BOOSTER NEUTRINO BEAM

SECTION III CHAPTER 06 OF THE FERMILAB SAD

Revision 1 August 8, 2023

This Chapter of the Fermilab Safety Assessment Document (SAD) contains a summary of the results of the Safety Analysis for the Booster Neutrino Beam of the Fermilab Main Accelerator that are pertinent to understanding the risks to the workers, the public, and the environment due to its operation.

SAD Chapter Review

This Section III, Chapter 6 of the Fermi National Accelerator Laboratory (Fermilab) Safety Assessment Document (SAD), *Booster Neutrino Beam*, was prepared and reviewed by the staff of the Accelerator Directorate (AD), Beams Division, External Beam Delivery Department in conjunction with the Environment, Safety, and Health (ES&H) Division Accelerator Safety Department.

Signatures below indicate review of this Chapter, and recommendation that it be approved and incorporated into the Fermilab SAD.

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Revision History

Printed versions of this Chapter of the Fermilab Safety Assessment Document (SAD) may not be the currently approved revision. The current revision of this Chapter can also be found on ES&H DocDB #1066 along with all other current revisions of all Chapters of the Fermilab SAD.

Author	Rev. No.	Date	Description of Change
John E. Anderson Jr. & Craig Moore	0	January 23, 2013	Initial release of the Booster Neutrino Beam Chapter for the Fermi National Accelerator Safety Assessment Document (SAD).
Jason D. Crnkovic	1	August 8, 2023	Updated document format and new consideration of Standard Industrial Hazards.

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Acronyms and Abbreviations

ACGIH	American Conference of Governmental Industrial Hygienists
ACNET	Accelerator Control Network System
AD	Accelerator Directorate
AHJ	Authority Having Jurisdiction
ALARA	As Low As Reasonably Achievable
ANSI	American National Standards Institute
APS-TD	Applied Physics and Superconducting Technology Directorate
ARA	Airborne Radioactivity Area
ASE	Accelerator Safety Envelope
ASHRAE	American Society of Heating, Refrigerating and Air Conditioning Engineers
ASME	American Society of Mechanical Engineers
ASO	Accelerator Safety Order, referring to DOE O 420.2D *Safety of Accelerators*
^{7}Be	Beryllium-7
BLM	Beam Loss Monitor
BNB	Booster Neutrino Beam
BPM	Beam Position Monitor
BY	Boneyard
CA	Controlled Area
CA	Contamination Area
CAS	Contractor Assurance System
CC	Credited Control
CCL	Coupled Cavity Linac
CDC	Critical Device Controller
CERN	European Organization for Nuclear Research
CFM	Cubic Feet per Minute
CFR	Code of Federal Regulations (United States)
Ci	Curie
CLW	Co-Located Worker (the worker in the vicinity of the work but not actively participating)
cm	centimeter
CPB	Cryogenics Plant Building
CSO	Chief Safety Officer
CUB	Central Utility Building
CW	Continuous Wave
CX	Categorically Excluded
D&D	Decontamination and Decommissioning
DA	Diagnostic Absorber

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

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

MC&A	Materials Control and Accountability
MCR	Main Control Room
MEBT	Medium Energy Beam Transport
MEI	Maximally Exposed Individual
MeV	Mega-electron volt
MI	Main Injector
MINOS	Main Injector Neutrino Oscillation Search
MMR	Material Move Request
MOI	Maximally-exposed Offsite Individual *(Note: due to the Fermilab Batavia Site being open to the public, the location of the MOI is taken to be the location closest to the accelerator that is accessible to members of the public.)*
MP	Meson Polarized
mrad	milli-radian
mrem	milli-rem
mrem/hr	milli-rem per hour
MT	Meson Test
MTA	400 MeV Test Area
MTF	Magnet Test Facility
^{22}Na	Sodium-22
NC	Neutrino Center
NE	Neutrino East
NEC	National Electrical Code
NEPA	National Environmental Policy Act
NESHAPS	National Emissions Standards for Hazardous Air Pollutants
NFPA	National Fire Protection Association
NM	Neutrino Muon
NMR	Nuclear Material Representative
NOvA	Neutrino Off-axis Electron Neutrino (ve) Appearance
NPH	Natural Phenomena Hazard
NRTL	Nationally Recognized Testing Laboratory
NIF	Neutron Irradiation Facility
NTSB	Neutrino Target Service Building, see also TSB
NuMI	Neutrinos at the Main Injector
NW	Neutrino West
ODH	Oxygen Deficiency Hazard
ORC	Operational Readiness Clearance
OSHA	Occupational Safety and Health Administration
pCi	pico-Curie
pCi/mL	pico-Curie per milliliter

PE	Professional Engineer
PIN	Personal Identification Number
PIP	Proton Improvement Plan
PIP-II	Proton Improvement Plan - II
PHAR	Preliminary Hazards Analysis Report
PPD	Particle Physics Directorate
PPE	Personnel Protective Equipment
QA	Quality Assurance
QAM	Quality Assurance Manual
RA	Radiation Area
RAF	Radionuclide Analysis Facility
RAW	Radioactive Water
RCT	Radiological Control Technician
RF	Radio-Frequency
RFQ	Radio-Frequency Quadrupole
RIL	RFQ Injector Line
RMA	Radioactive Material Area
RMS	Root Mean Square
RPCF	Radiation Physics Calibration Facility
RPE	Radiation Physics Engineering Department
RPO	Radiation Physics Operations Department
RRM	Repetition Rate Monitor
RSI	Reviewed Safety Issue
RSIS	Radiation Safety Interlock System
RSO	Radiation Safety Officer
RWP	Radiological Work Permit
SA	Shielding Assessment
SAA	Satellite Accumulation Areas
SAD	Safety Assessment Document
SCF	Standard Cubic Feet
SCFH	Standard Cubic Feet per Hour
SEWS	Site-Wide Emergency Warning System
SNS	Spallation Neutron Source
SR	Survey Riser
SRF	Superconducting Radio-Frequency
SRSO	Senior Radiation Safety Officer
SSB	Switchyard Service Building
SSP	Site Security Plan
SWIC	Segmented Wire Ionization Chambers

TLM	Total Loss Monitor
TLVs	Threshold Limit Values
TPC	Time Projection Chamber
TPES	Target Pile Evaporator Stack
TPL	Tagged Photon Lab
TSB	Target Service Building, see also NTSB
TSCA	Toxic Substances Control Act
TSW	Technical Scope of Work
T&I	Test and Instrumentation
UPB	Utility Plant Building
UPS	Uninterruptible Power Supply
USI	Unreviewed Safety Issue
VCTF	Vertical Cavity Test Facility
VHRA	Very High Radiation Area
VMS	Village Machine Shop
VMTF	Vertical Magnet Test Facility
VTS	Vertical Test Stand
WSHP	Worker Safety and Health Program
μs	micro-second

III-6. Booster Neutrino Beam

III-6.1. Introduction

This Section III, Chapter 6 of the Fermilab SAD covers the Booster Neutrino Beam (BNB) segment of the Fermilab Main Accelerator.

III-6.1.1 Purpose/Function

The original purpose of the BNB segment 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 BNB beamline was originally constructed for the first phase experiment called MiniBooNE operated by the Booster Neutrino Beam (BooNE) collaboration. Since the original construction, an additional experimental area SciBooNE was constructed and successfully ran. The beamline is currently being used to support the Short-Baseline Neutrino (SBN) Program at Fermilab, which includes the MicroBooNE (finished collecting data), ICARUS (collecting data), ANNIE (collecting data), and SBND (under construction) experiments. The facility is capable of being configured for a variety of 8 GeV neutrino physics.

III-6.1.2 Current Status

The BNB segment of the Fermilab Main Accelerator is currently: **Operational.**

III-6.1.3 Description

The BNB segment is a multi-purpose neutrino experimental facility located north of the Main Injector (MI) near the MI10 Service Building (see figure 1). The BNB segment accepts beam from the 8 GeV Line (MI8) segment, where the 8 GeV Line is covered under a separate SAD chapter. The BNB segment begins near the downstream end of the MI8 enclosure at cell 851, where the first element is a switching magnet. Bending and focusing magnets in MI transport the extracted beam from the switching magnet to the buried MI-12A carrier pipe that connects the MI to the 8 GeV Fixed Target beamline that includes the MI-12A and MI-12B enclosures. The beamline continues through the MI-12A and MI-12B enclosures to the BNB target station under the MI-12 Service Building. Following the target station are the decay region, 25-m and 50-m beam absorbers, MI-13 enclosure, and MI-13 electronics shed. This chapter assesses the carrier pipe; MI-12A, MI-12B, and MI-13 enclosures; target pile; decay pipe; 25-m and 50-m absorbers; MI-12 Service Building; and MI-13 electronics shed.

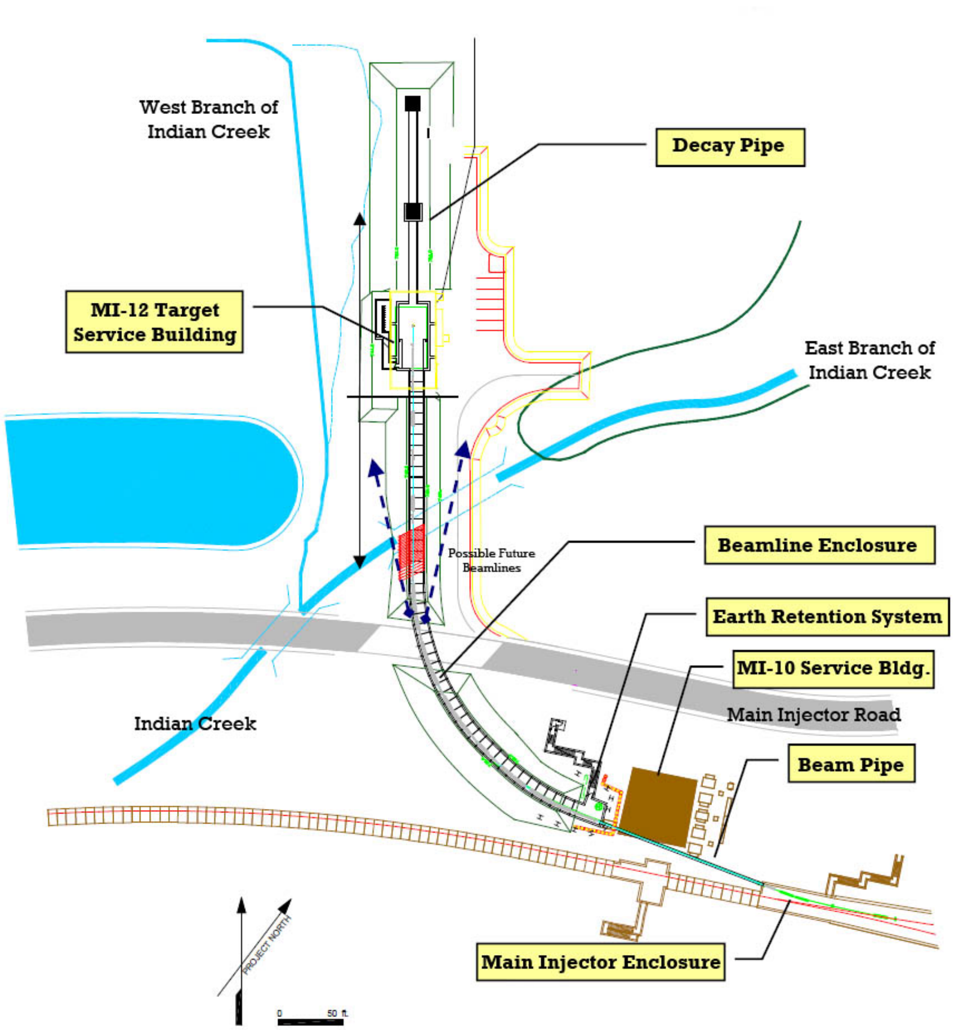

Figure 1. Booster Neutrino Beam (BNB) Layout Figure.

III-6.1.4 Location

The BNB segment of the Fermilab Main Accelerator is located on the Fermilab site in Batavia, IL (see figure 2). Specifically, this segment is located north of the MI segment (see Figure 3).

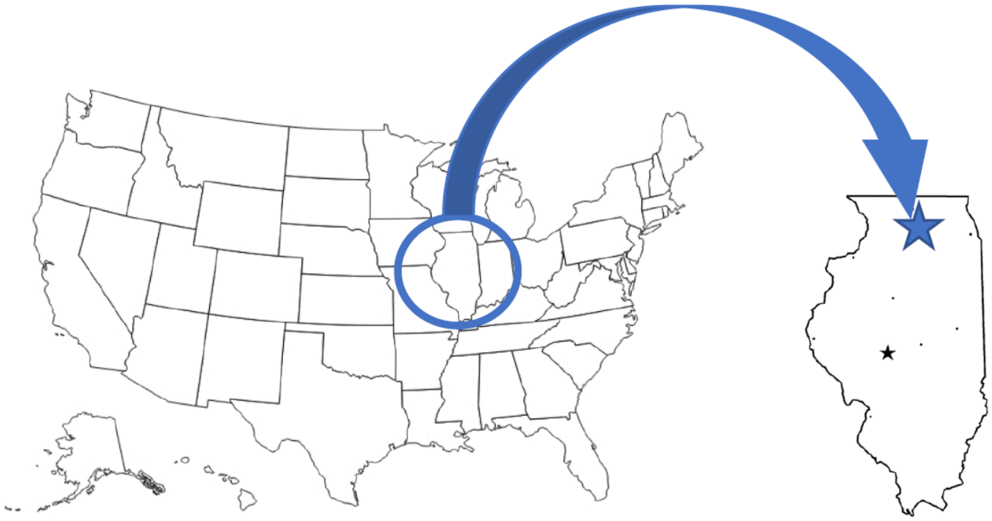

Figure 2. Regional view showing the location of the Fermilab site in Batavia, IL.

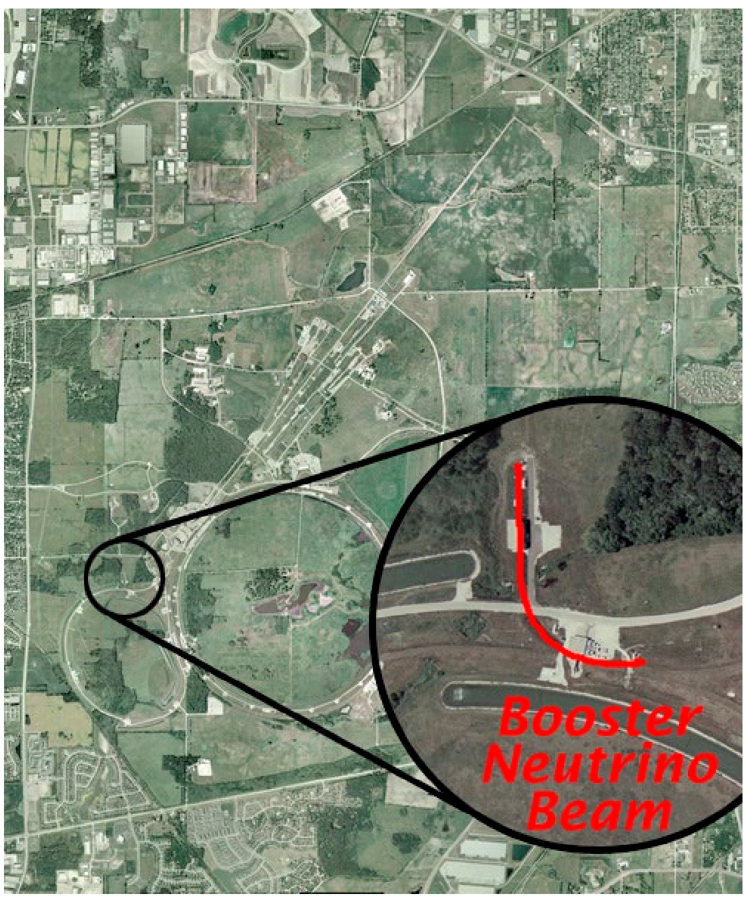

Figure 3. Aerial view of the Fermilab site, indicating the location of the Booster Neutrino Beam (BNB).

III-6.1.5 Management Organization

The BNB area is managed by AD, the Beams Division, and the External Beam Delivery Department.

III-6.1.6 Operating Modes

The BNB segment accepts 8 GeV proton beam from the Booster segment. The 8 GeV beam leaves the Booster enclosure as it would for the MI segment, down the MI8 beamline. It travels in the MI8 beamline through Q851. A switch magnet, MBEX (E:H851), located downstream of Q851 deflects selected Booster batches into the MI-12A and MI-12B enclosures. The next three quadrupoles, Q860, Q861 and Q862, capture the beam and focus it for transport through the 42-m drift tube (Jack Pipe) under the MI10 Service Building. Before the drift tube is also where BNB leaves the MI 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 provide the major bend to direct the beam toward the SBN experimental area.

Protons from the primary beam strike a beryllium target. The target is located within and concentric with the magnetic focusing horn, but it 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 detectors, many of the neutrinos would miss the detectors and be lost to the experiments. The pions coming off of that target are focused by the toroidal magnetic field generated from a high-current-carrying horn. The horn preferentially selects pions with beam energies from 0.75 to 3.75 GeV, which are of interest to the SBN Program. The horn operates at up to a 7.5 Hz repetition rate.

The horn focuses pions into a 50-m steel decay pipe that has a 1.8-meter 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 detectors used in the SBN Program (covered under separate SAD chapters). These neutrinos will range in energies from 0.3 to 1.5 GeV.

III-6.1.7 Inventory of Hazards

The following table lists all the identified hazards found in the BNB enclosure and support buildings. Section III-6.10 *Appendix – Risk Matrices* describes the baseline (unmitigated) risk, any preventative and/or mitigative controls in place to reduce the risk, and residual (mitigated) risk for facility worker, co-located worker, and Maximally-exposed Offsite Individual (MOI), i.e. a member of the public. A summary of these controls is described within Section III-6.2 *Safety Assessment.*

Prompt ionizing radiation, Oxygen Deficiency Hazard (ODH) due to cryogenic systems within accelerator enclosures, and fluorinert byproducts due to fluorinert use subject to particle beams have been identified as accelerator specific hazards, and as such, their controls are identified as Credited Controls. The analysis of these hazards and their Credited Controls will be discussed within this SAD chapter, and their Credited Controls summarized in the Accelerator Safety Envelope (ASE) for the Fermilab Main Accelerator. Accelerator specific controls are identified as **purple/bold** throughout this chapter.

All other hazards present in BNB are safely managed by other Department of Energy (DOE) approved applicable safety and health programs and/or processes, and their analyses have been performed according to applicable DOE requirements as flowed down through the Fermilab Environment, Safety, and Health Manual (FESHM). These hazards are considered to be Standard Industrial Hazards (SIHs), and their analysis will be summarized in this SAD Chapter.

Table 1. Hazard Inventory for Booster Neutrino Beam (BNB).

Radiological		**Toxic Materials**	
☒	Prompt Ionizing Radiation	☒	Lead
☒	Residual Activation	☒	Beryllium
☒	Groundwater Activation	☐	Fluorinert & Its Byproducts
☒	Surface Water Activation	☐	Liquid Scintillator
☒	Radioactive Water (RAW) Systems	☐	Ammonia
☒	Air Activation	☐	Nanoparticle Exposures
☒	Closed Loop Air Cooling	**Flammables and Combustibles**	
☒	Soil Interactions	☒	Combustible Materials (e.g., cables, wood cribbing, etc.)
☒	Radioactive Waste	☐	Flammable Materials (e.g., flammable gas, cleaning materials, etc.)
☒	Contamination	**Electrical Energy**	
☒	Beryllium-7	☒	Stored Energy Exposure
☒	Radioactive Sources	☒	High Voltage Exposure
☐	Nuclear Material	☒	Low Voltage, High Current Exposure
☐	Radiation Generating Devices (RGDs)	**Kinetic Energy**	
☐	Non-Ionizing Radiation Hazards	☒	Power Tools
Thermal Energy		☒	Pumps and Motors
☐	Bakeout	☒	Motion Tables
☒	Hot Work	☐	Mobile Shielding
☐	Cryogenics	**Magnetic Fields**	
Potential Energy		☒	Fringe Fields
☒	Crane Operations	**Other Hazards**	
☒	Compressed Gasses	☒	Confined Spaces
☒	Vacuum/Pressure Vessels/Piping	☒	Noise
☒	Vacuum Pumps	☒	Silica
☒	Material Handling	☒	Ergonomics
Access & Egress		☐	Asbestos
☒	Life Safety Egress	☒	Working at Heights

III-6.2. Safety Assessment

All hazards for the BNB segment of the Fermilab Main Accelerator are summarized in this section, with additional details of the analyses for accelerator specific hazards.

III-6.2.1 Radiological Hazards

BNB has radiological hazards in the form of prompt ionizing radiation (from particle beams), residual activation (from component activation), groundwater activation, surface water activation, radioactive water (RAW) systems, air activation, closed loop air cooling, soil interactions, radioactive waste, contamination, beryllium-7, and radioactive sources. Detailed shielding assessments [1][2] address these hazards and provide a detailed analysis of the facility demonstrating the required shielding, controls, and interlocks to comply with the Fermilab Radiological Control Manual (FRCM) [3]. Operating the BNB transport and targeting systems 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 BNB segment and demonstrate that the required overburden for shielding, use of signs, fences, and active interlocks comply with 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 [1] 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 [2] 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 7.5 Hz pulse rate of 8 GeV/c protons at an intensity of 6e12 protons/pulse for a rate of 1.62e17 protons/hr.

The assessments consider transverse and longitudinal shielding requirements; summarize labyrinth and penetration calculations; calculate air activation, estimate annual release, and list release points; calculate ground and surface water activation, list surface water discharge points, and monitoring locations; consider muon production; calculate residual dose rates; and specify active shielding controls and monitoring.

III-6.2.1.1 Prompt Ionizing Radiation

Several preventions and mitigations are used to reduce the risk associated with the prompt ionizing radiation hazards, which include the following. The Radiation Safety Interlock System (RSIS) uses a key tree system that captures the keys to an accelerator enclosure. These keys are electrically monitored through the Radiation Safety System and Electrical Safety System to turn off the accelerator enclosure if any key is removed from the key tree. Radiological signage is in various places throughout the accelerator complex, which warns of various hazards and occupancy restrictions. Radiological training is an educational system managed by ES&H personnel that establishes basic worker knowledge through presentations and testing. Certified interlocked beam loss detectors are electrically monitored through the Radiation Safety System, and they will turn off an accelerator enclosure if the radiation is measured to be over a predetermined threshold. Radiological shielding is material placed between radiation sources and the enclosure to be protected. Shielding is also placed between radiation sources and people, which prevents the close proximity of these sources and people. Public access gates will be used to prevent unauthorized access by the public. The following discussion in this section outlines the approach used to reduce the risk associated with prompt ionizing radiation hazards.

Prompt ionizing radiation is the principal radiation hazard when beam is transported through the BNB segment. 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 (via crane) shielding blocks be installed as specified.
- The average beam intensity shall not exceed 1.62e17 protons/hr.
- 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 7.5e20 protons is specified.

These documents demonstrate that the facility can safely operate within the guidelines of FRCM at a beam energy of 8 GeV and intensities up to 1.62e17 protons/hr with an annual intensity limit of 7.5e20 protons.

Additionally, baseline qualitative risks due to this hazard were assessed, and determined to be risk level I (major concern) for facility workers and co-located worker receptors, but through the use of preventive and mitigative hazard controls, the likelihood and consequence of this hazard is reduced, resulting in a risk level of IV, meaning residual risks are of minimal concern. For the public the baseline qualitative risk due to this hazard are managed through a series of preventive and mitigative controls, which mitigate consequences from the hazard from a baseline risk level III (minor concern) to a residual risk level of IV (minimal concern).

III-6.2.1.2 Residual Activation

Several preventions and mitigations are used to reduce the risk associated with the residual activation hazards, which include the following. General and/or job specific Radiological Work Permits (RWPs) are written by ES&H personnel, and they specify the work that is permitted to be performed, requirements to perform the work, and limitations of radiological exposure. A Log Survey Monitor (LSM) allows for real time monitoring of radiation levels during work, and its use is specified in the relevant RWP when deemed appropriate for the work. Radiological training is an educational system managed by ES&H personnel that establishes basic worker knowledge through presentations and testing. Radiological signage is in various places throughout the accelerator complex, which warns of various hazards and occupancy restrictions. Furthermore, work may be restricted or prevented until sufficient time has passed such that radiation levels are sufficiently low to allow for safer work to proceed. Target pile shielding is material placed between radiation sources in the target pile and the enclosure to be protected. Shielding is also placed between radiation sources and other materials that may come into the close proximity of people. Public access gates will be used to prevent unauthorized access by the public. The following discussion in this section outlines the approach used to reduce the risk associated with residual activation hazards.

By design, residual radiation in the BNB 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 segments of the Fermilab Main 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 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, a general 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. These tasks will be carried out under the direction of an ES&H 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.

Lastly, baseline qualitative risks due to this hazard were assessed, and determined to be risk level I (major concern) for facility workers and co-located worker receptors, but through the use of preventive and mitigative hazard controls, the likelihood and consequence of this hazard is reduced, resulting in a risk level of IV, meaning residual risks are of minimal concern. For the public the baseline qualitative risk due to this hazard are managed through a series of preventive and mitigative controls, which mitigate consequences from the hazard from a baseline risk level III (minor concern) to a residual risk level of IV (minimal concern).

III-6.2.1.3 Groundwater Activation

Several preventions and mitigations are used to reduce the risk associated with the groundwater activation hazards, which include the following. Facility designs employ shielding to mitigate the production of activation products in groundwater. Sump pits/enclosures capture activated water to prevent releases exceeding allowed discharge limits. Sump water is evaluated to determine the presence of tritium or other activation products to prevent exposure to people. The sump water is periodically sampled, and tank draining is performed by Radiological Control Technicians (RCTs) who have specialized training. The highly trained RCTs employ ALARA principles to mitigate exposures during tank draining activities. The following discussion in this section outlines the approach used to reduce the risk associated with prompt ionizing radiation hazards.

The greatest concern is the production of helium-3 (tritium) and sodium-22 radionuclides due to production rate and leachability into the groundwater, as well as the long half-lives of these radionuclides. 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 and decay pipe areas. The target pile was designed for the specified beam elevation, so as 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.

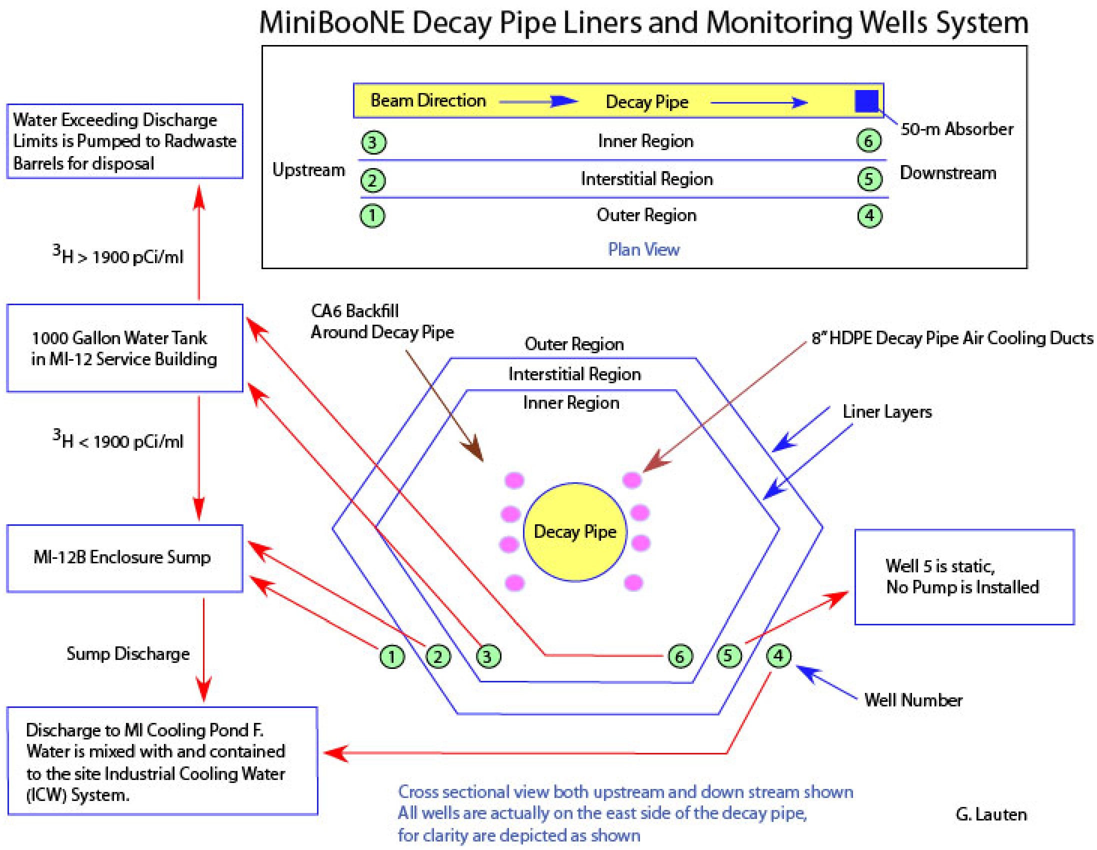

Figure 4. MiniBooNE Deca Pipe Liners and Monitoring Wells System.

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.

The AD External Beam Delivery Department in conjunction with ES&H 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 is likely the source for the slow increase in tritiated water collected from the downstream monitoring wells over the years. These failures between the well casings and suspected liner breach at the LMC do not change the current dewatering plans, but rather provide additional information for the development of strategies to reduce the amount of tritiated water collected requiring disposal.

III-6.2.1.4 Surface Water Activation

Baseline qualitative risk analysis of this hazard determined that for worker, co-located worker, and members of the public receptors, that potential exposures to groundwater activation, although anticipated, from the perspective of frequency of occurrence, carries a negligible exposure consequence, and therefore is rated at a risk level of IV (minimal concern). Through the use of preventive and mitigative measures by the facility, the residual qualitative risk for workers, co-located workers and members of the public, likelihood is reduced to "extremely unlikely", and a residual qualitative risk of IV (minimal concern).

Several preventions and mitigations are used to reduce the risk associated with the surface water activation hazards, which include the following. Soil, concrete, and/or steel shielding reduces surface water activation. Beam loss monitors in enclosures are used to prevent excessive beam loss during normal operations, as beam loss can produce activated materials. Radiation detectors in enclosures and berms reduce the amount of activation to surface water by promptly disabling the beam when losses go above a threshold value. An off-site discharge limit is applied to any water mixed into onsite surface water, as this prevents surface water concentrations from approaching the Derived Concentration Standard (DCS). Monitoring of potential mixed sources allow for diversion of water, preventing exposure to waters above the DCS. In situations where surface water activation is higher than expected (discovered by monitoring), the facility stops operations until the facility upset condition is resolved. Frequent surface water monitoring at many locations allows for the mitigation of increases in activity approaching the DCS. The following discussion in this section outlines the approach used to reduce the risk associated with surface water activation hazards.

In accordance with the dewatering plan, water from the exterior monitoring wells #1 and #4 is pumped to the MI 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 the water is 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 DCS of DOE Order 458.1 is disposed of as radioactive waste.

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

Baseline qualitative risk analysis of this hazard determined that for worker, co-located worker, and members of the public receptors, that potential exposures to surface water activation, although anticipated, from the perspective of frequency of occurrence, carries a negligible exposure consequence, and therefore is rated at a risk level of IV (minimal concern). Through the use of preventive and mitigative measures by the facility, the residual qualitative risk for workers, co-located workers and members of the public, likelihood is reduced from "anticipated: to "extremely unlikely", and a residual qualitative risk of IV (minimal concern).

III-6.2.1.5 Radioactive Water (RAW) Systems

Several preventions and mitigations are used to reduce the risk associated with the radioactive water (RAW) system hazards, which include the following. A RAW key control system prevents personnel access to radioactive water systems. Engineered secondary containment prevents unintended exposure to contaminated water. General and/or job specific RWPs are written by ES&H personnel, and they specify the work that is permitted to be performed, requirements to perform the work, and limitations of radiological exposure. A LSM allows for real time monitoring of radiation levels during work, and its use is specified in the relevant RWP when deemed appropriate for the work. The Run Condition gives operating parameters that reduce activation by limiting the total amount of beam that could be delivered. Specifically, this includes an operating limit for protons/hr. A RWP will specify that a RCT or RSO be present during certain kinds of work or work conditions. The radiological expert can make real time decisions to limit, stop, or prevent radiation exposure to personnel. Public access gates will be used to prevent unauthorized access by the public. Radiological shielding is material placed between radiation sources and people, which prevents the close proximity of these sources and people. The following discussion in this section outlines the approach used to reduce the risk associated with RAW system hazards.

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 (LCW) 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 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 FRCM. Routine analysis of the RAW system concentration levels, 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 hazard due to Radioactive Water (RAW) Systems was evaluated, for the potential hazards associated with workers, co-located workers and the public potentially being exposed to radioactive water beyond regulatory limits. The baseline, qualitative risks due to this hazard were assessed, and determined to be risk level I (major concern) for workers and co-located workers and risk level III (minor concern) for the public. Through the use of a number of preventive and mitigative hazard controls, the likelihood and consequence of this hazard is reduced, resulting in a risk level of IV to workers and co-located workers, meaning residual risks are of minimal concern. For the public, the baseline qualitative risk due to this hazard are managed through a series of preventive controls (locked facilities, interlocked systems preventing entry), so that the likelihood of experiencing this hazard remains Beyond Extremely Unlikely, with a reduction of overall residual risk of IV, meaning the risk is a minimal concern, not subject to additional evaluation.

III-6.2.1.6 Air Activation

Several preventions and mitigations are used to reduce the risk associated with the air activation hazards, which include the following. Target pile shielding is material placed between radiation sources in the target pile and the enclosure to be protected. Key issuance to enclosures is restricted until after the air monitors show that there is a sufficiently low level of radiation coming from the activated air components. A LSM allows for real time monitoring of radiation levels during work, and its use is specified in the relevant RWP when deemed appropriate for the work. The release of activated air is engineered to reduce potential exposure consequences. The air flow is engineered to dilute the activated air components and provide time for these components to decay away prior to the release of the air from the enclosure. The Run Condition gives operating parameters that reduce activation by limiting the total amount of beam that could be delivered. Specifically, this includes an operating limit for protons/hr. Public access gates will be used to prevent unauthorized access by the public. The following discussion in this section outlines the approach used to reduce the risk associated with air activation hazards.

The shielding assessment for the MiniBooNE configuration estimates that operation of the facility will release no more than 15 Ci/year. The 15 Ci/year will result in a dose at the site boundary of less than 0.015 mrem/year, which is 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 enclosures. Air release data from 2008 through 2011 shows an average annual release of 2.4 Ci/year from the target pile region, well below the assessed estimated release of 15 Ci/year. The dose at the site boundary is based on separate calculations discussed in the MiniBooNE Air Activation Analysis [8] and scaled to the 1.62e17 protons/hr found in the addendum to the MiniBooNE Target Station Shielding Assessment [2] using historical meteorological data.

ES&H routinely checks 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, a 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 reduces leakage except from around the horn region itself. Potential locations for the release of airborne radionuclides in measurable concentrations are identified and routinely monitored in accordance with standard Fermilab procedures to ensure compliance with applicable standards.

The hazard due to Air activation was evaluated, for the potential hazards associated with workers, co-located workers and the public potentially being exposed to radioactive water beyond regulatory limits. The baseline, qualitative risks due to this hazard were assessed, and determined to be risk level I (major concern) for workers and co-located workers and risk level III (minor concern) for the public. Through the use of a number of preventive and mitigative hazard controls, the likelihood and consequence of this hazard is reduced, resulting in a risk level of IV to workers and co-located workers, meaning residual risks are of minimal concern. For the public, the baseline qualitative risk due to this hazard are managed through a series of preventive controls (locked facilities, interlocked systems preventing entry), so that the likelihood of experiencing this hazard remains Beyond Extremely Unlikely, with a reduction of overall residual risk of IV, meaning the risk is a minimal concern, not subject to additional evaluation.

III-6.2.1.7 Closed Loop Air Cooling

Several preventions and mitigations are used to reduce the risk associated with the closed loop air cooling hazards, which include the following. The Run Condition gives operating parameters that reduce activation by limiting the total amount of beam that could be delivered. Specifically, this includes an operating limit for protons/hr. Engineered containment of the cooling air is used to keep it separate from the breathable air. Target pile shielding is material placed between radiation sources in the target pile and the enclosure to be protected. Key issuance to enclosures is restricted until after the air monitors show that there is a sufficiently low level of radiation coming from the activated air components. A LSM allows for real time monitoring of radiation levels during work, and its use is specified in the relevant RWP when deemed appropriate for the work. Public access gates will be used to prevent unauthorized access by the public. The release of activated air is engineered to reduce potential exposure consequences. The following discussion in this section outlines the approach used to reduce the risk associated with closed loop air cooling hazards.

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 carbon-11 which has a 20-minute half-life, nitrogen-13 which has a 10-minute half-life, oxygen-15 which has a 2-minute half-life, tritium which has a 12.3-year half-life, and argon-41 (produced by thermal neutron capture on argon-40) which has a 1.8-hour half-life.

Estimates for air activation from the beamline target and decay areas were developed by members of the Neutrinos at the Main Injector (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 enclosures, (ii) how much air from the target pile and decay pipe is mixed with the air in the enclosures, and (iii) how rapidly the air flows through the enclosures (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 for this case, so as 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 airtight to the extent possible by covering them with aluminum sheeting, as well as 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 airtight as possible.

The hazard due to closed loop air cooling, was evaluated, for the potential hazards associated with workers, co-located workers and the public potentially being exposed to radioactive water beyond regulatory limits. The baseline, qualitative risks due to this hazard were assessed, and determined to be risk level I (major concern) for workers and co-located workers and risk level III (minor concern) for the public. Through the use of a number of preventive and mitigative hazard controls, the likelihood and consequence of this hazard is reduced, resulting in a risk level of IV to workers and co-located workers, meaning residual risks are of minimal concern. For the public, the baseline qualitative risk due to this hazard are managed through a series of preventive controls (locked facilities, interlocked systems preventing entry), so that the likelihood of experiencing this hazard remains Beyond Extremely Unlikely, with a reduction of overall residual risk of IV, meaning the risk is a minimal concern, not subject to additional evaluation.

III-6.2.1.8 Soil Interactions

Several preventions and mitigations are used to reduce the risk associated with the soil interaction hazards, which include the following. The use of beamline designs that include measures to reduce unwanted beam particle losses, along with the use of beam dump (absorber) designs that minimizes radiological leakage through the use of shielding. The Run Condition gives operating parameters that reduce activation by limiting the total amount of beam that could be delivered. Specifically, this includes an operating limit for protons/hr. General and/or job specific RWPs are written by ES&H personnel, and they specify the work that is permitted to be performed, requirements to perform the work, and limitations of radiological exposure. A RWP may specify that personal protective equipment (PPE) be used during certain kinds of work or work conditions. The PPE limits the likelihood of bodily exposure to activated material and contamination. Public access gates will be used to prevent unauthorized access by the public. The primary concern is with the soil that surrounds the BNB target and decay pipe areas. These soil areas are further discussed in Section III-6.2.1.3, *Groundwater Activation*, of this Chapter.

The hazard due to soil interactions was evaluated, for the potential hazards associated with workers, co-located workers and the public potentially being exposed to radioactive soil beyond regulatory limits. The baseline, qualitative risks due to this hazard were assessed, and determined to be risk level IV (minimal concern). Through the use of a number of preventive and mitigative hazard controls, the likelihood and consequence of this hazard is further reduced, resulting in a reduced likelihood of encountering the hazard, and a a risk level of IV to workers, co-located workers, and the public, meaning residual risks are of minimal concern.

III-6.2.1.9 Radioactive Waste

Several preventions and mitigations are used to reduce the risk associated with the radioactive waste hazards, which include the following. Radiological shielding is material placed between radiation sources and people, which prevents the close proximity of these sources and people. Work may be restricted or prevented until sufficient time has passed such that radiation levels are sufficiently low to allow for safer work to proceed. General and/or job specific RWPs are written by ES&H personnel, and they specify the work that is permitted to be performed, requirements to perform the work, and limitations of radiological exposure. A LSM allows for real time monitoring of radiation levels during work, and its use is specified in the relevant RWP when deemed appropriate for the work. Fermilab has a material survey and release process. Any item exposed to beam-on conditions is surveyed by radiological workers and classified appropriately when removed from an enclosure. Items identified for disposal are surveyed and processed by Radiological Control organization personnel in accordance with FRCM Chapter 4. Public access gates will be used to prevent unauthorized access by the public. The following discussion in this section outlines the approach used to reduce the risk associated with radioactive waste hazards.

Radioactive waste is a standard radiological hazard that is managed within the established Radiological Protection Program (RPP) and as prescribed in FRCM. Waste minimization is an objective of the equipment design and operational procedures. Although production of radioactive material is not an operational function of BNB, beam loss and intentional beam interception, e.g. some beam diagnostic devices, will result in activation of beamline materials. 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. For example, radioactive water from the target and horn cooling systems, as well as any water from the decay region dewatering wells having concentrations in excess of the DCS of DOE Order 458.1, is disposed of as radioactive waste in accordance with the FRCM requirements.

The hazard due to radioactive waste was evaluated, for the potential hazards associated with workers, co-located workers and the public potentially being exposed to radioactive water beyond regulatory limits. The baseline, qualitative risks due to this hazard were assessed, and determined to be risk level III (minor concern) for workers, co-located workers and the public. Through the use of a number of preventive and mitigative hazard controls, the likelihood and consequence of this hazard is reduced for all receptors, resulting in a risk level of IV to workers and co-located workers, meaning residual risks are of minimal concern.

III-6.2.1.10 Contamination

Several preventions and mitigations are used to reduce the risk associated with the contamination hazards, which include the following. Shielding for activated contamination is material placed between radiation sources and the personnel to be protected. More generally, radiological shielding is material placed between radiation sources and people, which prevents the close proximity of these sources and members of the public. General and/or job specific RWPs are written by ES&H personnel, and they specify the work that is permitted to be performed, requirements to perform the work, and limitations of radiological exposure. A LSM allows for real time monitoring of radiation levels during work, and its use is specified in the relevant RWP when deemed appropriate for the work. A RWP may specify that PPE be used during certain kinds of work or work conditions. The PPE limits the likelihood of bodily exposure to activated material and contamination. RCTs and RSOs survey for and clean radiological contamination as part of the RWP process. Fermilab has a material survey and release process. Any item exposed to beam-on conditions is surveyed by radiological workers and classified appropriately when removed from an enclosure. Items identified for disposal are surveyed and processed by Radiological Control organization personnel in accordance with FRCM Chapter 4. Public access gates will be used to prevent unauthorized access by the public. Activated contamination leads to radioactive waste, where radioactive waste is discussed in Section III-6.2.1.9, *Radioactive Waste*, of this Chapter.

III-6.2.1.11 Beryllium-7

The baseline qualitative risks due to this hazard were assessed, and determined to be risk level I (major concern) for workers, co-located workers, and the public, but through the use of preventive and mitigative hazard controls, the likelihood and consequence of this hazard is reduced, resulting in a risk level of IV for workers, co-located workers, and the public meaning that the residual risks of this hazard are of minimal concern, and no further evaluation is necessary.

No prevention or mitigation is required for this type of hazard, as beryllium-7 is not hazardous in this pattern of facility use.

III-6.2.1.12 Radioactive Sources

Several preventions and mitigations are used to reduce the risk associated with the contamination hazards, which include the following. Unused radioactive sources are kept in storage, which prevents the close proximity of these sources and people. Furthermore, radioactive sources are kept in locked storage, where key issuance is a controlled process. Unused high activity sources are stored within shielded containers. Radiological training is an educational system managed by ES&H personnel that establishes basic worker knowledge through presentations and testing. Radiological signage on or near source cabinets give warning of the presence of radioactive sources. Public access gates will be used to prevent unauthorized access by the public.

Lastly, the baseline qualitative risks due to this hazard were assessed, and determined to be risk level I (major concern) for workers, co-located workers, and the public, but through the use of preventive and mitigative hazard controls, the likelihood and consequence of this hazard is reduced, resulting in a risk level of IV for workers, co-located workers and the public, meaning that the residual risks of this hazard are of minimal concern, and no further evaluation is necessary.

III-6.2.1.13 Nuclear Material

N/A.

III-6.2.1.14 Radiation Generating Devices (RGDs)

N/A.

III-6.2.1.15 Non-Ionizing Radiation Hazards

N/A.

III-6.2.2 Toxic Materials

BNB has toxic material hazards in the form of lead and beryllium. These hazards are part of SIHs discussed in SAD Section I Chapter 04, *Safety Analysis*.

III-6.2.2.1 Lead

This hazard has been evaluated within the common Risk Matrix table included in SAD Section I Chapter 04, *Safety Analysis*. Work in BNB involving this hazard implements the controls specified in the common Risk Matrix table. No unique controls are in use.

III-6.2.2.2 Beryllium

This hazard has been evaluated within the common Risk Matrix table included in SAD Section I Chapter 04, *Safety Analysis*. Work in BNB involving this hazard implements the controls specified in the common Risk Matrix table. No unique controls are in use.

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.

III-6.2.2.3 Fluorinert & Its Byproducts

N/A.

III-6.2.2.4 Liquid Scintillator

N/A.

III-6.2.2.5 Pseudocumene

N/A.

III-6.2.2.6 Ammonia

N/A.

III-6.2.2.7 Nanoparticle Exposures

N/A.

III-6.2.3 Flammables and Combustibles

BNB has flammable and combustible hazards in the form of combustible materials. These hazards are part of SIHs discussed in SAD Section I Chapter 04, *Safety Analysis*.

III-6.2.3.1 Combustible Materials

This hazard has been evaluated within the common Risk Matrix table included in SAD Section I Chapter 04, *Safety Analysis*. Work in BNB involving this hazard implements the controls specified in the common Risk Matrix table. No unique controls are in use.

III-6.2.3.2 Flammable Materials

N/A.

III-6.2.4 Electrical Energy

BNB has electrical energy hazards in the form of stored energy exposure, high voltage exposure, and low voltage, high current exposure. These hazards are part of SIHs discussed in SAD Section I Chapter 04, *Safety Analysis*.

III-6.2.4.1 Stored Energy Exposure

This hazard has been evaluated within the common Risk Matrix table included in SAD Section I Chapter 04, *Safety Analysis*. Work in BNB involving this hazard implements the controls specified in the common Risk Matrix table. No unique controls are in use.

III-6.2.4.2 High Voltage Exposure

This hazard has been evaluated within the common Risk Matrix table included in SAD Section I Chapter 04, *Safety Analysis*. Work in BNB involving this hazard implements the controls specified in the common Risk Matrix table. No unique controls are in use.

III-6.2.4.3 Low Voltage, High Current Exposure

This hazard has been evaluated within the common Risk Matrix table included in SAD Section I Chapter 04, *Safety Analysis*. Work in BNB involving this hazard implements the controls specified in the common Risk Matrix table. No unique controls are in use.

III-6.2.5 Thermal Energy

BNB has thermal energy hazards in the form of hot work. These hazards are part of SIHs discussed in SAD Section I Chapter 04, Safety Analysis.

III-6.2.5.1 Bakeout

N/A.

III-6.2.5.2 Hot Work

This hazard has been evaluated within the common Risk Matrix table included in SAD Section I Chapter 04, *Safety Analysis*. Work in BNB involving this hazard implements the controls specified in the common Risk Matrix table. No unique controls are in use.

III-6.2.5.3 Cryogenics

N/A.

III-6.2.6 Kinetic Energy

BNB has kinetic energy hazards in the form of power tools, pumps and motors, and motion tables. These hazards are part of SIHs discussed in SAD Section I Chapter 04, Safety Analysis.

III-6.2.6.1 Power Tools

This hazard has been evaluated within the common Risk Matrix table included in SAD Section I Chapter 04, *Safety Analysis*. Work in BNB involving this hazard implements the controls specified in the common Risk Matrix table. No unique controls are in use.

III-6.2.6.2 Pumps and Motors

This hazard has been evaluated within the common Risk Matrix table included in SAD Section I Chapter 04, *Safety Analysis*. Work in BNB involving this hazard implements the controls specified in the common Risk Matrix table. No unique controls are in use.

III-6.2.6.3 Motion Tables

This hazard has been evaluated within the common Risk Matrix table included in SAD Section I Chapter 04, *Safety Analysis*. Work in BNB involving this hazard implements the controls specified in the common Risk Matrix table. No unique controls are in use.

III-6.2.6.4 Mobile Shielding

N/A.

III-6.2.7 Potential Energy

BNB has potential energy hazards in the form of crane operations, compressed gasses, vacuum/pressure vessels/piping, vacuum pumps, and material handling. These hazards are part of SIHs discussed in SAD Section I Chapter 04, Safety Analysis.

III-6.2.7.1 Crane Operations

This hazard has been evaluated within the common Risk Matrix table included in SAD Section I Chapter 04, *Safety Analysis*. Work in BNB involving this hazard implements the controls specified in the common Risk Matrix table. No unique controls are in use.

III-6.2.7.2 Compressed Gasses

This hazard has been evaluated within the common Risk Matrix table included in SAD Section I Chapter 04, *Safety Analysis*. Work in BNB involving this hazard implements the controls specified in the common Risk Matrix table. No unique controls are in use.

III-6.2.7.3 Vacuum/Pressure Vessels/Piping

This hazard has been evaluated within the common Risk Matrix table included in SAD Section I Chapter 04, *Safety Analysis*. Work in BNB involving this hazard implements the controls specified in the common Risk Matrix table. No unique controls are in use.

III-6.2.7.4 Vacuum Pumps

This hazard has been evaluated within the common Risk Matrix table included in SAD Section I Chapter 04, *Safety Analysis*. Work in BNB involving this hazard implements the controls specified in the common Risk Matrix table. No unique controls are in use.

III-6.2.7.5 Material Handling

This hazard has been evaluated within the common Risk Matrix table included in SAD Section I Chapter 04, *Safety Analysis*. Work in BNB involving this hazard implements the controls specified in the common Risk Matrix table. No unique controls are in use.

III-6.2.8 Magnetic Fields

BNB has magnetic field hazards in the form of fringe fields. These hazards are part of SIHs discussed in SAD Section I Chapter 04, *Safety Analysis*.

III-6.2.8.1 Fringe Fields

This hazard has been evaluated within the common Risk Matrix table included in SAD Section I Chapter 04, *Safety Analysis*. Work in BNB involving this hazard implements the controls specified in the common Risk Matrix table. No unique controls are in use.

III-6.2.9 Other Hazards

BNB has other hazards in the form of confined spaces, noise, silica, ergonomics, and working at heights. These hazards are part of SIHs discussed in SAD Section I Chapter 04, *Safety Analysis*.

III-6.2.9.1 Confined Spaces

BNB has two confined spaces: the sump pit in the MI-12B enclosure and the MI-13 enclosure. This hazard has been evaluated within the common Risk Matrix table included in SAD Section I Chapter 04, *Safety Analysis*. Work in BNB involving this hazard implements the controls specified in the common Risk Matrix table. No unique controls are in use.

III-6.2.9.2 Noise

This hazard has been evaluated within the common Risk Matrix table included in SAD Section I Chapter 04, *Safety Analysis*. Work in BNB involving this hazard implements the controls specified in the common Risk Matrix table. No unique controls are in use.

III-6.2.9.3 Silica

This hazard has been evaluated within the common Risk Matrix table included in SAD Section I Chapter 04, *Safety Analysis*. Work in BNB involving this hazard implements the controls specified in the common Risk Matrix table. No unique controls are in use.

III-6.2.9.4 Ergonomics

This hazard has been evaluated within the common Risk Matrix table included in SAD Section I Chapter 04, *Safety Analysis*. Work in BNB involving this hazard implements the controls specified in the common Risk Matrix table. No unique controls are in use.

III-6.2.9.5 Asbestos

N/A.

III-6.2.9.6 Working at Heights

This hazard has been evaluated within the common Risk Matrix table included in SAD Section I Chapter 04, *Safety Analysis*. Work in BNB involving this hazard implements the controls specified in the common Risk Matrix table. No unique controls are in use.

III-6.2.10 Access & Egress

BNB has kinetic energy hazards in the form of life safety egress. These hazards are part of SIHs discussed in SAD Section I Chapter 04, *Safety Analysis*.

III-6.2.10.1 Life Safety Egress

This hazard has been evaluated within the common Risk Matrix table included in SAD Section I Chapter 04, *Safety Analysis*. Work in BNB involving this hazard implements the controls specified in the common Risk Matrix table. No unique controls are in use.

III-6.2.11 Environmental

BNB has environmental hazards related to air, water, and soil. These hazards are part of SIHs discussed in SAD Section I Chapter 04, *Safety Analysis*.

III-6.2.11.1 Hazard to Air

This hazard has been evaluated within the common Risk Matrix table included in SAD Section I Chapter 04, *Safety Analysis*. Work in BNB involving this hazard implements the controls specified in the common Risk Matrix table. No unique controls are in use.

III-6.2.11.2 Hazard to Water

This hazard has been evaluated within the common Risk Matrix table included in SAD Section I Chapter 04, *Safety Analysis*. Work in BNB involving this hazard implements the controls specified in the common Risk Matrix table. No unique controls are in use.

III-6.2.11.3 Hazard to Soil

This hazard has been evaluated within the common Risk Matrix table included in SAD Section I Chapter 04, *Safety Analysis*. Work in BNB involving this hazard implements the controls specified in the common Risk Matrix table. No unique controls are in use.

III-6.3. Summary of Hazards to Members of the Public

The BNB segment can be operated in a manner that will produce minimal hazards to members of the public. Fermilab has developed programs to prevent and mitigate hazards and uses systems engineered to reduce risk through passive and active means.

III-6.4. Summary of Credited Controls

The following sections give a summary of the credited controls for the BNB segment.

III-6.4.1 Passive Credited Controls

Passive controls are elements that are part of the physical design of the facility that require no action to function properly. These are fixed elements of the beamline that take direct human intervention to remove. The BNB enclosures are designed and constructed as a permanent concrete and earth-covered radiation shield to protect personnel from radiological exposure during beam operations.

III-6.4.1.1 Shielding

Most shielding is permanent, but the target station and 25-meter absorber components are protected by movable shielding.

III-6.4.1.1.1 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 MI 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.

Permanent Longitudinal Shielding

Cell or Longitudinal Range (ft)	Description	Current Shielding (efd)	Required (efd)
0-100	MI 8 GeV Extraction	23.2	23
100-217	Buried 24" Carrier Pipe	25.5	25
217-233	Buried 24" Carrier Pipe	24.5	25
233-268	Tunnel beyond MI10	19.4	14.2
268-278	Tunnel Under Berm Toe	19.4	14.2
278-400	Tunnel Under Berm	24	23
400-417	Tunnel Under Berm Toe	19.3	12.1
417-441	Indian Creek Rd around MI	19.3	12.1
441-447	Manhole PMH-PVI-2	16.4	12.1
447-475	Tunnel Under Berm Toe	20.2	12.1
475-490	Tunnel Under Berm	24.4	23
490-526	Box Culvert under Fe	24.5	23
526-544	Tunnel Under Berm	25.2	23
544-595	Tunnel Under Berm	24	15.2
595-645	Tunnel US of MI-12	26.1	25
645-656	MI-12	22.8	14.2
656-674	MI-12	19.5	14.2
674-702	Horn Shielding	39.3	20.8
702-710	MI-12	22.9	22.8
710-774	US Decay Pipe	26	22.8
764-774	Mid Range Abs. In Beam	25.8	22.8
764-774	Mid Range Abs. Out	37	22.8
774-846	DS Decay Pipe	26	22.8
846-856	Permanent Absorber	28.9	22.8

Permanent Transverse Shielding

Cell or Transverse Station (ft)	Description	Current Shielding (efd)	Required (efd)
101	MI Extraction Stub	24.6	23.0
188	MI10 Crossover	25.7	25.0
231	Stairway Alcove	26	14.2
250	Stairway Below Ground	20	14.2
301	Stairway Exit	24	23.0
351	Tunnel	23.1	23.0
427	Indian Creek Road	19	12.1
504	Box Culvert	23.2	23.0
545	Tunnel Downstream of Culvert	25.7	23.0
575	Tunnel	24	15.2
636	MI12 Upstream	22	14.2
660	MI12 Pretarget Vault	18.8	14.2
685	MI12 Horn Vault	30	20.8
701	MI12 Downstream End	26.94	22.8
765	Midrange Absorber In	31.8	22.8
765	Midrange Absorber Out	26	22.8
829	Decay Pipe	25.6	22.8
847	Permanent Absorber	38.2	22.8
882	LMC Manhole	53.4	22.8

III-6.4.1.1.2 Movable 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 a RSO.

Movable Shielding

Location	Shielding Type	Quantity	Purpose	Preferred Method of Configuration (if specified)	Comments
MI-12 SB	Concrete, Heavy Concrete, Steel, sandbags, and poly beads	Many Blocks	shield above vault and target area	PAD 118 & Enclosure Key	see as-built drawings 9-6-7-55
25 m Absorber	Sand, concrete, heavy concrete	Many Blocks	shield plug for 25 m Absorber hatch	PAD 118 & Enclosure Key	see as-built drawings 9-6-7-55

III-6.4.1.1.3 Penetration Shielding

The beamline has several utility penetrations routing between the exclusion 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 FRCM.

Penetration Shielding

Location	Shielding Type	Quantity	Purpose	Preferred Method of Configuration (if specified)	Comments
MI-12 SB	Poly Beads	Many bags	shield above east stripline penetration	sign	Plexiglas and Unistrut box, 28"x28"x36"
MI-12 SB	Poly Beads	Many bags	shield above west stripline penetration	sign	Plexiglas and Unistrut box, 28"x28"x36"
MI-12 SB	Concrete	Several blocks	shield above 90-degree monitor penetration	label	"E" block on top of several cinder blocks and steel bricks
MI-12 SB	Other	12	air barriers for 4" diameter penetrations	labels	set of 8 along east wall; set of 4 next to east strip line; each sealed on both ends with fire-stop foam

III-6.4.1.2 Fencing

Fencing is not required. In lieu of required fencing, temporary controls, such as guards, ropes, and/or postings, may be utilized as approved by the Senior Radiation Safety Officer (SRSO). Each use of a Compensatory Measure shall be documented using the USI Process.

Controlled Area Ropes

Rope Location	Required Posting	Gates (if applicable)	Configuration
All large entrances to berm cover posted with ropes and signs	Controlled Area	N/A	Ropes with signs
Personnel entrances posted next to entry	Controlled Area	N/A	Signs on building

III-6.4.1.2.1 Radiation Area Fencing

Radiation area fencing is not required.

III-6.4.1.2.2 Controlled Area Fencing

Controlled area fencing is not required.

III-6.4.2 Active Engineered Credited 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 BNB operations are discussed below.

III-6.4.2.1 Radiation Safety Interlock System

BNB enclosures are part of the MiniBooNE Radiation Safety Interlock System. There are interlocked exit labyrinths at both ends of the 8GeV Fixed Target beamline enclosures with an internal section gate that is used to divide the beamline 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 BNB extraction point in the 8 GeV Line except when the MI-12A, MI-12B, and MI-13 enclosures are properly secured and locked, 1000 CFM intake and exhaust fans are off, Target Air Flow Intake Switch is on, and area radiation monitors are made up.

The radiation safety interlock system inhibits beam by controlling redundant critical devices. The critical devices for the BNB segment are the E: HV860 power supply that feeds the extraction magnet and E:BS860 air operated beam stop in the MI enclosure. The system has a failure mode function in the event of a critical device failure, which will inhibit beam to the Booster segment and eliminate the possibility of beam reaching the BNB enclosures.

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

Radiation Safety System – Interlocked Radiation Monitors

Required radiation monitors specified in the listed Shielding Assessments, or as required by the assigned Radiation Safety Officer (RSO), must be interlocked to the RSIS.

Type	Location
Chipmunk	MI-12 Serv. Bldg Upstairs Stripline Pen
Chipmunk	MI-12B Shield Blocks
Chipmunk	MI-12 Service Building Downstream
Chipmunk	MiniBooNE Berm US of MI-12
Chipmunk	MiniBooNE Berm Indian Creek Culvert
Chipmunk	MiniBooNE Indian Creed Road
Chipmunk	MI-12A Upstream Berm

III-6.4.2.2 ODH Safety System

N/A.

III-6.4.3 Administrative Credited Controls

All BNB 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, directorate, 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.

III-6.4.3.1 Operation Authorization Document

Commissioning, normal operations, and emergency management of the BNB segment are all conducted under the auspices of the AD Headquarters, ES&H, AD External Beam Delivery Department, and the AD Accelerator Ops Department in accordance with the Fermilab SAD.

Beam will not be transported to the BNB segment without an approved Beam Permit and Run Condition. The Beam Permit specifies beam power limits as determined and approved by the AD Associate Lab Director (ALD) in consultation with the ES&H Head, RSO, AD Accelerator Ops Department Head, and External Beam Delivery Department Head. The run conditions list the operating modes and safety envelope for BNB. The Run Condition is issued by ES&H, and it is signed by the External Beam Delivery Department Head, AD Accelerator Ops Department Head, assigned RSO, and AD Head.

In order to run beam to BNB, 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 (MI and 8 GeV Line) must be ready for beam.

III-6.4.3.2 Staffing

At least one member of the AD Accelerator Ops Department who has achieved the rank of Operator II or higher shall be on shift. At least one member of the AD Accelerator Ops Department shall be present in the Main Control Room (MCR).

III-6.4.3.3 Accelerator Operating Parameters

The Booster Neutrino Beam area is assessed for a pulsed proton beam with a maximum kinetic energy of 8 GeV, intensity of 6.0e12 protons/pulse, and spill rate of 7.5 Hz. This equates to an hourly intensity rate of 1.62e17 protons/hr.

Accelerator operational approvals shall be obtained by following the AD Procedure ADAP-11-0001 Beam Permits, Run Conditions, and Startup administered by ES&H and the AD ALD. Beam Permit and Run Condition documents shall identify the beam power and operating parameters allowed for BNB within the current ASE. The Beam Permit specifies beam power limits as determined and approved by the AD ALD in consultation with the ES&H Head, RSO, AD Accelerator Ops Department Head, and External Beam Delivery Department Head. The Run Condition for BNB describes the operating configuration as reviewed by the AD Accelerator Ops Department Head and RSO, and is approved by the AD ALD.

The BNB segment will be operated within the following parameters:

Mode	Intensity	Energy
Beam from Cell 850 to BNB Target Station (Beam on Target)	9.00e18 protons/hr	8 GeV

III-6.5. Defense-in-Depth Controls

Additional shielding may be in place beyond the requirements stated in the Shielding Assessment.

III-6.6. Machine Protection Controls

BNB has a machine protection system. Major elements are beam losses, magnet currents, and beam positions.

III-6.7. Decommissioning

DOE Field Element Manager approval shall be obtained prior to the start of any decommissioning activities for the BNB segment.

III-6.8. Summary and Conclusion

Specific hazards associated with commissioning and operation of the BNB enclosures are identified and assessed in this chapter of the Fermilab Safety Assessment. The designs, controls, and procedures to mitigate BNB area specific hazards are identified and described. In addition to these specific safety considerations, the BNB segment is subject to the global and more generic safety requirements, controls and procedures outlined in Section 1 of this Fermilab SAD.

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

III-6.9. References

[1] 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.

[2] 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.

[3] Fermilab Radiological Control Manual (FRCM), The current web link is: https://publicdocs.fnal.gov/cgi-bin/ListBy?topicid=91

[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.

III-6.10. Appendix – Risk Matrices

Risk Assessment methodology was developed based on the methodology described in DOE-HDBK-1163-2020. Hazards and their potential events are evaluated for likelihood and potential consequence assuming no controls in place, which results in a baseline risk. A baseline risk (i.e., an unmitigated risk) value of III and IV does not require further controls based on the Handbook. Events with a baseline risk value of I or II do require prevention and/or mitigation measures to be established in order to reduce the risk value to an acceptable level of III or IV. Generally, preventive controls are applied prior to a loss event, reflecting a likelihood reduction, and mitigative controls are applied after a loss event, reflecting a consequence reduction. For each control put in place, likelihood or consequence can have a single "bin drop", resulting in a new residual risk (i.e., a mitigated risk). This risk assessment process is repeated for each hazard for Facility Workers (FW), Co-Located Workers (CLW), and Maximally-exposed Offsite Individual (MOI). At the conclusion of the risk assessments, controls that are in place for the identified accelerator specific hazards are identified as Credited Controls and further summarized in Section III-6.4 of this Chapter as well as SAD Chapter VII-A.1 *Accelerator Safety Envelope – Fermilab Main Accelerator*.