BOOSTER NEUTRINO BEAM

Maximum Credible Incident Analysis

Revision 0

Revision History

Author	Rev. No.	Date	Description of Change
Jason D. Crnkovic	0	February 28, 2024	Initial release of the Booster Neutrino Beam (BNB) maximum credible incident (MCI) analysis.

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Maximum Credible Incident Scenario for Accelerator Specific Hazards

Consideration and analysis of the MCI is focused on an onsite facility worker, onsite co-located worker, and maximally-exposed offsite individual (MOI) that is outside of the BNB areas. References [1-8] provide background material on the BNB segment and Ref. [9] provides a link to the *Fermilab Radiological Control Manual* (FRCM). The Radiation Safety Interlock System (RSIS) is used to keep individuals out of the BNB enclosures during beam operations. A change to the MCI for upstream segments will be evaluated for its effect on the BNB segment through the USI process.

Three simultaneous operating conditions are required for producing the MCI scenario: maximum beam power operations in the Booster segment, directing all the Booster output into the BNB segment via the 8-GeV Line segment, and the beam is mis-steered away from the design trajectory to cause very large losses. The Booster could in principle produce up to 7E+12 protons-per-pulse at a 15 Hz pulse rate (6.6667E-2 s accelerator cycle time) during maximum beam power output. This scenario corresponds to 3.78E+17 protons-per-hour with each proton having around 8 GeV of energy. A secondary yield of 1 and secondary beam energy of 8 GeV are also assumed, where secondary particles (e.g. pions or kaons) are produced through proton-beam-material interactions. The dose rate would be 1.27E+10 mrem-per-hour at a distance of 1 foot from a point loss for 3.78E+17 protons-per-hour striking the point loss and no shielding being present during the MCI scenario.

The MBex switch-magnet is used to direct beam pulses in the 8-GeV Line to the BNB segment, where it has no inherent repetition rate limit. The MBex magnet could direct all the beam pulses in the 8-GeV Line to the BNB segment if the magnet pulse timing was set incorrectly. Specifically, this would occur if Mbex pulses on a generic Booster reset event for an accelerating beam cycle instead of a Booster reset event for a MiniBooNE beam cycle.

The beam can be accidentally mis-steered leading to all of it being lost in the segment, which will generate hazardous radiation fields. One hour of total continuous beam loss during maximum beam power operations is considered for this scenario, which leads to 3.78E+17 protons of prompt radiation within the BNB segment. One hour is taken as the maximum credible time interval for total continuous beam loss due to the staffing requirements for monitoring and operating the Main Accelerator Complex.

This MCI analysis does not consider the beam bunch structure, and it treats the beam pulse structure as the smallest beam features. A proton pulse in the BNB segment is typically comprised of a train of 81 proton bunches, but this level of detail is not needed when calculating dose rates and doses. Prompt radiation causes hazardous radiation fields directly and indirectly through material effects. Three categories of beam-material interactions are considered for the BNB shielding requirements: beam hitting I) a magnet in an enclosure, II) a beam carrier pipe in an enclosure, or III) a beam carrier pipe buried in the ground. The BNB enclosures are designed and constructed with concrete, steel, and earth-covered radiation shielding to protect people from radiological exposure. The thickness of non-dirt shielding materials, e.g. concrete and steel, is typically converted into an effective feet of dirt thickness for comparison and standardization purposes. Most shielding is permanent, but the target station and 25-meter absorber components are protected by movable shielding, and some of the penetrations are also protected by shielding.

The three beam loss cases discussed in this document are based on the generic shielding methodology. Case I is when the beam causes point losses on a pole face of a dipole magnet that is inside of an enclosure. Case II is when the beam causes point losses on an aluminum beam pipe that is inside of an enclosure. Case III is when the beam causes point losses on a steel pipe that is buried in dirt. The enclosures are surrounded by dirt shielding, and in all cases the dirt shielding is surrounded by air. The effective dose-per-proton is determined for the outside air layer. The enclosures and shielding use a cylindrical geometry in all cases, where the enclosures have a 3 ft inner radius and 1 ft thick concrete walls.

The BNB segment is located in a non-public area of the campus, and this incident would result in a dose higher than 500 mrem to an individual when assuming that there is no shielding. The result is that the uncontrolled baseline qualitative risk level associated with this accident is I.

Fermilab uses Credited Controls that flow down to the Accelerator Safety Envelope (ASE) to mitigate the consequences of an MCI to the following conditions:

- Less than 5 rem in one hour in any area accessible by facility workers or co-located workers.
- Less than 500 mrem in one hour in all Laboratory areas to which the public is assumed to be excluded.
- Less than 100 mrem in one hour at Fermilab's site boundary and/or in any areas onsite in which the public is authorized (which includes Batavia Road, Prairie Path, parking lots open to the public, and general access areas including Wilson Hall, Ramsey Auditorium).

The accumulated dose outside of the shielding on the BNB berm is mitigated, by use of Credited Controls, to less than 500 mrem in an MCI. The closest possible location of a member of the public to the BNB enclosure is the west Linac parking lot. This location is approximately nineteen hundred feet away from the location of the Credited Control radiation monitors, which would result in dose of approximately: 500 mrem * 1/1900 = 0.26 mrem applying a conservative dose reduction of 1/r.

Summary of Credited Controls

Engineered systems and programs/procedures are used to prevent and mitigate hazards through passive and active means. Credited controls flow down to the ASE, which limit MCI radiation doses to less than 5 rem for workers, less than 500 mrem for MOIs in non-public areas of the campus, and less than 100 mrem for areas of the campus where the public is invited. The BNB segment is in an area where members of the public are not invited. Limiting doses to below 5 rem in the MI-12 Service Building and 500 mrem at other locations outside of the BNB areas leads to a negligible consequence level for prompt radiation exposure to workers and members of the public as identified in DOE Handbook 1163, Consequence Matrix Figure C-1 for a radiological hazard.

Engineering Credited Controls

Engineering controls are physical devices, elements, features, systems, etc. that isolate people from hazards. Engineering credited controls can be active or passive, and they are used in the BNB segment to prevent or mitigate prompt radiation risks associated with the MCI scenario.

Passive Engineering Credited Controls

Passive engineering controls are elements that make up parts of the Main Accelerator Complex facility which require no human action to protect people. There are fixed beamline elements that provide radiation shielding in the BNB segment that take direct human intervention to remove.

Cases I, II, and III require 17.9, 15.4, and 20.3 effective feet of dirt (e.f.d.), respectively, to limit the radiation dose rate to between 100 and 500 mrem-per-hour for a person outside of the beamline areas. Dose rates outside of labyrinths and penetrations are given special consideration (Table 1). The beam propagates near the design trajectory during normal operations, and it must interact with a magnet or carrier pipe before producing prompt radiation fields that emanate from the beamline. There are "special cases", e.g., absorbers, collimators, and targets, but these special cases are effectively case I, as the beam is interacting with a "thick" and "dense" piece of material in an enclosure. Hence, the special cases are treated the same as case I. When there is 17.9 and 20.3 e.f.d. of shielding that surrounds a BNB enclosure and buried beam carrier pipe, respectively, then a person outside of the area and right next to the shielding will receive at most a dose of 500 mrem during one hour of maximum beam power operations. The BNB carrier pipe and BNB decay pipe are both treated as a buried beam carrier pipe for this analysis.

Determination of radiation dose rates due to prompt radiation for the BNB segment are derived using incremental shielding assessment (ISA) spreadsheets along with Refs [1,3,15]. A base case of 120 GeV protons, 1.64E+14 protons-per-pulse, and a 1.33 second accelerator cycle time is assumed for the scaling spreadsheet when determining the longitudinal and transverse shielding requirements. A spreadsheet allows for scaling of both energy and intensity to the MCI. Hence, dose rates for the MCI are obtained from spreadsheets by using them with the beam conditions discussed in the section describing the MCI scenario.

An ISA scaling spreadsheet is based on generic shielding models, where these models have been developed over decades to provide conservative estimates for shielding requirements. Current models have their origins in the use of general rules-of-thumb (ROTs) for concrete and iron, where the use of ROTs eventually transitioned to the use of Monte Carlo simulations based on CASIM [10,11]. The current state of the art now uses models derived from Monte Carlo simulations based on MARS [11,12].

A beam that has been directed into either a magnet pole face or pipe creates an interaction region which generates a radiation field. As the field propagates through an enclosure gap, the dose rate decreases as a function of distance from the interaction region due primarily to a reduction in radiation flux via a geometric dilution. Table 5 gives air gap thicknesses at various locations along the BNB line. As the field propagates through the shielding that surrounds either an enclosure or a pipe, the dose rate decreases as a function of distance from the interaction region due to a reduction in radiation flux via both geometric dilution and material interactions.

Dose rates outside of penetrations and labyrinths are based on the generic dose rate methodology [15]. Generic penetration and labyrinth dose rate models have been developed over decades [13,14]. The models are based on analytic approximations and data-based studies done decades ago.

Permanent Shielding Including Labyrinths

The permanent shielding encompasses the structural elements surrounding the beamline components. A buried beam transport pipe separates the BNB concrete structure from the 8-GeV Line enclosure. 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. Radiation dose rates outside of labyrinths were estimated for the MCI scenario (Table 1), where the corresponding MCI doses were found to be less than 500 mrem.

The shielding has sufficient overburden such that a 500 mrem or greater dose due to prompt radiation cannot occur during the MCI scenario except at one location in the BNB segment. The location with insufficient shielding is the Manhole PMH-PVI-2 located at the 441-447 ft z-range. The BNB RSIS is used to limit the potential radiation doses at this location.

A shielding thickness of 17.9 e.f.d. is taken as the credited control for limiting prompt radiation-based exposure to an individual outside of BNB enclosures, except at the Manhole PMH-PVI-2, and any shielding thickness in excess of 17.9 e.f.d. is considered to be defense in depth. A shielding thickness of 16.4 e.f.d. is taken as the credited control for limiting prompt radiation-based exposure to an individual in the Manhole PMH-PVI-2, where any shielding thickness in excess of 16.4 e.f.d. is considered to be defense in depth. There is 16.9 e.f.d. of shielding at the Manhole PMH-PVI-2.

A shielding thickness of 20.3 e.f.d. is taken as the credited control for mitigating prompt radiation-based exposure to an individual outside of BNB areas that have a buried beam carrier pipe, where any shielding thickness in excess of 20.3 e.f.d. is considered to be defense in depth. The BNB carrier pipe and BNB decay pipe are both treated as a buried beam carrier pipe for this analysis. Tables 4 and 5 summarize the total, credited control, and defense in depth shielding at various locations along the BNB segment for the permanent shielding.

Table 1. Labyrinth and penetration dose rates during the MCI scenario [15]. The Stripline Pens are in the MI-12 Service Building, which is accessible by facility workers or co-located workers. A dose of 895 mrem would occur during one hour of running in the MCI scenario within the MI-12 Service Building, which is less than 5 rem. The other labyrinths and penetrations provide sufficient shielding to produce a dose less than 500 mrem during one hour of running in the MCI scenario.

Station (ft)	Description	L&P Proposed Eff. Dose Rate (mrem/hour)
MI8	MI8 exist door	6.63E-1
MI8	MI8 stairs	6.63E-1
151-168	MI10 Stairs	2.17E-3
552	MI12 Stairs Top	2.80E-3
552	MI12 Stairs Outside	6.16E-1
133	MI10 Ducts	6.47E-7
153	Vent Shaft	6.35E-2
Outside MI-12 Service Building	Dehumidifier Inlet	2.17E+1
569	4 Pens	2.71E-5
569	Stripline Pens	8.95E+2
574	8 Pens	5.43E-5
688	90-degree Monitor	1.18E-2
698	8 x 5-inch Ducts N. Wall	3.07E-7
715 & 855	6 Monitor Wells	1.43E-1
829	Berm Air Supply	2.38E-1
829	Berm Air Return	1.58E-2
855	Muon Mon. 50m Absorber	4.45E-7
875	MI-13 LMC	2.75E-1

Movable Shielding

Movable shielding is required to be in place to provide protection against radiation fields during BNB operations, where this type of shielding is not composed of dirt, but is instead made of materials such as concrete, steel, and sandbags. The thickness of non-dirt shielding materials is typically converted into an effective feet of dirt thickness for comparison and standardization purposes.

Within the MI-12 Service Building is an access shaft to the below grade enclosure 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 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 hatch by the 25m absorber is locked in-place, and the configuration is controlled by an RSO. Table 4 gives the total, credited control, and defense in depth shielding at various locations along the BNB segment for the movable shielding, where the credited control shielding thicknesses are discussed in the previous section.

Penetration Shielding

The beamline has several utility penetrations routing between a BNB area and the inside of a service building or the outside next to a service building. Radiation dose rates outside of penetrations were estimated for the MCI scenario (Table 1), where the Stripline Pens at station 569 ft and 90-degree Monitor at station 688 ft are the only penetrations assumed to have shielding [15]. The Stripline Pens and 90-degree Monitor shielding is taken as credited control shielding, and so this shielding is required to be in place to provide protection against radiation fields during BNB operations. The Stripline Pens are in the MI-12 Service Building, which is accessible by facility workers or co-located workers. The dose rate at the Stripline Pens is found to be 895 mrem-per-hour during the MCI scenario. This would lead to 895 mrem during one hour of running in the MCI scenario within the MI-12 Service Building, which is less than 5 rem. The other penetrations provide sufficient shielding to produce a dose less than 500 mrem during one hour of running in the MCI scenario.

Table 2. Location of credited control penetration shielding.

Station (ft)	Description	Credited Control Shielding
569	Stripline Pens	3 feet of polyethylene beads (50% packing fraction)
688	90-degree Monitor	Several blocks of concrete (5.5 e.f.d.)

Active Engineering Credited Controls

Active engineering controls are elements that make up parts of the Main Accelerator Complex facility that require human action to protect people, which may include active interaction with, monitoring, or periodic maintenance/calibration of the engineering control.

Radiation Safety Interlock System

The BNB enclosures are part of the BNB RSIS. There are interlocked exit labyrinths at both ends of the 8 GeV 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, and 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 RSIS inhibits beam by controlling redundant critical devices. The critical devices for the BNB segment are the E:HV860 power supply that feeds extraction magnets and the E:BS860 air operated beam stop in the 8-GeV Line 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.

Passive shielding is adequate to limit potential MCI radiation doses to less than 500 mrem for an individual outside of the BNB areas except in the Manhole PMH-PVI-2 located at the 441-447 ft z-range. Dose rates outside of labyrinths and penetrations are given special consideration (Table 1). Tables 4 and 5 summarize the shielding at various locations along the BNB segment. The credited detector is connected to the BNB RSIS and is operated in integrate mode, where this interlock system will inhibit beam to the BNB segment if the detector measures a radiation signal above the trip limit. The detector is located outside of the manhole and on a berm next to the manhole, where a credited control limit of 2.5 mrem will limit the MCI dose to be less than 500 mrem in the manhole. This manhole has not been designed for occupancy during beam operations. Figure 1 shows the location of the credited detector, and Table 3 gives the credited control limit for the detector.

The following outlines the approach used to determine the credited control limit for the detector that monitors the Manhole PMH-PVI-2 [16]. The BNB segment is assumed to produce a loss of 3.78E+17 protons-per-hour, equivalent to 7E+12 protons-per-pulse, at 8 GeV with 15 pulses-per-second. The Manhole PMH-PVI-2 lies beneath Indian Creek Road near station 444, where the road crosses over the MI-12A tunnel (approximately above the beamline). The total effective shielding thickness of the soil, concrete, and steel at this location is 16.9 e.f.d. The credited detector (chipmunk) is downstream of the manhole in a doghouse on the toe of the MI-12A berm, where the Fermilab GIS indicates that the detector is positioned 10 feet downstream of the manhole, as determined from an aerial photo.

A shielding thickness of 0.5 e.f.d. is taken as defense in depth for the manhole, which means that 16.4 e.f.d is taken as the credit control shielding thickness for the manhole. The chipmunk positioned 10 feet downstream of the manhole sits on a berm that provides an extra 5.1 e.f.d. of shielding as compared to the manhole. A tenth-value layer (TVL) for soil is taken as 3.38 feet, which leads to a dose rate attenuation factor of 1.55E-2 (5.1 e.f.d. of soil and 0.5 factor for the chipmunk distance of 10 feet.) between the manhole and chipmunk. Therefore, a detector trip setting of 7.8 mrem will prevent a dose in the manhole from exceeding 500 mrem in one hour. A conservative 2.5 mrem credited control limit is chosen for this chipmunk to prevent a dose of 500 mrem in the manhole during one hour of maximum beam power operations.

Following any enclosure access by people, 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 search and secure process consists of a thorough exploration of an enclosure to ensure that it is not occupied. 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 enclosures, controlled access procedures, training requirements, and procedures for interlock system maintenance.

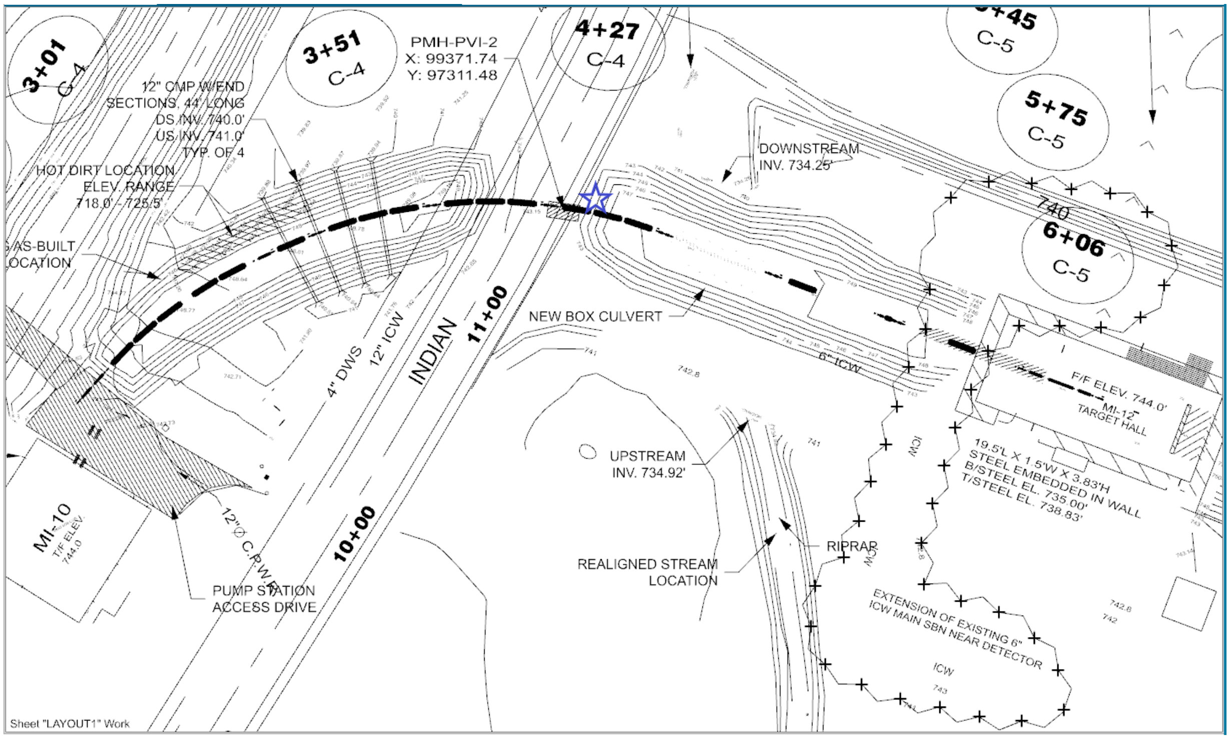

Figure 1. The approximate location of the credited detector in the BNB segment as indicated by the blue five-point star.

Table 3. Credited control detector used to limit the potential MCI radiation dose for the Manhole PMH-PVI-2 located at the 441-447 ft z-range [16].

Radiation Detector Type	Location	Credited Control Limit (mrem)
Chipmunk	MiniBooNE Indian Creek Road	2.5

Summary of Defense-in-Depth Controls

Defense-in-depth is the collection of non-credited-control methods used to further prevent and mitigate exposure to prompt radiation for individuals and equipment. The defense-in-depth used for the BNB segment includes service buildings with locked doors, radiation detectors, temporary guards, temporary ropes, signage, a safety training program, and a radiological ALARA program. Tables 4 and 5 summarize the defense-in-depth shielding for the BNB segment.

Table 4. Longitudinal shielding thicknesses obtained from Refs. [1,3] except for Manhole PMH-PVI-2 located at the 441-447 ft z-range. Longitudinal shielding thickness for Manhole PMH-PVI-2 is obtained from a recent radiological revaluation of this location [16]. Defense in depth shielding thickness is obtained by taking the difference of the current and credited control shielding thicknesses. The section describing the MCI scenario outlines the framework used to select the credited control shielding thicknesses. All the areas have sufficient shielding to produce a dose less than 500 mrem during one hour of running in the MCI scenario except for the Manhole PMH-PVI-2 located at the 441-447 ft z-range [16], where this area uses the RSIS to limit the dose during the MCI scenario.

Z Range (location) (ft)	Enclosure Type	Fixed Shielding (e.f.d.)	Movable Shielding (e.f.d.)	Current Shielding (e.f.d.)	Credited Control Shielding (e.f.d.)	Defense In Depth Shielding (e.f.d.)
0-100	MI 8 GeV Extraction	23.2		23.2	17.9	5.3
100-217	Buried 24" Carrier Pipe	25.5		25.5	20.3	5.2
217-233	Buried 24" Carrier Pipe	24.5		24.5	20.3	4.2
233-268	Tunnel Beyond MI10	19.4		19.4	17.9	1.5
268-278	Tunnel Under Berm Toe	19.4		19.4	17.9	1.5
278-400	Tunnel Under Berm	24		24	17.9	6.1
400-417	Tunnel Under Berm Toe	19.3		19.3	17.9	1.4
417-441	Indian Creek Road	19.3		19.3	17.9	1.4
441-447	Manhole PMH-PVI-2	16.9		16.9	16.4	0.5
447-475	Tunnel Under Berm Toe	20.2		20.2	17.9	2.3
475-490	Tunnel Under Berm	24.4		24.4	17.9	6.5
490-526	Box Culvert	24.5		24.5	17.9	6.6
526-544	Tunnel Under Berm	25.2		25.2	17.9	7.3
544-595	Tunnel Under Berm	24.0		24.0	17.9	6.1
595-645	Tunnel Upstream of MI-12	26.1		26.1	17.9	8.2
645-656	MI-12	22.8		22.8	17.9	4.9
656-674	MI-12		19.5	19.5	17.9	1.6
656-672	MI-12 Vault		19.5	19.5	17.9	1.6
672-690	Target Pile Upstream		34.6	34.6	17.9	16.7
690-697	Target Pile Collimator		38.0	38.0	17.9	20.1
697-699	Vault Downstream Wall	26.3		26.3	17.9	8.4
699-710	Decay Pipe under MI-12	24.1		24.1	20.3	3.8
710-763	Upstream Decay Pipe	26.2		26.2	20.3	5.9

763-776	Midrange Absorber In Beam		22.5	22.5	17.9	4.6
762-776	Midrange Absorber Out		23.3	23.3	17.9	5.4
776-846	Downstream Decay Pipe	26.0		26.0	20.3	5.7
846-856	Permanent Absorber	38.7		38.7	17.9	20.8

Table 5. Transverse shielding thicknesses obtained from Refs. [1,3]. Defense in depth shielding thickness is obtained by taking the difference of the shielding without air and credited control shielding thicknesses. The section describing the MCI scenario outlines the framework used to select the credited control shielding thicknesses. All the areas have sufficient shielding to produce a dose less than 500 mrem during one hour of running in the MCI scenario.

Transverse Station (location)	Enclosure Type	Shielding Without Air (e.f.d.)	Credited Control Shielding (e.f.d.)	Defense In Depth Shielding (e.f.d.)	Air Space In Enclosure (feet)
101	MI Extraction Stub	24.6	17.9	6.7	5.3
188	MI10 Crossover	25.7	17.9	7.8	1.0
231	Stairway Alcove	26.0	17.9	8.1	5.8
250	Stairway Exit Below Ground	20.0	17.9	2.1	5.7
301	Stairway Exit	24.0	17.9	6.1	5.7
351	Tunnel	23.1	17.9	5.2	5.7
427	Indian Creek Road	19.0	17.9	1.1	5.7
504	Box Culvert	23.2	17.9	5.3	5.7
545	Tunnel Downstream of Culvert	25.7	17.9	7.8	4.9
575	Tunnel	24.0	17.9	6.1	3.9
636	MI12 Upstream	22.0	17.9	4.1	2.0
660	MI12 Pretarget Vault	18.8	17.9	0.9	5.5
685	MI12 Horn Vault	30.0	17.9	12.1	3.3
693	MI12 Collimator	30.0	17.9	12.1	3.3
698	MI12 Downstream Wall	30.0	17.9	12.1	3.3
701	Decay Pipe Under MI12	26.9	20.3	6.6	3.0
765	Midrange Absorber In	31.8	17.9	13.9	0.0
765	Midrange Absorber Out	26.0	17.9	8.1	4.5
829	Decay Pipe	25.6	20.3	5.3	3.0
847	Permanent Absorber	38.2	17.9	20.3	0.0
882	Little Muon Counter Manhole (on 847 drawing)	53.4	17.9	35.5	0.0

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

Summary and Conclusion

Prompt ionizing radiation hazards associated with commissioning and operating the BNB segment are identified and assessed in this document. The designs, controls, and procedures to mitigate BNB 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.

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 workers and MOIs, or to the environment.

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