with a combination of the steel plates that make up the 25-meter absorber and concrete shielding blocks to mitigate the prompt radiation from beam hitting the absorber when in the down position to acceptable levels on the berm.

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 MI-12 building crane for the building access shaft or an external crane for the 25 meter absorber. The shielding for both areas is defined in the MiniBooNE Target Station Shielding Assessment, and post assessment documents. The shielding is locked in-place and the configuration is controlled by the AD RSO.

II - 5.5.2 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, shutdown operations, or provide warning alarms when operating parameters are exceeded. The active controls in place for the Booster Neutrino Beam area operations are discussed below.

II - 5.5.2.1 Radiation Safety Interlock System

Booster Neutrino Beam area enclosure is part of the MiniBooNE Radiation Safety Interlock System. The characteristics of the system are described in Chapter I of the Fermilab SAD.

There are interlocked exit labyrinths at both ends of the 8GeV Fixed Target beamline enclosure with an internal section gate that is used to divide the enclosure into two separate boundaries called MI-12A and MI-12B. At the downstream end of the decay region is a small, underground, interlocked, instrumentation enclosure called MI-13. The interlock system inhibits transport of beam beyond the Booster Neutrino Beam extraction point in the 8 GeV Line except when the MI-12A, MI-12B, and MI-13 enclosures are properly secured and locked, the 1000

CFM intake and exhaust fans are off, the Target Air Flow Intake switch is on, and the area radiation monitors are made up.

The radiation safety interlock system inhibits beam by controlling redundant critical devices. For the Booster Neutrino Beam Area, the critical devices are the E:HV860 power supply that feeds the extraction magnet and the E:BS860 air operated beam stop in the MI enclosure. In the event of a critical device failure, the system has a failure mode function that will reach back and inhibit beam to the Booster, thus eliminating the possibility of beam reaching the Booster Neutrino Beam area enclosures.

Following any personnel access to the enclosure, trained and qualified personnel from the AD Operations Department must search and secure the enclosure before permits from the radiation safety interlock system may be reestablished, except under strictly specified controlled access conditions. The radiation safety interlock systems are in conformance with the FRCM, and include requirements for hardware and system testing, inventory of interlock keys, search and secure procedures for the beamline enclosure, controlled access procedures, personnel training requirements, and procedures for maintenance of interlock systems.

II - 5.5.3 Administrative Controls

All Booster Neutrino Beam area operations with the potential to affect the safety of employees, researchers, or the public, or to adversely affect the environment, are performed using approved laboratory, division, or department procedures. These procedures are the administrative controls that encompass the human interactions that define safe accelerator operations. The administrative procedures and programs considered necessary to ensure safe accelerator operations are discussed below.

II - 5.5.3.1 Beam Permits and Run Conditions

Beam will not be transported to the Booster Neutrino Beam area 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 Booster Neutrino Beam area. 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 Booster Neutrino Beam area, the radiation safety interlock system for the MI-12A, MI-12B, and MI-13 enclosures must be searched and secured; the critical device E:HV860 must be energized; the beam stop BS860 must be open, and the upstream area (Main Injector and 8 GeV Line) must be ready for beam.

II - 5.5.3.2 Summary of beam operating and safety envelope parameters

The Booster Neutrino Beam area is assessed for a pulsed proton beam with a maximum kinetic energy of 8 GeV, with a beam intensity of 6.0×10^{12} protons per pulse, and a maximum spill rate of 7.5 Hz. This equates to an hourly intensity rate of 1.62×10^{17} protons/hour. The maximum integrated beam intensity shall be no more than 7.5×10^{20} protons at 8 GeV per year.

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 Booster Neutrino Beam area 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 External Beams Department Head. The Run Condition for the Booster Neutrino Beam area describes the operating configuration as reviewed by the AD RSO, AD Operations Department Head, and as approved by the AD Head.

II - 5.5.3.3 Beamline Operations

Commissioning, normal operations, and emergency management of the Booster Neutrino Beam area are all conducted under the auspices of the AD Headquarters, the AD ES&H Department, AD External Beams Department, and the AD Operations Department in accordance with the Fermilab SAD.

II - 5.6 Summary & Conclusion

Specific hazards associated with commissioning and operation of the Booster Neutrino Beam area enclosures are identified and assessed in this chapter of the Fermilab Safety Assessment. The designs, controls, and procedures to mitigate Booster Neutrino Beam area specific hazards are identified and described. In addition to these specific safety considerations, the Booster Neutrino Beam area 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 Booster Neutrino Beam area 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 - 5.7 Glossary, Acronyms

AD	Fermilab Accelerator Division
ALARA	As Low As Reasonably Achievable
ES&H	Environment, Safety and Health
FODO	Focus-Defocus
FRCM	Fermilab Radiological Control Manual
GeV	Gigaelectronvolt
HEP	High Energy Physics
IEPA	Illinois Environmental Protection Agency
LSND	Liquid Scintillator Neutrino Detector
MI	Main Injector
RAW	Radioactive Water
RSO	Radiation Safety Officer
RWP	Radiation Work Permit
SAD	Safety Assessment Document
TPC	Time Projection Chamber

II - 5.8 References

[1] **Fermilab Radiological Control Manual**. **-** The current web link is: http://www-esh.fnal.gov/home/esh_home_page.page?this_page=900

[2] **8 GeV Fixed Target Shielding Assessment,** C. Moore, page 1, April 19, 2002. **MiniBooNE-Era Doses for MI8 Labyrinths & Penetrations**, B. Higgins, June 3, 2002. **Safety Envelope for 8 GeV Line and MiniBooNE Operation**, Michael A. Gerardi, December 4, 2009. **8GeV Line and MiniBooNE Nova-Era Operational Limits**, Michael A. Gerardi, December 4, 2009.

[3] **MiniBooNE Target Station Shielding Assessment**, P. Kasper, J. Link, and P. Martin, August 2, 2002. **Addendum to the MiniBooNE Target Station Shielding Assessment**, P. Kasper, R. Zimmermann, and B. Higgins, June 18, 2004. **8 GeV Beam Line and MiniBooNE Beam Line Nova-Era Operational Limits**, M. Gerardi, March 10, 2010.

[4] **MiniBooNE Liner Integrity Study** - TM-2159, November, 2001.

[5] **Report of Investigation, MiniBooNE Experiment Beamline Containment Region -** Patrick Engineering - MiniBooNE Technical Note 44, February, 2002**.**

[6] **Plan for Dewatering and Monitoring the MI-12 Decay Region –** P. Kasper, MiniBooNE Technical Note 45, August 1, 2002.

[7] **MiniBooNE Safety Committee, Failure of Decay Region Liner –** Meeting Minutes, 20 February, 2002.

[8] **MiniBooNE Air Activation Analysis** – MiniBooNE Technical Note 43, C. Bhat, P. Kasper, P. Martin, and R. Stefanski, August 1, 2002.