FERMI NATIONAL ACCELERATOR LABORATORY

ACCELERATOR SAFETY ENVELOPE

Fermilab Main Accelerator

Revision 13 August 11, 2023

Appendix A of the Safety Assessment Document

Accelerator Safety Envelope

Fermilab Main Accelerator

Approval Page

Line Organization Review and Recommendation

This Appendix A Chapter 01 of the Fermi National Accelerator Laboratory (Fermilab) Safety Assessment Document (SAD), *Accelerator Safety Envelope – Fermilab Main Accelerator*, was prepared and reviewed by the staff of the Environment, Safety & Health Division (ESH) Accelerator Safety Department in conjunction with the Accelerator Directorate (AD) Line Management for each segment of the Fermilab Main Accelerator.

Signatures below indicate review of this Accelerator Safety Envelope (ASE), and recommendations that it be incorporated into the Appendices of the Fermilab SAD.

☐ _____
AD Associate Lab Director

☐ _____
Accelerator Safety Department Head

☐ _____
SAD Review Subcommittee Chair

Directorate & Fermi Site Office Final Approval

Final approval of this Accelerator Safety Envelope for the Fermilab Main Accelerator is granted by the Fermilab Director and the DOE Field Element Manager.

_____
Director, Fermi National Accelerator Laboratory

_____
DOE Field Element Manager, Fermi Site Office

Revision History

Author	Rev. No.	Date	Description of Change
Maddie Schoell	13	August 11, 2023	Following the revision of Department of Energy (DOE) Order 420.2C, *Safety of Accelerators*, to DOE O 420.2D and the FY23 PEMP Notable Goal 4, including comments and concerns noted in the memo "Request to Approve Fermilab's Accelerator Safety Envelope and Concurrence with Safety Assessment Documents for the Neutrino, Meson and Neutrino Switchyard 120 Experimental Areas Including SpinQuest" dated January 4, 2023 – major revisions were made to the ASE. • Separated ASEs for the Fermilab Main Accelerator from the FAST Accelerator, removing FAST from this ASE. • Major overhaul of outline of ASE, including general descriptions and information within Section 1 through Section 6 • Added Section 7 to specifically describe Credited Controls for each segment of the Fermilab Main Accelerator • Updated shielding assessment reference for the Neutrino Area. • Removed reference for Memo, "Accelerator Safety Envelope Limitations for Operating Areas" and included content from the memo within the ASE.
Maddie Schoell	12	August 25, 2020	Updated "Area" column for MuCool Test Area to reflect new name, MeV Test Area (MTA). Updated shielding assessment references for MeV Test Area. Updated safety envelope beam intensities for MeV Test Area, and updated associated reference. Updated "ASE Violation Determination and Actions" section to clarify deficiency in credited control and ASE violations.
Maddie Schoell	11	February 11, 2020	Updated shielding assessment references for the Muon Campus. Safety envelope beam intensities did not change. Updated "Area" column titles for Muon Campus areas for clarity.

Author	Rev. No.	Date	Description of Change
John E. Anderson Jr.	10	November 12, 2019	Updated text for the "Control" section of the Operator Staffing section to reflect MCR responsibility for accelerator operations within the ASE beam intensity limits. Updated organizational name changes.
John E. Anderson Jr.	9	January 11, 2018	Removed Experimental ORC requirement from the ASE. Updated reference to the Routine Monitoring Program to reflect ESH Centralization. Clarified when shielding deficiencies would be an ASE violation.
John E. Anderson Jr.	8	August 28, 2017	Updated ASE energy limit for the Fermilab Accelerator Science and Technology (FAST) Facility.
John E. Anderson Jr.	7	March 3, 2017	Updated titles from ES&H reorganization, updated PPD ORC process to the FESHM ORC Process, and updated shielding assessment references for the Muon Campus and Booster accelerator areas. Safety envelope beam intensities did not change. Added Muon Campus 8 GeV beam on target intensity scaled from the 120 GeV intensity for clarity.
John E. Anderson Jr.	6	January 2, 2015	Added Safety Envelope beam intensity limits for the Advanced Superconducting Test Accelerator (ASTA) Injector. Changed Antiproton Source to Muon Campus. Updated references.
John E. Anderson Jr.	5	January 3, 2014	Updated ASE text to reflect recommendations from the Accelerator Readiness Review conducted October 1-3, 2013. Changes included moving numerical beam operating intensity limits from the ASE to a Division level document, scaling numerical beam safety envelope intensity limits to a 500 mrem accident condition, removing operating surveillance limits, and removing industrial hazards such as oxygen monitoring, cryogenic relief valve monitoring, and flammable gas system monitoring.

Author	Rev. No.	Date	Description of Change
John E. Anderson Jr.	4	April 25, 2013	Updated Department of Energy (DOE) DOE Order 420.2B, *Safety of Accelerator Facilities*, to DOE O 420.2C. Updated ASE text to reflect credible accident scenarios. Modified Operating and Safety Envelope beam parameters for the Main Injector, Recycler, and NuMI. Updated shielding assessment references for the revised Main Injector, Recycler, and NuMI shielding assessments. Updated Linac groundwater limit reference to new MARS calculations. Removed Operating and Safety Envelope beam parameters for Tevatron Circulating Beam, A0 and C0 Abort Absorbers, and the Pelletron; placing the areas in standby. Removed the Booster Radiation Damage Facility Operating and Safety Envelope beam parameters.
John E. Anderson Jr.	3	February 15, 2012	Added Operating and Safety Envelope beam intensity limits for the Neutrino Area.
John E. Anderson Jr.	2	March 21, 2011	Added Operating and Safety Envelope beam intensity limits for the HINS Linac at MDB.
John E. Anderson Jr.	1	January 20, 2011	Added Operating and Safety Envelope beam intensity limits for the MuCool Test Area.
John E. Anderson Jr.	0	December 10, 2009	Initial release of the laboratory-wide Accelerator Safety Envelope (ASE). The ASE is derived from the Safety Class Structures, Systems, or Components section of Fermilab Environment Safety and Health Manual (FESHM) Chapter 3010, *Significant and Reportable Occurrences*, and the Safety Envelope section of the existing Fermilab Safety Assessment Documents (SADs). This document supersedes and replaces the Safety Envelope section of the existing Fermilab SADs. Completed Safety Envelope calculations for the 8 GeV Line and MiniBooNE areas and revised Safety Envelope. Revised 8 GeV Line and MiniBooNE Operating limits to support future program needs based on post assessment documents.

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Section 1. Introduction and Scope

This document constitutes the integrated Accelerator Safety Envelope (ASE) for full power operation of all segments of the Fermilab Main Accelerator. It defines the Credited Controls that are established for all of the segments that make up the Fermilab Main Accelerator to assure that the level of risk to all workers, the public, and the environment is maintained at acceptable levels. This ASE is established in accordance with the DOE Order 420.2D, *Safety of Accelerators*, (DOE O 420.2D), and as flowed down through the Fermilab Environment, Safety and Health Manual (FESHM) including the Fermilab Radiological Control Manual (FRCM).

Section 2. Select Definitions and Acronyms

The following terms and/or acronyms are commonly used when discussing operation of the Fermilab Main Accelerator. Definitions that come directly from DOE O 420.2D, *Safety of Accelerators*, are noted with an asterisk (*), with further information on the interpretation and application of the definition for use at the Fermilab Main Accelerator in italics.

***Accelerator** A device and its components employing electrostatic or electromagnetic fields to impart kinetic energy to molecular, atomic, or sub-atomic particles and capable of creating a radiological area as defined by 10 CFR Part 835, Occupational Radiation Protection. Accelerator components include injectors, targets, beam dumps, detectors, experimental enclosures, accelerator enclosures, experimental areas, and experimental apparatus utilizing the accelerator. The accelerator also includes associated support and test facilities, equipment, systems, and utilities necessary to operate the accelerator or utilize the accelerated beam.

***Accelerator Facility** The accelerator, plant, buildings, structures, and equipment supporting the accelerator and its operations that are under direct control of the contractor

All facilities at Fermilab in some way contain components or conduct activities supporting an accelerator and its operations. As such, all facilities are described in the Safety Assessment Document (SAD).

***Accelerator Operations** Activities within the accelerator facility that, over the lifecycle of the facility, support 1) production or utilization of accelerator beams; 2) research and experimental activities utilizing accelerator beams; 3) handling, storage and analysis of accelerator induced radioactive components and materials within the accelerator facility boundary; 4) receipt, preparation, assembly, inspection, and installation of samples into the accelerator beam; or 5) removal, disassembly, handling, analysis, and storage for radioactive dose minimization to meet the definition of ALARA in 10 CFR Part 835, Occupational Radiation Protection, or transportation requirements, and packaging of samples after use in the

accelerator beam. Accelerator Operations excludes radioisotope processing activities that are not required to operate or maintain the accelerator.

***Accelerator Readiness Review (ARR)** A structured method for verifying that hardware, personnel, and procedures associated with commissioning or routine operations are ready to permit the activity to be undertaken safely.

***Accelerator Safety Envelope (ASE)** A documented set of verifiable physical and administrative requirements, bounding conditions, and credited controls that ensure safe operation and address accelerator specific hazards and risks.

Accelerator Safety Envelope Intensity Calculated intensity that, assuming a one (1) hour point source loss would produce a 500 mrem accident condition

Accelerator Specific Hazard Hazards are classified as Accelerator Specific when their nature is uniquely defined by the configuration of the accelerator and they are not fully mitigated by Fermilab standard safety management programs. The passive, active engineered, and administrative mitigations which reduce accelerator specific hazards within Applicable Accelerator Facilities from unacceptable to acceptable risk are the Credited Controls

Applicable Accelerator Facility An Accelerator Facility further posted as an Exclusion Area.

***Commissioning** A phase of an accelerator facility operation that is typically used to conduct initial beam testing and/or verify design specifications. Commissioning periods may be tailored to the needs of each facility and there may be great variations in their duration, breadth, and formality, but in all cases, the activities will be bounded by an ASE and preceded by an ARR and DOE approval.

Compensatory Measure An approved alternative measure that may be used on a case-by-case basis in lieu of a Credited Control, with appropriate and documented approvals.

***Credited Control** Controls determined through the Safety Analysis to be essential for safe operation directly related to the protection of workers, the public, and the environment.

Credited Controls are implemented to mitigate Accelerator Specific Hazards within Applicable Accelerator Facilities to acceptable levels. For other facilities, controls to mitigate similar hazards are managed through programs and requirements specified in FESHM.

***DOE Element** First-tier organizations at DOE/NNSA HQ and in the field as listed in the Correspondence Style Guide, Office of the Executive Secretariat.

***DOE Field Element Manager** The manager having overall responsibility for a DOE field element including execution of oversight policy implementation. The Field Element Manager directs activities of DOE/NNSA field or site offices and has line accountability for all site program, project execution, and contract management.

The Fermilab Site Office (FSO) Manager is the DOE Field Element Manager.

***DOE Program Secretarial Officer (PSO)** An Assistant Secretary, Office Director, Head of Program Element, or NNSA Deputy Administrator to whom designated field offices directly report and who has overall landlord responsibilities for the assigned direct reporting elements.

Nominal Operating Intensity Intensity identified by the machine and/or Project, supported by the Shielding Assessment.

Maximum Operating Intensity The maximum intensity a given segment is allowed to operate at without requiring additional actions/approvals/responses. This value is the Nominal Operating Intensity plus 5%, in order to accommodate potential fluctuation in beam intensity due to changes in efficiency.

***Radiation** Ionizing radiation, including the accelerated particle beam and the radiation produced when the beam interacts with matter or changes direction. Radiation includes alpha particles, beta particles, gamma rays, X-rays, neutrons, high-speed electrons, high-speed protons, and other particles capable of producing ions.

***Radioisotope Processing** Chemical, thermal, or physical actions taken to separate, isolate, refine, or enrich specific isotopes of a chemical element.

***Residual Radioactivity** Radioactivity in structures, materials, soils, groundwater, and other media at a site resulting from the accelerator or accelerator operations.

***Reviewed Safety Issue** The outcome of the evaluation and determination phase of the USI Process.

***Risk** A quantitative or qualitative expression of possible harm, which considers both the probability that a hazard will cause harm and the amount of harm; or, alternatively, an estimate of the probability of occurrence of a hazard-related incident and the severity of the consequence associated with the incident.

Fermilab utilizes a qualitative risk assessment, following the methodology found in DOE-HDBK-1163-2020, Integration of Hazard Analyses.

***Safety Analysis** A documented process to systematically identify the hazards of a given operation; including a description and analyses of the adequacy of measures

taken to eliminate, control, or mitigate the hazards and risks of normal operation; and identification and analyses of potential accidents and their associated risks.

***Safety Assessment Document (SAD)** A document containing the results of a Safety Analysis for an accelerator or accelerator facility pertinent to understanding the risks to workers, the public, and the environment of operating the accelerator.

***Unreviewed Safety Issue (USI)** An activity or discovered condition with accelerator specific hazards that have yet to be evaluated to determine if the activity or discovered condition introduces accelerator specific hazards that are not adequately addressed by the current SAD and approved ASE.

***USI Process** The process or methodology used to evaluate/review USIs to determine if the activity or discovered condition is adequately addressed by the current SAD and approved ASE.

Section 3. Description of Credited Controls

The Credited Controls identified in the ASE are a set of passive, active engineered, and administrative controls in use at the Fermilab Main Accelerator that define the bounding conditions and limitations for safe and environmentally sound operations. In accordance with FRCM Article 236, Fermilab utilized Credited Passive and Active Engineered Controls whenever the maximum calculated accident condition can exceed 500 mrem in an hour. The Credited Controls listed in the ASE must be in place and functional for all operational areas. During periods of down time or maintenance, Credited Controls may be removed and managed under the Safety Configuration Management program to ensure they are replaced prior to resumption of operations.

For each Credited Control, the following is specified:

- **Applicability** – the condition in which the Credited Control is valid.
- **Basis** – description of the need for the Credited Control.
- **Requirement** – specific elements that must be in place during beam operation. Beam operation to the affected area without required elements in place is an ASE violation.
- **Compensatory Measure(s)** – An approved temporary alternative that may be taken to allow for safe operation when a requirement is not in place.
- **Required Surveillance** – management and monitoring practices that must be performed to assure continued effectiveness of the Credited Control. Surveillances are to be carried out at the minimum specified interval. Beam operation to the affected area without the required surveillance being performed within the minimum specified interval is an ASE violation.
- **Response** – actions to be taken if there is a suspected deficiency, missing control, or other potential ASE violation for that particular Credited Control.

The Credited Controls are divided into three main categories: passive controls, active engineered controls, and administrative controls.

Passive

Passive Credited Controls are elements that are part of the physical design of the facility that require no action to function properly. These are fixed elements that take human intervention to remove. The types of Passive Credited Controls in use for the Fermilab Main Accelerator include:

- Shielding (i.e., Permanent/Structural, Labyrinths, Movable, Penetration Shielding)
- Fencing (i.e., Radiation Area fencing, Controlled Area fencing)

Acceptable methods for configuration of movable and/or penetration shielding include, but are not limited to: locked chains, Unistrut to block or inhibit movement, cover plates over penetration holes, etc.

Fermilab uses a more current methodology, utilizing engineering drawings and Monte Carlo simulations, to perform shielding assessments which do not have easily produced tables of required shielding. For these areas, the shielding assessment and its references should be used to easily convey required shielding. For shielding assessments that utilize an incremental shielding assessment methodology, there are tables specifying shielding. For these areas, the tables of shielding will be summarized in the SAD and ASE.

Active Engineered

Active Engineered Credited Controls are systems designed to reduce the risks from accelerator operations to an acceptable level. The types of Active Engineered Credited Controls in use for the Fermilab Main Accelerator include:

- Radiation Safety Interlock System (RSIS)
- Oxygen Deficiency Hazard (ODH) Safety System
- Fluorinert system filter

Radiation Safety Interlock System (RSIS)

Radiation Safety Interlock Systems (RSIS) are used to prevent injury, death, or serious over-exposure from beam-on radiation. The principle method employed by the RSIS is to establish and maintain Exclusion Areas surrounding accelerator operating areas. If there is a potential for personnel to inadvertently access the defined Exclusion Area, the RSIS is designed to inhibit accelerator operations in that area.

The RSIS may also include interlocked radiation monitors to supplement passive shielding Credited Controls. If dose rates exceed specified levels supported by the Shielding Assessment, the RSIS is designed to inhibit accelerator operations in that area.

The RSIS utilize a modular redundant design where no single component failure will result in a loss of protection. To accomplish this, two separate fail-safe circuits are used to detect specific conditions. All

circuits within the RSIS are designed in such a way that if a circuit fails, or specified input is lost, the failure would initiate a system shutdown resulting in a safe condition.

Oxygen Deficiency Hazard (ODH) Safety Systems

ODH Safety Systems are used to prevent injury or death from exposure to oxygen deficient environments. ODH Classifications are determined based on a quantitative risk assessment, further described in FESHM 4240. ODH Classifications are then used to determine required personnel training and qualification and other ODH control measures. ODH Safety Systems utilize various components (e.g., area oxygen monitors, vents, fan, etc.) to maintain the posted ODH Classification.

ODH Safety System component failures are taken into account in the initial ODH analysis, and surveillance requirements are determined based on the analysis. In the event of a known failure of an ODH Safety System component that is necessary to maintain the original ODH Classification, the area is evacuated and ODH Classification is updated as needed based on existing out-of-service policy or updated ODH analysis.

ODH Safety System components that are required to maintain the posted ODH Classification within an interlocked and/or posted Exclusion Areas will be identified as Credited Controls and summarized in this ASE.

Fluorinert System Filter

Fluorinert may be used for high voltage insolation and cooling. Exposure of the Fluorinert to prompt radiation produces contaminants that if allowed to build up in the system can become toxic. To control this hazard, a filter is installed in the cooling skid to remove these contaminants. The filter has a visual indicator to inform the technician as to when the filter needs to be changed.

Administrative

Administrative Credited Controls encompass the human interactions that define safe operations. These are the accelerator operating policies and procedures that are followed to ensure safe accelerator operations. The types of Administrative Credited Controls in use for the Fermilab Main Accelerator include:

- Operation Authorization Document
    - Must include the following information:
        - Segment Name
        - Issue Date
        - Mode(s) of Operation
        - Operating Parameters (i.e., ASE Intensity Limit)
        - Critical Device Controller (CDC)
        - Critical Devices
        - Exclusion Area(s)
        - Credited Controls

i. Shielding Requirements
ii. Fencing Requirements
iii. RSIS Required Components and Inputs, including interlocked detectors
iv. ODH System Requirements
v. Staffing Requirements
vi. Accelerator Operating Parameters (i.e., ASE Intensity Limit)

- May also include additional information beneficial to those operating the Fermilab Main Accelerator (e.g., Nominal Operating Intensity, Maximum Operating Intensity, assigned Radiation Safety Officer, cool off period, etc.)

- Staffing
- Accelerator Operating Parameters

ASE Intensity Determination

The Accelerator Beam Intensity Limit is determined as follows –

Fermilab rigorously maintains normal operations as defined in the various radiological shielding assessments through passive shielding, movable shielding, penetration shielding, radiological fences, radiation safety interlocks, and the approved Beam Permit and Running Condition for each operating area. The beam intensity limits for Normal operations are to ensure compliance with the requirements established in the Fermilab Radiological Control Manual (FRCM) and applicable federal regulations such as 10 CFR 835 and 40 CFR 141. The use of beam intensity limits for Normal operations are excessively conservative in our application of the basis for the Accelerator Safety Envelope with respect to abnormal operations.

The FRCM provides guidance that impacts associated with abnormal operations should be adequately addressed to assure that the level of risk to a person offsite or outside the facility is maintained at an adequate level. We currently limit operations on the basis of the normal and accident condition postings, at the Nominal Operating Intensity, that are associated with a given area, and recognize that should a beam loss accident occur, it would likely last for significantly less than one hour. Since we maintain a relatively open site, the risk to a person offsite or outside the facility is one in the same.

The FRCM requires credited passive or active engineered controls to be established to protect from abnormal beam loss events when the calculated dose from beam lost in a point source, at the same place, continuously for one hour can produce a 500 mrem accident condition outside of the accelerator shielding. This accident condition is not considered credible since such a high beam power lost in a point source would likely degrade the accelerator vacuum such that continued operations would not be possible. However, it does provide an upper limit on the allowable beam intensity to identify when credited passive or active engineered controls are necessary.

Each shielding assessment for operating areas was reviewed to determine the beam intensity needed to create a 500 mrem accident condition, the ASE Intensity. When reviewing the shielding assessments, the following scaling criteria were used.

1. Areas protected by interlocked detectors were ignored since the detector will limit the duration of any accident condition. An exception was made for the Linac, Booster, and FAST areas since their shielding assessments are based on the use of interlocked detectors. In those three cases, the detector trip setting was scaled to a 500 mrem accident condition. The calculated scaling factor was then used to calculate the beam intensity needed to cause the 500 mrem accident condition based on the current operating limits.
2. When shielding spreadsheets were available, the category 1, 2, & 3 areas were changed to category 4 and the beamline intensity was increased until a failure appeared on the spreadsheet.
3. When shielding spreadsheets were available, the beam intensity for category 4 areas was increased until a failure appeared. The beam intensity needed for a category 4 area failure was then scaled up by a factor of 100. Category 4 areas are required to be fenced and locked radiological areas. The assumption made is the dose on the outside of the fenced in area would be 5 mrem or less for a 500 mrem accident condition inside the fenced area, or a factor of 100 less.
4. When actual accident condition doses were known through MARS, similar Monte Carlo modeling, or measurements, the dose was simply scaled to a 500 mrem accident condition dose to derive the beam intensity scaling factors needed to create a 500 mrem accident condition. The beam intensity was then scaled by the calculated scaling factor.
5. When fences were used for normal operating losses, up to 100 mrem inside of the fenced area, the intensity was scaled up by a factor of 100. The assumption made was the dose on the outside of the fenced in area would be 5 mrem or less for 100 mrem normal operating condition inside the fenced area, or a factor of 100 less than the 500 mrem accident condition.

For each area reviewed, the most conservative intensity limit was identified and used to define the Accelerator Safety Envelope (ASE) Intensity for the area. The intensity limits, their basis, and scaling calculations are summarized in Section 7. The ASE Intensity limits are specified in protons or electrons/hour since the concern is prompt radiation exposures from beam operations.

Risk assessment methodology from DOE-HDBK-1163-2020 was used to determine the potential risk of an accident scenario at ASE Intensities. A 500 mrem accident scenario at ASE Intensities would have a negligible consequence to members of the public. The likelihood of a 500 mrem accident scenario at ASE Intensities is Beyond Extremely Unlikely based on the intrinsic design of the accelerator. This would result in a Baseline Risk level of IV, which per DOE-HDBK-1163-2020 is an acceptable level of risk

requiring no additional controls. As a result, controls are established and put in place based on the Operating Intensity assessed in the applicable Shielding Assessments rather than the calculated ASE Intensity.

Radiological Hazard Consequences, derived from Figure C-1, "Example Qualitative Consequence Matrix", DOE-HDBK-1163-2020.

Likelihood (L, of event)/year
A = Anticipated (L > 1.0E-02)
U = Unlikely (1.0E-02> L >1.0E-04)
EU = Extremely Unlikely (1.0E-04 > L >1.0E-06)
BEU = Beyond Extremely Unlikely (1.0E-06> L)

Consequence (C, of event)/year
H = High
M = Moderate
L = Low
N = Negligible

Risk (R, Qualitative Ranking)
I = situation (event) of major concern
II = situation (event) of concern
III = situation (event) of minor concern
IV = situation (event) of minimal concern

Control(s) Type
P = Preventive (reduce event occurrence likelihood)
M = Mitigative (reduces event consequences)
Acronyms
MOI = Maximally-exposed Offsite Individual
rem = Roentgen equivalent man

C	Offsite (MOI)	Onsite-2 (co-located worker)	Onsite-1 (facility worker)
H	C ≥ 25.0 rem	C ≥ 100 rem	C ≥ 100 rem
M	25.0 rem > C ≥ 5 rem	100 rem > C ≥ 25 rem	100 rem > C ≥ 25 rem
L	5 rem > C	25 rem > C	25 rem > C
N	0.5 rem > C	5 rem > C	5 rem > C

Risk Matrix

Consequences	Likelihood: A	U	EU	BEU
H	I	I	II	III
M	II	II	III	IV
L	III	III	IV	IV
N	IV	IV	IV	IV

Figure 1. Summary Table Explaining the Risk Assessment for Radiological Hazards Derived from DOE-HDBK-1163.

Section 4. ASE Violation Determination and Actions

Determination

Any beam operation to the affected segment of the Fermilab Main Accelerator with a known loss of Credited Control (except ODH Safety System Credited Controls) and/or the safety function of the Credited Control is a violation of the ASE.

> For Credited Controls that have additional overburden or Defense-in-Depth controls, it may not be immediately obvious if a deficiency is in the overburden or in the Credited Controls. In this case, it is not yet known if there even is a deficiency in Credited Controls constituting an ASE Violation. In these circumstances, the appropriate Line Organization and ESH Division Subject Matter Experts (SMEs) will investigate to determine if Credited Controls were impacted. This determination shall be documented following the USI Process, as described in Section 6 of this ASE. If it is determined that Credited Controls were impacted, beam operations shall be terminated immediately and not resume until the Reviewed Safety Issue (RSI) is finalized. If beam operations were to resume without the Reviewed Safety Issue (RSI) being finalized, that would constitute an ASE Violation.

For ODH Safety System Credited Controls, in the event of a known failure of an ODH Safety System component that is necessary to maintain the original ODH Classification, and the Cryo Coordinator/Facility Manager determine that there is a need to reclassify the area (as opposed to replacing components), the area is evacuated and ODH Classification is updated as needed based on existing out-of-service policy or updated ODH analysis. Reentry into the area, before the ODH Classification is updated, is limited to personnel approved by the Cryo Coordinator/Facility Manager to perform work necessary for the ODH reclassification, any other access is a violation of the ASE.

Beam operation of the segment of the Fermilab Main Accelerator beyond the specified ASE Intensity Limit is a violation of the ASE.

Beam operation of the segment of the Fermilab Main Accelerator with required surveillance of a Credited Control not conducted within specified frequency, as defined for each segment in Section 7 of this ASE, is an ASE violation.

Questions regarding determination of an ASE violation shall be addressed to the Environment, Safety & Health (ESH) Division Accelerator Safety Department Head and the Accelerator Division (AD) Associate Lab Director.

Actions

In the event that the ASE is violated, beam operations to the affected segment of the Fermilab Main Accelerator shall be terminated and put in a safe and stable configuration, and not resume until the circumstances of the event are reviewed and approval to resume operations is received. Non-affected segments of the Fermilab Main Accelerator may continue operations. The USI Process, as described in Section 6 of this ASE, will be used to analyze and document the circumstances of the ASE violation. Once the RSI has been finalized for the event causing the ASE violation, approval to resume operations to the affected segment of the Fermilab Main Accelerator will be issued by the AD Associate Lab Director and the DOE Field Element Manager.

Events determined to be ASE violations follow FESHM Chapter 3010 *Significant and Reportable Occurrences*, to provide the appropriate DOE notification and reporting.

Section 5. Configuration Management for Credited Controls

To ensure the integrity of the Credited Controls during accelerator operation, several methods of Configuration Management are in place.

- Excavation within the “Excavation Waiver Prohibited Zone” around the accelerator are required to go through the JULIE process. Part of the JULIE process includes ES&H Division Radiation Safety personnel review to determine if required shielding may be impacted.
- Required movable and penetration shielding is posted and/or locked and/or bolted in place where applicable.
- Components that are part of the Radiation Safety Interlock System (RSIS) are labeled.
- Surveillance is performed, as specified in Section 7.

If shielding or fencing is planned to be removed, the assigned Radiation Safety Officer (RSO) is responsible for ensuring the affected segment of the Fermilab Main Accelerator is locked off in a safe state, using RSO Configuration Control locks.

If any Credited Control is not in place, either planned or discovered, the assigned RSO is responsible for ensuring the affected segment of the Fermilab Main Accelerator is locked off in a safe state, using RSO Configuration Control locks.

Removal of Credited Controls (i.e., rescinding Operation Authorization Documents, removing shielding or fencing, etc.) during maintenance periods is common, and the assigned RSO is responsible for

ensuring the affected segment of the Fermilab Main Accelerator is locked off in a safe state, using RSO Configuration Control locks.

The ES&H Division Radiation Physics Operations and Accelerator Safety Departments utilize a Configuration Control Log to track instances of placing affected segment of the Fermilab Main Accelerator in a Configuration Controlled off state. This Log keeps track of reasons why the affected segment of the Fermilab Main Accelerator was locked off, what must be done prior to resuming operations, and confirmation that conditions are back in place and confirmed before operations are permitted to resume.

Section 6. Unreviewed Safety Issue (USI) Process

The Unreviewed Safety Issue (USI) Process is used to evaluate proposed activities/modifications and/or discovered conditions to ensure all hazards are adequately addressed in by the current SAD and approved ASE. The USI Process begins with completion of the USI Determination form, which includes multiple questions that will evaluate the proposed activity/modification and/or discovered condition to determine if it is already fully evaluated and included in the SAD and ASE or if and updated evaluation is necessary. At the conclusion of the USI Process, the review of the proposed activity/modification and/or discovered condition is classified as a Reviewed Safety Issue (RSI).

Proposed activities/modifications and/or discovered conditions at the Fermilab Main Accelerator are subject to the USI Process.

Compensatory Measures shall be reviewed and approved by the SRSO, and documented using the USI Process, prior to implementation.

Section 7. Summary of Credited Controls for All Segments of the Fermilab Main Accelerator Complex

Linac Credited Controls

Passive – Shielding

Applicability	During beam operations to the Linac segment of the Fermilab Main Accelerator.
Basis	Based on the Nominal Operating Intensity of 3.54e17 particles/hr, supported by the following Shielding Assessments, the shielding is required in the locations listed below. Shielding Assessment(s): • 1993 Radiation Shielding Assessment of Linac High Energy Enclosure Following the 1993 Upgrade Installation & Low Intensity Commissioning [1]
Requirement	Required shielding specified in the listed Shielding Assessments will be installed in its proper configuration during applicable beam operations. The listed Shielding Assessment(s) utilizes measurements rather than simulations required shielding is found in the listed Shielding Assessment.
Compensatory Measure(s)	In lieu of required shielding, temporary controls, such as guards, fencing, ropes, and/or postings, may be utilized as approved by the SRSO. Each use of a Compensatory Measure shall be documented using the USI Process.
Required Surveillance	Required shielding shall be verified annually, not to exceed twelve (12) months.
Response	Beam operation to the Linac will be terminated. Beam operation to the Linac will not resume until approval is received from the AD Associate Lab Director and the DOE Field Element Manager.

Passive – Fencing

Applicability	During beam operations to the Linac segment of the Fermilab Main Accelerator.
Basis	Based on the Nominal Operating Intensity of 3.54e17 particles/hr, supported by the following Shielding Assessments, the shielding is required in the locations listed below. Shielding Assessment(s): • 1993 Radiation Shielding Assessment of Linac High Energy Enclosure Following the 1993 Upgrade Installation & Low Intensity Commissioning [1]
Requirement	Required fencing specified in the listed Shielding Assessments will be installed in its proper configuration during applicable beam operations.

Radiation Area Fencing
None required

Controlled Area Fencing
none

Compensatory Measure(s) In lieu of required fencing, temporary controls, such as guards, ropes, and/or postings, may be utilized as approved by the SRSO. Each use of a Compensatory Measure shall be documented using the USI Process.

Required Surveillance Required fencing shall be verified annually, not to exceed twelve (12) months.

Response Beam operation to the Linac will be terminated. Beam operation to the Linac will not resume until approval is received from the AD Associate Lab Director and the DOE Field Element Manager.

Active Engineered – Radiation Safety Interlock System (RSIS)

Applicability During beam operations to the Linac segment of the Fermilab Main Accelerator.

Basis Based on the Nominal Operating Intensity of 3.54e17 particles/hr, supported by the following Shielding Assessments, the RSIS is established with interlocked barriers around the Exclusion Area, as well as inclusion of required interlocked radiation monitors.

Shielding Assessment(s):
- 1993 Radiation Shielding Assessment of Linac High Energy Enclosure Following the 1993 Upgrade Installation & Low Intensity Commissioning [1]

Requirement The Radiation Safety Interlock System (RSIS) must prevent entry into the following Exclusion Area(s) during appliable beam operation:
- Linac

Required components of the RSIS shall be specified in the Linac's Operation Authorization Document.

The following components of the Radiation Safety Interlock System (RSIS) shall be in place, with no known loss of safety function, during applicable beam operations.

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	Linac Dump #1 Berm US
Chipmunk	Linac Dump #1 Berm DS
Chipmunk	Linac Enclosure Tank #1
Chipmunk	Linac Gallery Tank #2
Chipmunk	Linac Gallery Tank #3
Chipmunk	Linac Gallery Tank #4
Chipmunk	Linac Gallery Tank #5
Chipmunk	Linac Gallery Tank #6
Chipmunk	Linac Gallery Tank #7
Chipmunk	Linac Gallery Tank #8
Chipmunk	Linac Gallery Tank #9
Scarecrow	Linac Enclosure 400 MeV Labyrinth
Scarecrow	Linac Enclosure Tank #3
Chipmunk	Booster Chute
Chipmunk	Booster Tunnel Dump #1

Compensatory Measure(s) In lieu of required interlocked detectors, temporary controls, such as guards, fencing, ropes, and/or postings, may be utilized as approved by the SRSO. Each use of a Compensatory Measure shall be documented using the USI Process.

Required Surveillance The RSIS for the Linac segment shall undergo certification annually, not to exceed twelve (12) months.

Response Beam operation to the Linac will be terminated. Beam operation to the Linac will not resume until approval is received from the AD Associate Lab Director and the DOE Field Element Manager.

Active Engineered – Oxygen Deficiency Hazard (ODH) Safety System

Applicability not applicable

Basis not applicable

Requirement none

Compensatory Measure(s) not applicable

Required Surveillance none

Response not applicable

Administrative – Operation Authorization Document

Applicability	During beam operations to the Linac segment of the Fermilab Main Accelerator.
Basis	To summarize the bounding conditions for safe operation of the Linac, and to provide explicit approval for operations of the Linac.
Requirement	An approved Linac Beam Permit & Running Condition shall be issued prior to Linac beam operations.
Compensatory Measure(s)	none
Required Surveillance	The Linac Beam Permit and Running Condition shall be verified annually, not to exceed twelve (12) months.
Response	Beam operation to the Linac will be terminated. Beam operation to the Linac will not resume until approval is received from the AD Associate Lab Director and the DOE Field Element Manager.

Administrative – Staffing

Applicability	During beam operations to the Linac segment of the Fermilab Main Accelerator.
Basis	To ensure operations within bounding conditions specified in Operation Authorization Document, and to disable beam operation to the Linac and initiate an immediate response in the event of a determined ASE violation.
Requirement	The following staffing shall be in place during applicable beam operation: • At least one member of the AD Operations Department who has achieved the rank of Operator II or higher shall be on shift. • At least one member of the AD Operations Department shall be present in the Main Control Room (MCR).
Compensatory Measure(s)	none
Required Surveillance	none

Response Beam operation to the Linac will be terminated. Beam operation to the Linac will not resume until approval is received from the AD Associate Lab Director and the DOE Field Element Manager.

Administrative – Accelerator Operating Parameters

Applicability During beam operations to the Linac segment of the Fermilab Main Accelerator.

Basis Linac lower level penetrations up to NTF are interlocked to 50 mrem outside the beamline enclosure with Chipmunks by the transmission lines for tanks 1-5. Using scaling criteria 1, the Chipmunk trip point scaled to a 500 mrem accident condition results in a factor of 10. The current operating limit is 6.7×10^{17} protons/hour. Scaling up by 10 sets the Linac ASE to 6.7×10^{18} protons/hour up to NTF.
Linac upper level downstream waveguide penetration limit is 10 mrem/hour for 3.54×10^{17} protons/hour. The Chipmunks at the lower level penetrations for the transmission lines for tanks 6-9 were adjusted down to trip at 10 mrem. The calculated dose at the upper level penetrations is similar to the dose at the lower level penetrations allowing the lower level penetration Chipmunks to also protect the upper level waveguide penetrations. Using scaling criteria 1, the Chipmunk trip point scaled to a 500 mrem accident condition results in a factor of 50. The current operating limit is 3.54×10^{17} protons/hour. Scaling up by 50 sets the Linac ASE to 1.77×10^{19} protons/hour after NTF.

Requirement The Linac segment will be operated within the following parameters:

Mode	Intensity	Energy
Full Operation	1.77e19 protons/hr	400 MeV

These parameters are further specified in the Operation Authorization Document.

Linac intensity is monitored via: L:RF3INT

Compensatory Measure(s) Alternative methods of monitoring intensity may be used.

Required Surveillance none

Response Beam operation to the Linac will be terminated. Beam operation to the Linac will not resume until approval is received from the AD Associate Lab Director and the DOE Field Element Manager.

Neutron Irradiation Facility (NIF) Credited Controls

Passive – Shielding

Applicability	During beam operations to the NIF segment of the Fermilab Main Accelerator.
Basis	Based on the Nominal Operating Intensity of 6.70e17 particles/hr, supported by the following Shielding Assessments, the shielding is required in the locations listed below. Shielding Assessment(s): • 1993 Radiation Shielding Assessment of Linac High Energy Enclosure Following the 1993 Upgrade Installation & Low Intensity Commissioning [1] • 1992 Neutron Therapy Facility 1992 Shielding Assessment [2]
Requirement	Required shielding specified in the listed Shielding Assessments will be installed in its proper configuration during applicable beam operations. The listed Shielding Assessment(s) utilized the more current Monte Carlo simulation methodology, required shielding is found in the listed Shielding Assessment(s).
Compensatory Measure(s)	In lieu of required shielding, temporary controls, such as guards, fencing, ropes, and/or postings, may be utilized as approved by the SRSO. Each use of a Compensatory Measure shall be documented using the USI Process.
Required Surveillance	Required shielding shall be verified annually, not to exceed twelve (12) months.
Response	Beam operation to the NIF will be terminated. Beam operation to the NIF will not resume until approval is received from the AD Associate Lab Director and the DOE Field Element Manager.

Passive – Fencing

Applicability	During beam operations to the NIF segment of the Fermilab Main Accelerator.
Basis	Based on the Nominal Operating Intensity of 6.70e17 particles/hr, supported by the following Shielding Assessments, the shielding is required in the locations listed below. Shielding Assessment(s): • 1993 Radiation Shielding Assessment of Linac High Energy Enclosure Following the 1993 Upgrade Installation & Low Intensity Commissioning [1] • 1992 Neutron Therapy Facility 1992 Shielding Assessment [2]

Requirement Required fencing specified in the listed Shielding Assessments will be installed in its proper configuration during applicable beam operations.

Radiation Area Fencing

Fence Location	Required Posting	Gates (if applicable)	Configuration
Interlocked gate enclosure north side of NTF lower level	Radiation Area During NIF operations	Rolling Stone gate	Locked with interlock key
Gate and fencing south side of NIF lower level	Radiation Area during NIF operations	NIF south gate	• 4 ft height • Standing upright between 60-120° • No missing or bent pieces creating a person-sized hole (~1ft^2) • Gates locked with NIF reset key

Rope Location	Required Posting	Gates (if applicable)	Configuration
Area outside shield door south side of NIF	Radiation Area	N/A	Waist high
Roped area main level north of NIF	Radiation Area	N/A	Waist high

Controlled Area Fencing

none

Compensatory Measure(s)	In lieu of required fencing, temporary controls, such as guards, ropes, and/or postings, may be utilized as approved by the SRSO. Each use of a Compensatory Measure shall be documented using the USI Process.
Required Surveillance	Required fencing shall be verified annually, not to exceed twelve (12) months.
Response	Beam operation to the NIF will be terminated. Beam operation to the NIF will not resume until approval is received from the AD Associate Lab Director and the DOE Field Element Manager.

Active Engineered – Radiation Safety Interlock System (RSIS)

Applicability	During beam operations to the NIF segment of the Fermilab Main Accelerator.
Basis	Based on the Nominal Operating Intensity of 6.70e17 particles/hr, supported by the following Shielding Assessments, the RSIS is established with interlocked barriers around the Exclusion Area, as well as inclusion of required interlocked radiation monitors. Shielding Assessment(s): • 1993 Radiation Shielding Assessment of Linac High Energy Enclosure Following the 1993 Upgrade Installation & Low Intensity Commissioning [1] • 1992 Neutron Therapy Facility 1992 Shielding Assessment [2]
Requirement	The Radiation Safety Interlock System (RSIS) must prevent entry into the following Exclusion Area(s) during appliable beam operation: • NIF Treatment Room Required components of the RSIS shall be specified in the NIF's Operation Authorization Document. The following components of the Radiation Safety Interlock System (RSIS) shall be in place, with no known loss of safety function, during applicable beam operations. <u>Radiation Safety System – Interlocked Radiation Monitors</u> none
Compensatory Measure(s)	In lieu of required interlocked detectors, temporary controls, such as guards, fencing, ropes, and/or postings, may be utilized as approved by the SRSO. Each use of a Compensatory Measure shall be documented using the USI Process.

Required Surveillance	The RSIS for the NIF segment shall undergo certification annually, not to exceed twelve (12) months.
Response	Beam operation to the NIF will be terminated. Beam operation to the NIF will not resume until approval is received from the AD Associate Lab Director and the DOE Field Element Manager.

Active Engineered – Oxygen Deficiency Hazard (ODH) Safety System

Applicability	not applicable
Basis	not applicable
Requirement	none
Compensatory Measure(s)	not applicable
Required Surveillance	none
Response	not applicable

Administrative – Operation Authorization Document

Applicability	During beam operations to the NIF segment of the Fermilab Main Accelerator.
Basis	To summarize the bounding conditions for safe operation of the NIF, and to provide explicit approval for operations of the NIF.
Requirement	An approved NIF Beam Permit & Running Condition shall be issued prior to NIF beam operations.
Compensatory Measure(s)	none
Required Surveillance	The NIF Beam Permit and Running Condition shall be verified annually, not to exceed twelve (12) months.
Response	Beam operation to the NIF will be terminated. Beam operation to the NIF will not resume until approval is received from the AD Associate Lab Director and the DOE Field Element Manager.

Administrative – Staffing

Applicability During beam operations to the NIF segment of the Fermilab Main Accelerator.

Basis To ensure operations within bounding conditions specified in Operation Authorization Document, and to disable beam operation to the NIF and initiate an immediate response in the event of a determined ASE violation.

Requirement The following staffing shall be in place during applicable beam operation:

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

Compensatory Measure(s) none

Required Surveillance none

Response Beam operation to the NIF will be terminated. Beam operation to the NIF will not resume until approval is received from the AD Associate Lab Director and the DOE Field Element Manager.

Administrative – Accelerator Operating Parameters

Applicability During beam operations to the NIF segment of the Fermilab Main Accelerator.

Basis The shielding assessment for NIF (referenced above) were performed at 6.72e18 particles per hour. Nominal Operations were limited to ~10% of the assessed intensity. For NIF, the ASE Intensity is set lower than the assessed intensity, knowing that the Nominal Operating Intensity remains far below the ASE limit.

Requirement The NIF segment will be operated within the following parameters:

Mode	Intensity	Energy
Full Operation	6.70e18 particles/hr	66 MeV

These parameters are further specified in the Operation Authorization Document.

NIF intensity is monitored via: L:CINT

Compensatory Measure(s) Alternative methods of monitoring intensity may be used.

Required Surveillance	none
Response	Beam operation to the NIF will be terminated. Beam operation to the NIF will not resume until approval is received from the AD Associate Lab Director and the DOE Field Element Manager.

400 MeV Test Area (MTA) Credited Controls

Passive – Shielding

Applicability During beam operations to the MTA segment of the Fermilab Main Accelerator.

Basis Based on the Nominal Operating Intensity of 2.70e15 protons/hr, supported by the following Shielding Assessments, the shielding is required in the locations listed below.

Shielding Assessment(s):

- Shielding Assessment Document for the MeV Test Area at the Fermilab Linac Endstation, August 24, 2020 [3]
- MTA Air Exchange Post-Assessment Memo [4]

Requirement Required shielding specified in the listed Shielding Assessments will be installed in its proper configuration during applicable beam operations.

The listed Shielding Assessment(s) utilized the incremental shielding assessment methodology, required shielding is summarized here.

Permanent Longitudinal Shielding

Cell or Longitudinal Range (ft)	Description	Current Shielding (efd)	Required (efd)
0-41	Main Linac enclosure	14.9	3.0
41-55	Linac high ceiling	13.3	3.0
55-103	Linac ramp	15.7	3.0
103-106	Beam stop alcove	18.1	9.6
106-115	Hatch	21.7	12.0
115-147	MTA upstream stub	10.4	9.6
147-187	MTA main hall	10.6	9.6
187-193	Pipe to absorber	19.0	9.6
193-203	Absorber in berm	21.7	9.6

Permanent Transverse Shielding

Cell or Transverse Station (ft)	Description	Current Shielding (efd)	Required (efd)
15	C-Magnet	13.0	6.3
45	13-ft Ceiling	11.9	6.3
57	10-ft Ceiling	14.2	9.5
104	Beam Stop Alcove	18.1	9.5
110	Hatch Waveguide	21.7	9.5
110	Hatch Waveguide	21.7	9.5

112	Hatch Waveguide	21.7	9.5
115	Hatch Waveguide	21.7	9.5
135	MTA Stub	10.4	9.5
157	MTA Exp Hall	10.2	9.5
167	MTA Rollup Door	15.0	9.5

Movable Shielding

Location	Shielding Type	Quantity	Purpose	Preferred Method of Configuration (if specified)	Comments
Hatch	Sand	Many sandbags	201 MHz 9-inch coaxial transm. line	Sign & chain	
Hatch	Sand	Many sandbags	805 MHz waveguide 10x5 in.	Sign & chains	
Hatch	Sand	Many sandbags	Cable tray 18x18 in., to Linac gallery	Sign & chain	
Fridge bldg.	Concrete	Many blocks	1.9-ft. shield wall & cage		Shadows multiple 1-leg cryo & cable penetrations
MTA Berm	Sand and Poly	15' sand, 3' poly	Required Shielding for sending beam to MTA	Lid is locked with chain	

Penetration Shielding

Location	Shielding Type	Quantity	Purpose	Preferred Method of Configuration (if specified)	Comments
Hatch	Concrete	Many blocks fill tunnel	Shield wall between Linac and Mucool	Signs and chains	Contains multiple penetrations
Hatch	Sand	Fills annulus	Beam pipe penetration		
Gas manifold room	Poly Beads	29 ft long	Three 3-in. penetrations		Gas lines & cables
Ceiling	Poly Beads	Voids filled	20-in. vent penetration		8.5-in. hydrogen vent &

					multiple relief lines
Fridge bldg.	Poly Beads	Annulus filled	10-in. cryo penetration	Chain	6.5-in. cryo transfer line
Fridge bldg.	Poly Beads	Annulus filled	8-in. cryo penetration	Chain	4-in. cooldown line
Fridge bldg.	Solid Poly	Multiple rods	Four 4-in. penetrations	Chain	Cables & pipes
MTA penetrations to fridge room	Sand and Poly	20' sand, 3' poly	Required Shielding for sending beam to MTA	Locked in place with grate and chain	6 total penetrations

Compensatory Measure(s) In lieu of required shielding, temporary controls, such as guards, fencing, ropes, and/or postings, may be utilized as approved by the SRSO. Each use of a Compensatory Measure shall be documented using the USI Process.

Required Surveillance Required shielding shall be verified annually, not to exceed twelve (12) months.

Response Beam operation to the MTA will be terminated. Beam operation to the MTA will not resume until approval is received from the AD Associate Lab Director and the DOE Field Element Manager.

Passive – Fencing

Applicability During beam operations to the MTA segment of the Fermilab Main Accelerator.

Basis Based on the Nominal Operating Intensity of 2.70e15 protons/hr, supported by the following Shielding Assessments, the shielding is required in the locations listed below.

Shielding Assessment(s):
- Shielding Assessment Document for the MeV Test Area at the Fermilab Linac Endstation, August 24, 2020 [3]
- MTA Air Exchange Post-Assessment Memo [4]

Requirement Required fencing specified in the listed Shielding Assessments will be installed in its proper configuration during applicable beam operations.

Radiation Area Fencing

Fence Location	Required Posting	Gates (if applicable)	Configuration
Linac running north to south along parking lot	Radiation Area	LINVA1	• 4 ft height • Standing upright

			between 60-120° • No missing or bent pieces creating a person-sized hole (~1ft^2) Gates locked with Rad Fence Padlock
Linac running around MTA enclosure next to parking lot	Radiation Area	LINVA 2	• 4 ft height • Standing upright between 60-120° • No missing or bent pieces creating a person-sized hole (~1ft^2) • Gates locked with Rad Fence Padlock
Linac southend between MTA gas shed and Booster Gallery	Radiation Area	MTAPA2	• 4 ft height • Standing upright between 60-120° • No missing or bent pieces creating a person-sized hole (~1ft^2) • Gates locked with Rad Fence Padlock

Controlled Area Fencing

Fence Location	Required Posting	Gates (if applicable)	Configuration
MTA pit between MTA enclosure and MTA gas shed	Controlled Area	MTAPA1	• 4 ft height • Standing upright between 60-120° • No missing or bent pieces creating a person-sized hole (~1ft^2)

Compensatory Measure(s) In lieu of required fencing, temporary controls, such as guards, ropes, and/or postings, may be utilized as approved by the SRSO. Each use of a Compensatory Measure shall be documented using the USI Process.

Required Surveillance Required fencing shall be verified annually, not to exceed twelve (12) months.

Response Beam operation to the MTA will be terminated. Beam operation to the MTA will not resume until approval is received from the AD Associate Lab Director and the DOE Field Element Manager.

Active Engineered – Radiation Safety Interlock System (RSIS)

Applicability During beam operations to the MTA segment of the Fermilab Main Accelerator.

Basis Based on the Nominal Operating Intensity of 2.70e15 protons/hr, supported by the following Shielding Assessments, the RSIS is established with interlocked barriers around the Exclusion Area, as well as inclusion of required interlocked radiation monitors.

Shielding Assessment(s):
- Shielding Assessment Document for the MeV Test Area at the Fermilab Linac Endstation, August 24, 2020 [3]
- MTA Air Exchange Post-Assessment Memo [4]

Requirement The Radiation Safety Interlock System (RSIS) must prevent entry into the following Exclusion Area(s) during appliable beam operation:

- MTA

Required components of the RSIS shall be specified in the MTA's Operation Authorization Document.

The following components of the Radiation Safety Interlock System (RSIS) shall be in place, with no known loss of safety function, during applicable beam operations.

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	MTA Berm

Compensatory Measure(s) In lieu of required interlocked detectors, temporary controls, such as guards, fencing, ropes, and/or postings, may be utilized as approved by the SRSO. Each use of a Compensatory Measure shall be documented using the USI Process.

Required Surveillance The RSIS for the MTA segment shall undergo certification annually, not to exceed twelve (12) months.

Response Beam operation to the MTA will be terminated. Beam operation to the MTA will not resume until approval is received from the AD Associate Lab Director and the DOE Field Element Manager.

Active Engineered – Oxygen Deficiency Hazard (ODH) Safety System

Applicability During personnel access into the MTA

Basis Based on the ODH Analysis, the ODH Safety System is established with specified required components.

Requirement The following components of the Oxygen Deficiency Hazard (ODH) Safety System shall be in place, with no known loss of safety function, during personnel access into applicable areas.

- None (Administratively classified at ODH1, but is true ODH0)

Compensatory Measure(s) Temporary updated ODH postings and associated requirements and/or restrictions may be implemented following a component failure to allow reentry to fix failed

components based on either: (1) an existing and approved out-of-service policy, or (2) an updated ODH analysis approved by the Cryogenic Safety Subcommittee (CSS).

Required Surveillance
- N/A

Response N/A.

Administrative – Operation Authorization Document

Applicability During beam operations to the MTA segment of the Fermilab Main Accelerator.

Basis To summarize the bounding conditions for safe operation of the MTA, and to provide explicit approval for operations of the MTA.

Requirement An approved MTA Beam Permit & Running Condition shall be issued prior to MTA beam operations.

Compensatory Measure(s) none

Required Surveillance The MTA Beam Permit and Running Condition shall be verified annually, not to exceed twelve (12) months.

Response Beam operation to the MTA will be terminated. Beam operation to the MTA will not resume until approval is received from the AD Associate Lab Director and the DOE Field Element Manager.

Administrative – Staffing

Applicability During beam operations to the MTA segment of the Fermilab Main Accelerator.

Basis To ensure operations within bounding conditions specified in Operation Authorization Document, and to disable beam operation to the MTA and initiate an immediate response in the event of a determined ASE violation.

Requirement The following staffing shall be in place during applicable beam operation:
- At least one member of the AD Operations Department who has achieved the rank of Operator II or higher shall be on shift.
- At least one member of the AD Operations Department shall be present in the Main Control Room (MCR).

Compensatory Measure(s) none

Required Surveillance none

Response Beam operation to the MTA will be terminated. Beam operation to the MTA will not resume until approval is received from the AD Associate Lab Director and the DOE Field Element Manager.

Administrative – Accelerator Operating Parameters

Applicability During beam operations to the MTA segment of the Fermilab Main Accelerator.

Basis The MeV Test Area (MTA) Longitudinal, Transverse, and Labyrinths and Penetrations spreadsheets were scaled to find the weakest point in the MTA shielding.
Longitudinal spreadsheet criterion 3 locations, when changed to 4, along with criterion 8 locations, when changed to 9, fail at 3.47 x 10^{16} protons/hour.
Transverse spreadsheet criterion 3 locations, when changed to 4, along with criterion 7 locations, when changed to 9, fail at 3.03 x 10^{16} protons/hour.
Labyrinths and Penetrations spreadsheet criteria 1-3 locations, when changed to criterion 4, fail at 2.11 x 10^{16} protons/hour.
Labyrinths and Penetrations are the limiting case, so the MTA ASE limit is 2.11 x 10^{16} protons/hour.

Requirement The MTA segment will be operated within the following parameters:

Mode	Intensity	Energy
Beam to MTA Experimental Hall and Beamline Stub	2.11e16 protons/hr	400 MeV

These parameters are further specified in the Operation Authorization Document.

MTA intensity is monitored via: E:UTR101

Compensatory Measure(s) Alternative methods of monitoring intensity may be used.

Required Surveillance none

Response Beam operation to the MTA will be terminated. Beam operation to the MTA will not resume until approval is received from the AD Associate Lab Director and the DOE Field Element Manager.

Booster Credited Controls

Passive – Shielding

Applicability	During beam operations to the Booster segment of the Fermilab Main Accelerator.
Basis	Based on the Nominal Operating Intensity of 2.70e17 protons/hr, supported by the following Shielding Assessments, the shielding is required in the locations listed below. Shielding Assessment(s): • 2017 Booster Shielding Assessment [5]
Requirement	Required shielding specified in the listed Shielding Assessments will be installed in its proper configuration during applicable beam operations. The listed Shielding Assessment(s) utilized the more current Monte Carlo simulation methodology, required shielding is found in the listed Shielding Assessment(s).
Compensatory Measure(s)	In lieu of required shielding, temporary controls, such as guards, fencing, ropes, and/or postings, may be utilized as approved by the SRSO. Each use of a Compensatory Measure shall be documented using the USI Process.
Required Surveillance	Required shielding shall be verified annually, not to exceed twelve (12) months.
Response	Beam operation to the Booster will be terminated. Beam operation to the Booster will not resume until approval is received from the AD Associate Lab Director and the DOE Field Element Manager.

Passive – Fencing

Applicability	During beam operations to the Booster segment of the Fermilab Main Accelerator.
Basis	Based on the Nominal Operating Intensity of 2.70e17 protons/hr, supported by the following Shielding Assessments, the shielding is required in the locations listed below. Shielding Assessment(s): • 2017 Booster Shielding Assessment [5]
Requirement	Required fencing specified in the listed Shielding Assessments will be installed in its proper configuration during applicable beam operations. <u>Radiation Area Fencing</u> none <u>Controlled Area Fencing</u> none

However, Controlled Area postings are required in the following locations:

Posting Location	Required Posting	Gates (if applicable)	Configuration
Stanchions or postings as able. Period 1 to Booster road	Controlled Area	NA	Stanchion, buildings or equipment posted
Road over enclosure posted	Controlled Area	NA	Stanchions posted
Stanchions or postings as able, booster road to Period 12	Controlled Area	NA	Stanchion, buildings or equipment posted
Booster road to Cross gallery parking over enclosure	Controlled Area	NA	Stanchions posted

Compensatory Measure(s) In lieu of required fencing, temporary controls, such as guards, ropes, and/or postings, may be utilized as approved by the SRSO. Each use of a Compensatory Measure shall be documented using the USI Process.

Required Surveillance Required fencing shall be verified annually, not to exceed twelve (12) months.

Response Beam operation to the Booster will be terminated. Beam operation to the Booster will not resume until approval is received from the AD Associate Lab Director and the DOE Field Element Manager.

Active Engineered – Radiation Safety Interlock System (RSIS)

Applicability During beam operations to the Booster segment of the Fermilab Main Accelerator.

Basis Based on the Nominal Operating Intensity of 2.70e17 protons/hr, supported by the following Shielding Assessments, the RSIS is established with interlocked barriers around the Exclusion Area, as well as inclusion of required interlocked radiation monitors.

Shielding Assessment(s):
- 2017 Booster Shielding Assessment [5]

Requirement The Radiation Safety Interlock System (RSIS) must prevent entry into the following Exclusion Area(s) during appliable beam operation:

- Booster
- 8 GeV Line

Required components of the RSIS shall be specified in the Booster's Operation Authorization Document.

The following components of the Radiation Safety Interlock System (RSIS) shall be in place, with no known loss of safety function, during applicable beam operations.

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	Booster East Fan Room (Short 12)
Chipmunk	Booster Crossover at CUB (Short 19)
Chipmunk	Booster/Line W Gal Intersect (Long 22)
Chipmunk	Booster Per 1 Exit Stairwell (Short 1)
Chipmunk	MI-8 Line in WBT (12' US of Buttress)
Chipmunk	MI-8 Line on Berm (WBT)
TLM	BSTR TLM1 Per 23, 24, 1
TLM	BSTR TLM2 Per 2, 3, 4
TLM	BSTR TLM3 Per 5, 6
TLM	BSTR TLM4 Per 8, 9, 10
TLM	BSTR TLM5 Per 11, 12, 13
TLM	BSTR TLM6 Per 14, 15, 16
TLM	BSTR TLM7 Per 17, 18, 19
TLM	BSTR TLM8 Per 20, 21, 22
TLM	BSTR TLM3a Per 6, 7

Compensatory Measure(s) In lieu of required interlocked detectors, temporary controls, such as guards, fencing, ropes, and/or postings, may be utilized as approved by the SRSO. Each use of a Compensatory Measure shall be documented using the USI Process.

Required Surveillance The RSIS for the Booster segment shall undergo certification annually, not to exceed twelve (12) months.

Response Beam operation to the Booster will be terminated. Beam operation to the Booster will not resume until approval is received from the AD Associate Lab Director and the DOE Field Element Manager.

Active Engineered – Oxygen Deficiency Hazard (ODH) Safety System

Applicability Not applicable

Basis Not applicable

Requirement	none
Compensatory Measure(s)	Not applicable
Required Surveillance	none
Response	none

Administrative – Operation Authorization Document

Applicability	During beam operations to the Booster segment of the Fermilab Main Accelerator.
Basis	To summarize the bounding conditions for safe operation of the Booster, and to provide explicit approval for operations of the Booster.
Requirement	An approved Booster Beam Permit & Running Condition shall be issued prior to Booster beam operations.
Compensatory Measure(s)	none
Required Surveillance	The Booster Beam Permit and Running Condition shall be verified annually, not to exceed twelve (12) months.
Response	Beam operation to the Booster will be terminated. Beam operation to the Booster will not resume until approval is received from the AD Associate Lab Director and the DOE Field Element Manager.

Administrative – Staffing

Applicability	During beam operations to the Booster segment of the Fermilab Main Accelerator.
Basis	To ensure operations within bounding conditions specified in Operation Authorization Document, and to disable beam operation to the Booster and initiate an immediate response in the event of a determined ASE violation.
Requirement	The following staffing shall be in place during applicable beam operation: • At least one member of the AD Operations Department who has achieved the rank of Operator II or higher shall be on shift. • At least one member of the AD Operations Department shall be present in the Main Control Room (MCR).

Compensatory Measure(s) none

Required Surveillance none

Response Beam operation to the Booster will be terminated. Beam operation to the Booster will not resume until approval is received from the AD Associate Lab Director and the DOE Field Element Manager.

Administrative – Accelerator Operating Parameters

Applicability During beam operations to the Booster segment of the Fermilab Main Accelerator.

Basis Booster operating limits are defined by an array of Chipmunks and Total Loss Monitors (TLMs) distributed around the ring. These detectors are set to trip at values equivalent to 5 mrem on the surface. Using scaling criteria 1, the trip point scaled to a 500 mrem accident condition results in a factor of 100. The current operating limit is 2.7×10^{17} protons/hour. Scaling up by 100 sets the Booster ASE limit to 2.7×10^{19} protons/hour.

Requirement The Booster segment will be operated within the following parameters:

Mode	Intensity	Energy
Booster Operation	2.7e19 protons/hr	8 GeV

These parameters are further specified in the Operation Authorization Document.

Booster intensity is monitored via: B:CHGBBM

Compensatory Measure(s) Alternative methods of monitoring intensity may be used.

Required Surveillance none

Response Beam operation to the Booster will be terminated. Beam operation to the Booster will not resume until approval is received from the AD Associate Lab Director and the DOE Field Element Manager.

8 GeV Beamline Credited Controls

Passive – Shielding

Applicability During beam operations to the 8 GeV Beamline segment of the Fermilab Main Accelerator.

Basis Based on the Nominal Operating Intensity of 2.84e17 protons/hr, supported by the following Shielding Assessments, the shielding is required in the locations listed below.

Shielding Assessment(s):

- 2002 Shielding Assessment Document for the 8 GeV Fixed Target Facility [6]
- 2010 Post-Assessment Memo "8 GeV Beamline & MiniBooNE Beamline NOvA-Era Operational Limits" [7]

Requirement Required shielding specified in the listed Shielding Assessments will be installed in its proper configuration during applicable beam operations.

The listed Shielding Assessment(s) utilized the incremental shielding assessment methodology, required shielding is summarized here.

Permanent Longitudinal Shielding

Cell or Longitudinal Range (ft)	Description	Current Shielding (efd)	Required (efd)
CB803-810	MI-8 w/buried steel	24.5	23
CB810-850	MI-8	24.5	23

Permanent Transverse Shielding

Cell or Transverse Station (ft)	Description	Current Shielding (efd)	Required (efd)
145	MI-8 enclosure 803	26.4	23.0
177	MI-8 enclosure 803	25.2	23.0
195	MI-8 enclosure 805	25.6	23.0
205	MI-8 enclosure 805	25.2	23.0
220	MI-8 enclosure 805	25.6	23.0
235	MI-8 enclosure 806	25.7	23.0
247	MI-8 enclosure 807	26.8	23.0
255	MI-8 807, near manholes	25.1	23.0
265	MI-8 enclosure 807	27.7	23.0
275	MI-8 enclosure 808	27.3	23.0
285	MI-8 enclosure 808	26.4	23.0
300	MI-8 enclosure 808	26.6	23.0
315	MI-8 enclosure 809	26.2	23.0
335	MI-8 enclosure 809	26.2	23.0

370	MI-8 enclosure 809	26.3	23.0
CB817+40	MI-8 enclosure 817	24.8	23.0
CB818+17	MI-8 enclosure 818	25.6	23.0
CB818+38	MI-8 enclosure 818	26	23.0
CB823	MI-8 823 intermediate alcove	25.8	23.0
CB827+12	MI-8 enclosure 827	24.5	23.0
CB827+34	MI-8 enclosure 827	24.5	23.0
CB828+10	MI-8 enclosure 828	24.6	23.0
CB842+10	MI-8 enclosure 843 exit	24.7	23.0
CB841+36	MI-8 enclosure 841	24.6	23.0
CB841+12	MI-8 enclosure 841	25	23.0
CB837	MI-8 enclosure 837 alcove	24.8	23.0
CB843	MI-8 843 intermediate alcove	26.2	23.0

Movable Shielding

Location	Shielding Type	Quantity	Purpose	Preferred Method of Configuration (if specified)	Comments
MI-817	Concrete	16 A- & 52 B-blocks; some hand-stack	Equipment hatch at MI-817	PAD-118 & MI-8 Enter locks	Steel is buried outside of hatch for additional shielding; see drawing
MI-812	Steel & Poly Beads	6.72' steel & 1.5' poly	Sight riser SP-1 at MI-812		
MI-816	Steel & Poly Beads	6.72' steel & 1.5' poly	Sight riser SP-2 at MI-816		
MI-833	Poly Beads	7.5' poly	Sight riser at MI-833		Sight riser from MC-1 line to MI-8 line. See 000130-MUC for top.
MI-833.5	Steel & Poly Beads	6.72' steel & 1.5' poly	Sight riser at MI-833.5		
MI-807	Concrete	24"x64" in corner of MH-14	Inside electrical manhole MH-14 near MI-807		

Penetration Shielding

none

Compensatory Measure(s)	In lieu of required shielding, temporary controls, such as guards, fencing, ropes, and/or postings, may be utilized as approved by the SRSO. Each use of a Compensatory Measure shall be documented using the USI Process.
Required Surveillance	Required shielding shall be verified annually, not to exceed twelve (12) months.
Response	Beam operation to the 8 GeV Beamline will be terminated. Beam operation to the 8 GeV Beamline will not resume until approval is received from the AD Associate Lab Director and the DOE Field Element Manager.

Passive – Fencing

Applicability	During beam operations to the 8 GeV Beamline segment of the Fermilab Main Accelerator.
Basis	Based on the Nominal Operating Intensity of 2.84e17 protons/hr, supported by the following Shielding Assessments, the shielding is required in the locations listed below. Shielding Assessment(s): • 2002 Shielding Assessment Document for the 8 GeV Fixed Target Facility [6] • 2010 Post-Assessment Memo "8 GeV Beamline & MiniBooNE Beamline NOvA-Era Operational Limits" [7]
Requirement	Required fencing specified in the listed Shielding Assessments will be installed in its proper configuration during applicable beam operations. <u>Radiation Area Fencing</u> none <u>Controlled Area Fencing</u> none
Compensatory Measure(s)	In lieu of required fencing, temporary controls, such as guards, ropes, and/or postings, may be utilized as approved by the SRSO. Each use of a Compensatory Measure shall be documented using the USI Process.
Required Surveillance	Required fencing shall be verified annually, not to exceed twelve (12) months.
Response	Beam operation to the 8 GeV Beamline will be terminated. Beam operation to the 8 GeV Beamline will not resume until approval is received from the AD Associate Lab Director and the DOE Field Element Manager.

Active Engineered – Radiation Safety Interlock System (RSIS)

Applicability During beam operations to the 8 GeV Beamline segment of the Fermilab Main Accelerator.

Basis Based on the Nominal Operating Intensity of 2.84e17 protons/hr, supported by the following Shielding Assessments, the RSIS is established with interlocked barriers around the Exclusion Area, as well as inclusion of required interlocked radiation monitors.

Shielding Assessment(s):
- 2002 Shielding Assessment Document for the 8 GeV Fixed Target Facility [6]
- 2010 Post-Assessment Memo "8 GeV Beamline & MiniBooNE Beamline NovA-Era Operational Limits" [7]

Requirement The Radiation Safety Interlock System (RSIS) must prevent entry into the following Exclusion Area(s) during appliable beam operation:
- MI-8
- MI-10
- Muon Campus Transport Mid
- MI-12A

Required components of the RSIS shall be specified in the 8 GeV Beamline's Operation Authorization Document.

The following components of the Radiation Safety Interlock System (RSIS) shall be in place, with no known loss of safety function, during applicable beam operations.

<u>Radiation Safety System – Interlocked Radiation Monitors</u>
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	Transport Mid/DS Gate
Chipmunk	Transport Mid/US Gate
Chipmunk	MI-8 Service Building Labyrinth Gate

Compensatory Measure(s) In lieu of required interlocked detectors, temporary controls, such as guards, fencing, ropes, and/or postings, may be utilized as approved by the SRSO. Each use of a Compensatory Measure shall be documented using the USI Process.

Required Surveillance	The RSIS for the 8 GeV Beamline segment shall undergo certification annually, not to exceed twelve (12) months.
Response	Beam operation to the 8 GeV Beamline will be terminated. Beam operation to the 8 GeV Beamline will not resume until approval is received from the AD Associate Lab Director and the DOE Field Element Manager.

Active Engineered – Oxygen Deficiency Hazard (ODH) Safety System

Applicability	Not applicable
Basis	Not applicable
Requirement	none
Compensatory Measure(s)	Not applicable
Required Surveillance	none
Response	none

Administrative – Operation Authorization Document

Applicability	During beam operations to the 8 GeV Beamline segment of the Fermilab Main Accelerator.
Basis	To summarize the bounding conditions for safe operation of the 8 GeV Beamline, and to provide explicit approval for operations of the 8 GeV Beamline.
Requirement	An approved 8 GeV Beamline Beam Permit & Running Condition shall be issued prior to 8 GeV beam operations.
Compensatory Measure(s)	none
Required Surveillance	The 8 GeV Beamline Beam Permit and Running Condition shall be verified annually, not to exceed twelve (12) months.
Response	Beam operation to the 8 GeV Beamline will be terminated. Beam operation to the 8 GeV Beamline will not resume until approval is received from the AD Associate Lab Director and the DOE Field Element Manager.

Administrative – Staffing

Applicability	During beam operations to the 8 GeV Beamline segment of the Fermilab Main Accelerator.
Basis	To ensure operations within bounding conditions specified in Operation Authorization Document, and to disable beam operations to the 8 GeV Beamline and initiate an immediate response in the event of a determined ASE violation.
Requirement	The following staffing shall be in place during applicable beam operation: • At least one member of the AD Operations Department who has achieved the rank of Operator II or higher shall be on shift. • At least one member of the AD Operations Department shall be present in the Main Control Room (MCR).
Compensatory Measure(s)	none
Required Surveillance	none
Response	Beam operation to the 8 GeV Beamline will be terminated. Beam operation to the 8 GeV Beamline will not resume until approval is received from the AD Associate Lab Director and the DOE Field Element Manager.

Administrative – Accelerator Operating Parameters

Applicability	During beam operations to the 8 GeV Beamline segment of the Fermilab Main Accelerator.
Basis	Longitudinal and Transverse spreadsheets were scaled using criteria 2 and 3 to find the weakest point in the shielding. Transverse spreadsheet category 1-3 areas changed to 4 fail at 2.35×10^{19} protons/hour. Longitudinal spreadsheet category 1-3 areas changed to 4 fail at 6.5×10^{19} protons/hour. Transverse spreadsheet is the limiting area, so the ASE limit is 2.35×10^{19} protons/hour.
Requirement	The 8 GeV Beamline segment will be operated within the following parameters:

Mode	Intensity	Energy
Beam transport from Cell 803 to Cell 850	2.35e19 protons/hr	8 GeV

These parameters are further specified in the Operation Authorization Document.

8 GeV Beamline intensity is monitored via: B:BBM800

Compensatory Measure(s) Alternative methods of monitoring intensity may be used.

Required Surveillance none

Response Beam operation to the 8 GeV Beamline will be terminated. Beam operation to the 8 GeV Beamline will not resume until approval is received from the AD Associate Lab Director and the DOE Field Element Manager.

Booster Neutrino Beam (BNB) Credited Controls

Passive – Shielding

Applicability During beam operations to the BNB segment of the Fermilab Main Accelerator.

Basis Based on the Nominal Operating Intensity of 1.62e17 protons/hr, supported by the following Shielding Assessments, the shielding is required in the locations listed below.

Shielding Assessment(s):

- 2002 Shielding Assessment Document for the 8 GeV Fixed Target Facility [8]
- 2004 Addendum to the MiniBooNE Target Station [9]
- 2010 Post-Assessment Memo "8 GeV Beamline & MiniBooNE Beamline NovA-Era Operational Limits" [7]

Requirement Required shielding specified in the listed Shielding Assessments will be installed in its proper configuration during applicable beam operations.

The listed Shielding Assessment(s) utilized the incremental shielding assessment methodology, required shielding is summarized here.

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

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

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

Compensatory Measure(s) In lieu of required shielding, temporary controls, such as guards, fencing, ropes, and/or postings, may be utilized as approved by the SRSO. Each use of a Compensatory Measure shall be documented using the USI Process.

Required Surveillance Required shielding shall be verified annually, not to exceed twelve (12) months.

Response Beam operation to the BNB will be terminated. Beam operation to the BNB will not resume until approval is received from the AD Associate Lab Director and the DOE Field Element Manager.

Passive – Fencing

Applicability During beam operations to the BNB segment of the Fermilab Main Accelerator.

Basis Based on the Nominal Operating Intensity of 1.62e17 protons/hr, supported by the following Shielding Assessments, the shielding is required in the locations listed below.

Shielding Assessment(s):

- 2002 Shielding Assessment Document for the 8 GeV Fixed Target Facility [8]
- 2004 Addendum to the MiniBooNE Target Station [9]
- 2010 Post-Assessment Memo "8 GeV Beamline & MiniBooNE Beamline NovA-Era Operational Limits" [7]

Requirement Required fencing specified in the listed Shielding Assessments will be installed in its proper configuration during applicable beam operations.

Radiation Area Fencing
none

Controlled Area Fencing
none

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

Compensatory Measure(s)	In lieu of required fencing, temporary controls, such as guards, ropes, and/or postings, may be utilized as approved by the SRSO. Each use of a Compensatory Measure shall be documented using the USI Process.
Required Surveillance	Required fencing shall be verified annually, not to exceed twelve (12) months.
Response	Beam operation to the BNB will be terminated. Beam operation to the BNB will not resume until approval is received from the AD Associate Lab Director and the DOE Field Element Manager.

Active Engineered – Radiation Safety Interlock System (RSIS)

Applicability During beam operations to the BNB segment of the Fermilab Main Accelerator.

Basis Based on the Nominal Operating Intensity of 1.62e17 protons/hr, supported by the following Shielding Assessments, the RSIS is established with interlocked barriers around the Exclusion Area, as well as inclusion of required interlocked radiation monitors.

Shielding Assessment(s):
- 2002 Shielding Assessment Document for the 8 GeV Fixed Target Facility [8]
- 2004 Addendum to the MiniBooNE Target Station [9]
- 2010 Post-Assessment Memo "8 GeV Beamline & MiniBooNE Beamline NovA-Era Operational Limits" [7]

Requirement The Radiation Safety Interlock System (RSIS) must prevent entry into the following Exclusion Area(s) during appliable beam operation:
- MI-12A
- MI-12B
- MI-13

Required components of the RSIS shall be specified in the BNB's Operation Authorization Document.

The following components of the Radiation Safety Interlock System (RSIS) shall be in place, with no known loss of safety function, during applicable beam operations.

<u>Radiation Safety System – Interlocked Radiation Monitors</u>

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

Compensatory Measure(s) In lieu of required interlocked detectors, temporary controls, such as guards, fencing, ropes, and/or postings, may be utilized as approved by the SRSO. Each use of a Compensatory Measure shall be documented using the USI Process.

Required Surveillance The RSIS for the BNB segment shall undergo certification annually, not to exceed twelve (12) months.

Response Beam operation to the BNB will be terminated. Beam operation to the BNB will not resume until approval is received from the AD Associate Lab Director and the DOE Field Element Manager.

Active Engineered – Oxygen Deficiency Hazard (ODH) Safety System

Applicability Not applicable

Basis Not applicable

Requirement none

Compensatory Measure(s) Not applicable

Required Surveillance none

Response none

Administrative – Operation Authorization Document

Applicability During beam operations to the BNB segment of the Fermilab Main Accelerator.

Basis To summarize the bounding conditions for safe operation of the BNB, and to provide explicit approval for operations of the BNB.

Requirement	An approved BNB Beam Permit & Running Condition shall be issued prior to BNB beam operations.
Compensatory Measure(s)	none
Required Surveillance	The BNB Beam Permit and Running Condition shall be verified annually, not to exceed twelve (12) months.
Response	Beam operation to the BNB will be terminated. Beam operation to the BNB will not resume until approval is received from the AD Associate Lab Director and the DOE Field Element Manager.

Administrative – Staffing

Applicability	During beam operations to the BNB segment of the Fermilab Main Accelerator.
Basis	To ensure operations within bounding conditions specified in Operation Authorization Document, and to disable beam operation to the BNB and initiate an immediate response in the event of a determined ASE violation.
Requirement	The following staffing shall be in place during applicable beam operation: • At least one member of the AD Operations Department who has achieved the rank of Operator II or higher shall be on shift. • At least one member of the AD Operations Department shall be present in the Main Control Room (MCR).
Compensatory Measure(s)	none
Required Surveillance	none
Response	Beam operation to the BNB will be terminated. Beam operation to the BNB will not resume until approval is received from the AD Associate Lab Director and the DOE Field Element Manager.

Administrative – Accelerator Operating Parameters

Applicability	During beam operations to the BNB segment of the Fermilab Main Accelerator.

Basis

Longitudinal, Transverse, and Labyrinth and Penetration spreadsheets were scaled using criteria 2 and 3 to find the weakest point in the shielding. MARS simulations were scaled using criteria 4.
Transverse spreadsheet category 1-3 areas changed to category 4 fail at 1.59×10^{20} protons/hour.
Longitudinal spreadsheet category 1-3 areas changed to category 4 fail at 4.59×10^{19} protons/hour.
Labyrinth and Penetration spreadsheet category 1-3 areas changed to category 4 fail at 6.75×10^{20} protons/hour.
MARS simulations for Target areas are less than 5 mrem/hour with 9×10^{16} protons on target/hour. Scaling 5 mrem to 500 mrem is a factor of 100. The MARS simulations fail at $9 \times 10^{16} * 100 = 9 \times {}^{18}$ protons/hour.
The MARS simulations are the limiting area, so the ASE limit is $9 \times {}^{18}$ protons/hour.

Requirement

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

These parameters are further specified in the Operation Authorization Document.

BNB intensity is monitored via: E:TOR860

Compensatory Measure(s)

Alternative methods of monitoring intensity may be used.

Required Surveillance

none

Response

Beam operation to the BNB will be terminated. Beam operation to the BNB will not resume until approval is received from the AD Associate Lab Director and the DOE Field Element Manager.

Main Injector (MI) Credited Controls

Passive – Shielding

Applicability During beam operations to the Main Injector segment of the Fermilab Main Accelerator.

Basis Based on the Nominal Operating Intensities of 2.93e17 protons/hr at 8 GeV and 120 GeV and 2.34e17 protons/hr at 150 GeV, supported by the following Shielding Assessments, the shielding is required in the locations listed below.

Shielding Assessment(s):

- 2012 Recycler Ring Incremental Shielding Assessment 2.25e17 protons/hr [10]
- 2018 Main Injector 1500kW Incremental Shielding Assessment [11]

Requirement Required shielding specified in the listed Shielding Assessments will be installed in its proper configuration during applicable beam operations.

The listed Shielding Assessment(s) utilized the incremental shielding assessment methodology, required shielding is summarized here.

Permanent Longitudinal Shielding

Cell or Longitudinal Range (ft)	Description	Current Shielding (efd)	Required (efd)
10836 - 003	8 GeV transition, Cell 100	25.4	20.7
003 - 073	Tunnel, Cells 101-102	25.2	20.7
073 - 116	MI-10 alcove, Cell 102	25.2	20.7
116 - 300	MI-14, Cells 104-107	25.1	20.7
300 - 897	Tunnel, Cells 107-118	24.9	20.7
500	Culvert, Cell 111	23.8	20.7
898-926	Intermediate alcove, Cell 118	25.0	20.7
1255	Culvert, Cell 124	24.1	20.7
897 - 1655	Tunnel, Cells 118-201	25.1	20.7
1655 - 1705	MI-20 alcove, Cell 201	25.6	20.7
1705 - 2572	Tunnel, Cells 201-217	24.6	20.7
2572 - 2599	Intermediate Culvert, Cell 218	25.0	20.7
2599 - 3506	Tunnel, Cells 219-305	24.6	20.7
3506 - 3590	MI-30 alcove, Cell 305	24.2	20.7
3590 - 4591	Tunnel, Cells 306-326	24.1	20.7

4591 - 4610	Intermediate alcove, Cell 327	24.5	20.7
4610 - 4860	Tunnel, Cells 328-331	24.1	20.7
4860 - 4893	Culvert, Cell 332	27.2	20.7
4893 - 5450	Tunnel, Cells 333-401	24.1	20.7
5450 - 5550	MI-39, Cells 401-403	25.5	20.7
5550 - 5720	MI-40 alcove, Cells 403-406	24.6	20.7
5720 - 5839	Tunnel, Cells 406.5-409	25.0	20.7
5839 - 5868	Intermediate alcove, Cell 409	24.7	20.7
5868 - 7071	Tunnel, Cells 409-501	24.8	20.7
6342 - 6370	Intermediate alcove, Cell 418	24.2	20.7
6668 - 6694	Culvert, Cell 424	23.9	20.7
7071 - 7129	MI-50 alcove, Cell 501	24.6	20.7
7129 - 7950	Tunnel, Cells 501-516	24.4	20.7
7950 - 8102	Tunnel, Cells 516-520	24.2	20.7
8102 - 8144	MI-52 alcove, Cell 520	24.7	20.7
8144 - 8283	Tunnel, Cells 520-523	24.5	20.7
8283 - 8325	Tunnel, Cells 523-524	24.5	20.7
8325-8386	Tunnel, Cells 524-525.5	24.4	20.7
8386 - 8496	Tunnel, Cells 525.5-527.5	24.3	20.7
8496 - 8563	Tunnel, Cells 527.5-529	25.2	20.7
8563 - 8571	Exit stairs, Cell 529	27.5	20.7
8571 - 8696	Tunnel, Cells 529-532	27.2	20.7
8687 - 8695	Exit stairs, Cell 532	26.7	20.7
8696 - 8766	Tunnel, Cells 532-601.5	28.0	20.7
8766 - 9262	Tunnel, Cells 601.5-610.5	26.7	20.7
9231 - 9239	Exit stairs, Cell 610	28.6	20.7
9262 - 9340	Tunnel, Cells 610.5-612.5	25.6	20.7
9340 - 9348	Exit stairs, Cell 612.5	26.3	20.7
9348 - 9389	Tunnel, Cells 612.5-613.5	25.0	20.7

9389 - 9419	Tunnel, Cells 613.5-614	25.2	20.7
9419 - 9476	Tunnel, Cells 614-615	25.5	20.7
9476 - 9567	Tunnel, Cells 615-617	25.1	20.7
9567 - 9604	Tunnel, Cells 617-618	25.3	20.7
9604 - 9647	Tunnel, Cells 618-619	25.5	20.7
9647 - 9792	Tunnel, Cells 619-621.5	25.5	20.7
9792 - 9910	Tunnel, Cells 621.5-624	24.4	20.7
9892 - 9900	Exit stairs, Cell 624	24.8	20.7
9910 - 10745	Tunnel, Cells 624-640	25.1	20.7
10483	Culvert, Cell 634	24.1	20.7
10745 - 10836	8 GeV transition, Cells 640-100	25.1	20.7
10837	Culvert, Cell 100	23.4	20.7
5514 - 5550	**Abort** Tunnel, Cell 402	25.5	20.7
5550 - 5628	**Abort** Alcove, Cells 402-403	24.6	20.7
5628 - 5734	**Abort** Stub, Cells 404-406	24.6	20.7
5734 - 5827	**Abort** Pipe, Cells 406-408	31.5	23.1
5827 - 5877	**Abort** Enclosure, Cells 408-409	24.7	20.7

Permanent Transverse Shielding

Cell or Transverse Station (ft)	Description	Current Shielding (efd)	Required (efd)
10	Tunnel US of MI-14, Cell 100	24.8	20.7
90	MI-10 Stair, Cell 102	26.1	20.7
110	MI-10, Cell 103	24.7	20.7
143	Near MI-12A Stair, Cell 103	25.0	20.7
185	MI-14, Cell 104	25.3	20.7
200	MI-14, Cell 105	25.2	20.7
220	MI-14, Cell 105	25.0	20.7
265	MI-14, Cell 106	25.2	20.7
285	MI-14, Cell 106	25.0	20.7
315	MI-14 Driveway, Cell 107	24.9	20.7

435	Culvert, Cell 109	24.9	20.7
500	Culvert, Cell 110	23.4	20.7
560	Culvert, Cell 111	25.4	20.7
740	Stair Exit, Cell 115	25.2	20.7
825	Typical Sight Riser, Cell 116	24.8	20.7
855	Culvert, Cell 117	23.0	20.7
908	Intermediate Alcove, Cell 118	25.3	20.7
1211	Culvert, Cell 123	25.4	20.7
1236	Culvert, Cell 123	24.8	20.7
1256	CulvertCell 124	27.6	20.7
1300	Stair Exit, Cell 124	25.2	20.7
1643	MI-20 Stair, Cell 130	26.0	20.7
1995	Stair Exit, Cell 207	25.3	20.7
2445	Stair Exit, Cell 214	25.2	20.7
2585	Exhaust Air Fan, Cell 217	25.1	20.7
2965	Stair Exit, Cell 225	25.0	20.7
3075	Culvert, Cell 228	22.8	20.7
3520	MI-30 Stair, Cell 305	26.2	20.7
3577	MI-31 Tunnel, Cell 306	24.6	20.7
3612	MI-31 Stub, Cell 306	25.6	20.7
3650	MI-31, Cell 307	25.5	20.7
3980	Stair Exit, Cell 314	25.0	20.7
4075	Culvert, Stair Exit, Cell 316	23.0	20.7
4500	Stair Exit, Cell 324	24.9	20.7
4600	Exhaust Air Fan, Cell 327	25.0	20.7
4875	Culvert, Cell 331	27.4	20.7
5050	Stair Exit, Cell 334	25.0	20.7
5470	Tunnel US of MI-39, Cell 401	25.7	20.7
5480	MI-39, Cell 401	24.0	20.7
5500	MI-39, Cell 402	25.6	20.7
5525	MI-39, Cell 402	25.9	20.7
5545	MI-39, Cell 403	25.8	20.7
5615	MI-40, Cell 403	25.6	20.7
5707	MI-40 Alcove, Cell 406	25.0	20.7
5733	MI-40 Alcove, Cell 406	25.0	20.7
5800	MI near Abort Pipe, Cell 408	25.0	20.7

5834	Abort Enclosure, Cell 409	25.0	20.7
5850	Abort Enclosure, Cell 409	25.5	20.7
5862	Abort Enclosure, Cell 409	25.7	20.7
5876	Abort Enclosure, Cell 409	24.6	20.7
6072	Stair Exit, Cell 413	25.0	20.7
6352	Exhaust Air Fan, Cell 418	24.9	20.7
6527	Stair Exit, Cell 421	24.5	20.7
6690	Culvert, Cell 424	23.6	20.7
6902	Culvert, Cell 427	24.0	20.7
6936	Whittaker Road, Cell 428	25.4	20.7
6970	CulvertCell 428	23.8	20.7
7093	MI-50 walkway, Cell 501	24.2	20.7
7185	Culvert, Cell 502	23.8	20.7
7550	Stair Exit, Cell 509	25.6	20.7
7905	Enclosure under Road, Cell 515	25.3	20.7
8000	Enclosure under Road, Cell 517	25.1	20.7
8050	Retaining Wall, Cell 518	25.6	20.7
8115	MI-52 Stair, Cell 520	27.9	20.7
8287	P150 Transition, Cell 523	25.3	20.7
8313	P150 Transition, Cell 524	24.6	20.7
8400	P150 Transition, Cell 525	24.3	20.7
8450	MI at P150 Transition, Cell 526	25.0	20.7
8475	MI at P150 Transition, Cell 527	25.3	20.7
8569	Stair Exit, Cell 529	23.5	20.7
8690	Stair Exit, Cell 531	26.8	20.7
8690	MI Enclosure, Cell 531	22.4	20.7
8703	MI Enclosure, Cell 532	27.4	20.7
8715	MI Enclosure, Cell 532	28.0	20.7
8735	MI Enclosure, Cell 532	27.8	20.7
8752	MI Enclosure, Cell 601	28.0	20.7
8769	MI Enclosure, Cell 601	26.5	20.7
8782	MI Enclosure, Cell 601	26.5	20.7

8792	MI Enclosure, Cell 601	26.5	20.7
8801	MI Enclosure, Cell 602	26.1	20.7
8811	MI Enclosure, Cell 602	26.5	20.7
8838	MI Enclosure, Cell 602	26.5	20.7
8863	MI Enclosure, Cell 603	26.3	20.7
8875	MI Enclosure, Cell 603	26.4	20.7
8912	MI Enclosure, Cell 604	26.4	20.7
8934	MI Enclosure, Cell 604	26.6	20.7
8967	MI Enclosure, Cell 605	26.6	20.7
8974	MI Enclosure, Cell 605	26.7	20.7
8985	MI Enclosure, Cell 605	26.6	20.7
9004	MI Enclosure, Cell 605	26.5	20.7
9010	MI Enclosure, Cell 606	26.5	20.7
9023	MI Enclosure, Cell 606	26.6	20.7
9041	MI Enclosure, Cell 606	26.5	20.7
9060	MI Enclosure, Cell 606	26.5	20.7
9131	MI Enclosure, Cell 608	26.4	20.7
9214	MI Enclosure, Cell 609	27.0	20.7
9243	MI-60 stairs Q609, Cell 611	21.6	20.7
9350	Stair Exit Q612, Cell 612	21.8	20.7
9495	MI on left, Cell 615	27.1	20.7
9629	Alongside NUMI Stub, Cell 618	28.3	20.7
9832	MI-62 stairs, Cell 622	24.5	20.7
9890	MI-62 overpass, Cell 623	24.1	20.7
10016	Culvert, Cell 626	23.4	20.7
10388	Stair Exit, Cell 633	25.9	20.7
10484	Culvert, Cell 643	24.2	20.7
10600	8GeV Tunnel, MI beam, Cell 636	24.5	20.7
10752	8GeV Merge, MI beam, Cell 640	25.4	20.7
10795	Stair Exit, MI beam, Cell 641	25.5	20.7
10837	Culvert, MI beam, Cell 100	23.4	20.7
5707	Abort Stub, Abort line, Cell 406	25.0	20.7
5733	Abort Stub, Abort line, Cell 406	25.0	20.7
5800	Abort Buried pipe, Cell 407	32.1	23.1

5834	Abort Enclosure, Cell 408	32.1	20.7
5850	Abort Enclosure, Cell 408	37.9	20.7
5862	Abort Enclosure, Cell 409	38.9	20.7
5876	Abort Enclosure, Cell 409	32.5	20.7

Movable Shielding

Location	Shielding Type	Quantity	Purpose	Preferred Method of Configuration (if specified)	Comments
MI-10 SB	Solid Poly & Poly Beads	6" thick solid poly box filled >24" deep with poly beads	Bus penetrations from SB crossover to tunnel alcove	Surrounded by aluminum enclosure	See PPH3-AIP08
MI-10 SB	Poly Beads	> 4' depth	Fill annulus between four 12" dia. carrier penetrations and LCW pipes		See PPH3-AIP09
MI-20 SB	Poly Beads	> 4' depth	Fill annulus between four 12" dia. carrier penetrations and LCW pipes	labels	See PPH3-AIP10
MI-20 SB	Solid Poly & Poly Beads	6" thick solid poly box filled >24" deep with poly beads	Bus penetrations from SB crossover to tunnel alcove	Surrounded by aluminum enclosure	See PPH3-AIP11
MI-30 SB	Solid Poly & Poly Beads	6" thick solid poly box filled >24" deep with poly beads	Bus penetrations from SB crossover to tunnel alcove	Surrounded by aluminum enclosure	See PPH3-AIP12
MI-30 SB	Poly Beads	> 4' depth	Fill annulus between four 12" dia. carrier penetrations and LCW pipes	labels	See PPH3-AIP13
MI-40 SB	Solid Poly & Poly Beads	6" thick solid poly box filled >24" deep with poly beads	Bus penetrations from SB crossover to tunnel alcove	Surrounded by aluminum enclosure	See PPH3-AIP14

MI-40 SB	Poly Beads	> 4' depth	Fill annulus between four 12" dia. carrier penetrations and LCW pipes	labels	See PPH3-AIP15
MI-50 SB	Solid Poly & Poly Beads	6" thick solid poly box filled >24" deep with poly beads	Bus penetrations from SB crossover to tunnel alcove	Surrounded by aluminum enclosure	See PPH3-AIP16
MI-50 SB	Poly Beads	> 4' depth	Fill annulus between four 12" dia. carrier penetrations and LCW pipes	labels	See PPH3-AIP17
MI-52 SB	Solid Poly & Poly Beads	6" thick solid poly box filled >24" deep with poly beads	Bus penetrations from SB crossover to tunnel alcove	Surrounded by aluminum enclosure	See PPH3-AIP18
MI-52 SB	Poly Beads	> 4' depth	Fill one empty and annulus between three 12" dia. carrier penetrations and LCW pipes	labels	See PPH3-AIP19
MI-62 SB	Poly Beads	> 4' depth	Fill one empty and annulus between three 12" dia. carrier penetrations and LCW pipes	labels	See PPH3-AIP20
MI-31 Stub	Steel & Concrete	Many rods & blocks	Protect MI-31 from MI & Recycler		6' long steel rods inside two 6" dia. e-cooling carrier pipes & two 2' thick concrete walls (one wall on each end); this is in addition to the 7' of steel & 4.5' of concrete that was there when e-cooling was in use

P150	Concrete & Poly Beads	Many blocks	Protect F-sector from Recycler losses		In P150 tunnel, voids filled with bags of poly beads
A150	Concrete & Poly Beads	Many blocks	Protect F-sector from Recycler losses		In A150 tunnel, voids filled with bags of poly beads

Penetration Shielding

Location	Shielding Type	Quantity	Purpose	Preferred Method of Configuration (if specified)	Comments
MI-609	Steel and Poly	1	Site Riser penetration		a steel cylinder 11 5/8" dia x 62 5/8" long followed by a poly bead plug 11" dia. x 30" long
MI-601	Steel and Poly	1	Site Riser penetration		a steel cylinder 11 5/8" dia x 62 5/8" long followed by a poly bead plug 11" dia. x 30" long
MI-116.5	Steel and Poly	1	Site Riser penetration		a steel cylinder 11 5/8" dia x 62 5/8" long followed by a poly bead plug 11" dia. x 30" long
MI-633	Steel and Poly	1	Site Riser penetration		a steel cylinder 11 5/8" dia x 62 5/8" long followed by a poly bead plug 11" dia. x 30" long
MI-207	Steel and Poly	1	Site Riser penetration		Steel (11"dia. X 8' long

					cylinder, 2600 lb.) and one poly bead bomb (12" dia. X 3' long)
MI-301	Steel and Poly	1	Site Riser penetration		Steel (11"dia. X 8' long cylinder, 2600 lb.) and one poly bead bomb (12" dia. X 3' long)
MI-309	Steel and Poly	1	Site Riser penetration		Steel (11"dia. X 8' long cylinder, 2600 lb.) and one poly bead bomb (12" dia. X 3' long)
MI-332	Steel and Poly	1	Site Riser penetration		Steel (11"dia. X 8' long cylinder, 2600 lb.) and one poly bead bomb (12" dia. X 3' long)
MI-416	Steel and Poly	1	Site Riser penetration		Steel (11"dia. X 8' long cylinder, 2600 lb.) and one poly bead bomb (12" dia. X 3' long)
MI-507	Steel and Poly	1	Site Riser penetration		Steel (11"dia. X 8' long cylinder, 2600 lb.) and one poly bead bomb (12" dia. X 3' long)
MI-60 SB	Steel & Solid Poly	20 assemblies	20 single-leg RF penetrations in MI-60 RF gallery		Does not include the unused RF penetrations
MI-60 SB	Steel & Solid Poly	1 assembly	Long 8" dia. LCW penetration		"#2"; in Room 118

MI-60 SB	Steel & Solid Poly	1 assembly	Long 8" dia. LCW penetration		"#5"; in RF gallery
MI-60 SB	Steel & Solid Poly	1 assembly	Long 8" dia. LCW penetration		"#3"; in RF gallery
MI-60 SB	Steel & Solid Poly	1 assembly	Long 10" dia. LCW penetration		"#6"; in RF gallery
MI-60 SB	Steel & Solid Poly	1 assembly	Long 10" dia. LCW penetration		"#4"; in RF gallery
MI-60 SB	Steel & Solid Poly	1 assembly	Long 8" dia. LCW penetration		"#1"; in corner of RF gallery
MI-60 SB	Steel & Solid Poly	1 assembly	Short 8" dia. LCW penetration		"#1"; in Room 118
MI-60 SB	Steel & Solid Poly	1 assembly	Short 8" dia. LCW penetration		"#2"; in corner of RF gallery
MI-60 SB	Steel & Solid Poly	1 assembly on cart	K145A & K145B penetrations in Room 117	PAD-118 lock on cart	Cart has attached chipmunk
MI-60 SB	Steel & Solid Poly	1 assembly on cart	RF5A & RF5B penetrations in Room 118	PAD-118 lock on cart	Cart has attached chipmunk
MI-60 SB	Gravel & Solid Poly	13.2' of gravel & 4" of poly	Unused RF32 penetration in MI-60 RF gallery		
MI-60 SB	Gravel & Solid Poly	15.1' of gravel & 6.5" of poly	Unused RF71 penetration in MI-60 RF gallery		
MI-60 SB	Gravel & Solid Poly	15.1' of gravel & 6.5" of poly	Unused RF114 penetration in MI-60 RF gallery		
MI-62 SB	Solid Poly	1' thick	Three unused bus penetrations		
MI-14 SB	Sand	At least 15.4' in penetration	Two unused single-leg penetrations (#1 & #2)	PAD-118, MI Enter, and Confined Space locks	Penetrations end in vault outside of MI-14 SB
MI-14 SB	Solid Poly & Poly Beads	>3' beads at bottom; 1' solid at top of 1st leg; vault filled with beads	Two penetrations (#3 & #4) into MI-14 SB	PAD-118, MI Enter, and Confined Space locks	Penetrations pass through vault outside of MI-14 SB
MI-39 SB	Sand	At least 15.8' in penetration	Two unused single-leg penetrations (#3 & #4)	PAD-118 and Confined Space locks	Penetrations end in vault outside of MI-39 SB
MI-39 SB	Poly Beads	3' beads at bottom; 3' of beads over penetrations in vault	Two penetrations (#1 & #2) into MI-39 SB	PAD-118 and Confined Space locks	Penetrations pass through vault outside of MI-39 SB

Compensatory Measure(s)	In lieu of required shielding, temporary controls, such as guards, fencing, ropes, and/or postings, may be utilized as approved by the SRSO. Each use of a Compensatory Measure shall be documented using the USI Process.
Required Surveillance	Required shielding shall be verified annually, not to exceed twelve (12) months.
Response	Beam operation to the Main Injector will be terminated. Beam operation to the Main Injector will not resume until approval is received from the AD Associate Lab Director and the DOE Field Element Manager.

Passive – Fencing

Applicability	During beam operations to the Main Injector segment of the Fermilab Main Accelerator.
Basis	Based on the Nominal Operating Intensities of 2.93e17 protons/hr at 8 GeV and 120 GeV and 2.34e17 protons/hr at 150 GeV, supported by the following Shielding Assessments,, the fencing is required in the locations listed below. Shielding Assessment(s): • 2012 Recycler Ring Incremental Shielding Assessment 2.25e17 protons/hr [10] • 2018 Main Injector 1500kW Incremental Shielding Assessment [11]
Requirement	Required fencing specified in the listed Shielding Assessments will be installed in its proper configuration during applicable beam operations. <u>Radiation Area Fencing</u> none <u>Controlled Area Fencing</u> none
Compensatory Measure(s)	In lieu of required fencing, temporary controls, such as guards, ropes, and/or postings, may be utilized as approved by the SRSO. Each use of a Compensatory Measure shall be documented using the USI Process.
Required Surveillance	Required fencing shall be verified annually, not to exceed twelve (12) months.
Response	Beam operation to the Main Injector will be terminated. Beam operation to the Main Injector will not resume until approval is received from the AD Associate Lab Director and the DOE Field Element Manager.

Active Engineered – Radiation Safety Interlock System (RSIS)

Applicability During beam operations to the Main Injector segment of the Fermilab Main Accelerator.

Basis Based on the Nominal Operating Intensities of 2.93e17 protons/hr at 8 GeV and 120 GeV and 2.34e17 protons/hr at 150 GeV, supported by the following Shielding Assessments, the RSIS is established with interlocked barriers around the Exclusion Area, as well as inclusion of required interlocked radiation monitors.

Shielding Assessment(s):
- 2012 Recycler Ring Incremental 2.25e17 protons/hr [10]
- 2018 Main Injector 1500kW Incremental Shielding Assessment [11]

Requirement The Radiation Safety Interlock System (RSIS) must prevent entry into the following Exclusion Area(s) during appliable beam operation:
- MI-10
- MI-20—MI62
- TeV F Sector
- MI/TeV Crossovers

Required components of the RSIS shall be specified in the Main Injector's Operation Authorization Document.

The following components of the Radiation Safety Interlock System (RSIS) shall be in place, with no known loss of safety function, during applicable beam operations.

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-10 SB LCW
Chipmunk	MI-20 SB LCW
Chipmunk	MI-30 SB LCW
Chipmunk	MI-40 SB LCW
Chipmunk	MI-50 SB LCW
Chipmunk	MI-52 SB LCW
Chipmunk	MI-62 SB LCW
Chipmunk	MI-60 S Room 117 Pipe & BUS Pen
Chipmunk	MI-60 S Room 110 LCW Pens RF Gal
Chipmunk	MI-60 N Room 110 LCW Pens RF Gal
Chipmunk	MI-60 N Room 118 LCW Pen
Chipmunk	MI-60 N Room 118 Pen

Compensatory Measure(s)	In lieu of required interlocked detectors, temporary controls, such as guards, fencing, ropes, and/or postings, may be utilized as approved by the SRSO. Each use of a Compensatory Measure shall be documented using the USI Process.
Required Surveillance	The RSIS for the Main Injector segment shall undergo certification annually, not to exceed twelve (12) months.
Response	Beam operation to the Main Injector will be terminated. Beam operation to the Main Injector will not resume until approval is received from the AD Associate Lab Director and the DOE Field Element Manager.

Active Engineered – Oxygen Deficiency Hazard (ODH) Safety System

Applicability	Not applicable
Basis	Not applicable
Requirement	none
Compensatory Measure(s)	Not applicable
Required Surveillance	none
Response	none

Active Engineered – Fluorinert System Filter

Applicability	During beam operations to the Main Injector segment of the Fermilab Main Accelerator.
Basis	To ensure removal of contaminants produced from fluorinert use in prompt radiation environments.
Requirement	The fluorinert system filter is installed.
Compensatory Measure(s)	none
Required Surveillance	The fluorinert system filter shall be verified annually, not to exceed twelve (12) months.

Response	Beam operation to the Main Injector will be terminated. Beam operation to the Main Injector will not resume until approval is received from the AD Associate Lab Director and the DOE Field Element Manager.

Administrative – Operation Authorization Document

Applicability	During beam operations to the Main Injector segment of the Fermilab Main Accelerator.
Basis	To summarize the bounding conditions for safe operation of the Main Injector, and to provide explicit approval for operations of the Main Injector.
Requirement	An approved Main Injector Beam Permit & Running Condition shall be issued prior to beam operations.
Compensatory Measure(s)	none
Required Surveillance	The Main Injector Beam Permit and Running Condition shall be verified annually, not to exceed twelve (12) months.
Response	Beam operation to the Main Injector will be terminated. Beam operation to the Main Injector will not resume until approval is received from the AD Associate Lab Director and the DOE Field Element Manager.

Administrative – Staffing

Applicability	During beam operations to the Main Injector segment of the Fermilab Main Accelerator.
Basis	To ensure operations within bounding conditions specified in Operation Authorization Document, and to disable beam operation to the Main Injector and initiate an immediate response in the event of a determined ASE violation.
Requirement	The following staffing shall be in place during applicable beam operation: • At least one member of the AD Operations Department who has achieved the rank of Operator II or higher shall be on shift. • At least one member of the AD Operations Department shall be present in the Main Control Room (MCR).
Compensatory Measure(s)	none

Required Surveillance none

Response Beam operation to the Main Injector will be terminated. Beam operation to the Main Injector will not resume until approval is received from the AD Associate Lab Director and the DOE Field Element Manager.

Administrative – Accelerator Operating Parameters

Applicability During beam operations to the Main Injector segment of the Fermilab Main Accelerator.

Basis Longitudinal and Transverse spreadsheets were scaled using criteria 4 to find the weakest point in the shielding.
Transverse spreadsheet Category 4 areas fail at 7.45 x 10^{17} protons/hour.
Longitudinal spreadsheet Category 4 areas fail at 2.55 x 10^{18} protons/hour.
Transverse spreadsheet is the limiting area, so the ASE limit is 7.45 x 10^{17} protons/hour.

Requirement The Main Injector segment will be operated within the following parameters:

Mode	Intensity	Energy
Full Operation	7.45e17 protons/hr	8 GeV
Full Operation	7.45e17 protons/hr	120 GeV
Full Operation	6.23e17 protons/hr	150 GeV

These parameters are further specified in the Operation Authorization Document.

Main Injector intensity is monitored via: I:TOR852

Compensatory Measure(s) Alternative methods of monitoring intensity may be used.

Required Surveillance none

Response Beam operation to the Main Injector will be terminated. Beam operation to the Main Injector will not resume until approval is received from the AD Associate Lab Director and the DOE Field Element Manager.

Recycler Credited Controls

Passive – Shielding

Applicability During beam operations to the Recycler segment of the Fermilab Main Accelerator.

Basis Based on the Nominal Operating Intensity of 2.25e17 protons/hr, supported by the following Shielding Assessments, the shielding is required in the locations listed below.

Shielding Assessment(s):

- 2012 Recycler Ring Incremental 2.25e17 protons/hr [10]
- 2018 Main Injector 1500kW Incremental Shielding Assessment [11]

Requirement Required shielding specified in the listed Shielding Assessments will be installed in its proper configuration during applicable beam operations.

The listed Shielding Assessment(s) utilized the incremental shielding assessment methodology, required shielding is summarized here.

Permanent Longitudinal Shielding

Cell or Longitudinal Range (ft)	Description	Current Shielding (efd)	Required (efd)
100	Culvert	23.4	19.6
100-101	Tunnel	25.4	19.6
101-102	Tunnel	25.2	19.6
102-103	MI-10 Alcove	25.2	19.6
104-107	MI-14	25.1	19.6
107-118	Tunnel	24.9	19.6
111	Culvert #4	23.8	19.6
118	Intermediate Alcove	25.0	19.6
124	Culvert	24.1	19.6
118-201	Tunnel	25.1	19.6
201	MI-20 Alcove	25.6	19.6
201-217	Tunnel	24.6	19.6
218	Intermediate Alcove	25.0	19.6
219-305	Tunnel	24.6	19.6
305-306	MI-30 Alcove	24.2	19.6
306-326	Tunnel	24.1	19.6
327	Intermediate Alcove	24.5	19.6
328-331	Tunnel	24.1	19.6
332	Culvert	27.2	19.6

333-401	Tunnel	24.1	19.6
401-403	MI-39	25.5	19.6
402.5-406.5	MI-40 Alcove	24.6	19.6
406.5-409	Tunnel	25.0	19.6
409	Intermediate Alcove	24.7	19.6
409-501	Tunnel	24.8	19.6
418	Intermediate Alcove	24.2	19.6
424	Culvert	23.9	19.6
501-516	Tunnel	24.4	19.6
516-520	Tunnel	24.2	19.6
501	MI-50 Alcove	24.6	19.6
520	MI-52 Alcove	24.7	19.6
520-523	Tunnel	24.5	19.6
523-524	Tunnel	24.5	19.6
524-525.5	Tunnel	24.4	19.6
525.5-527.5	Tunnel	24.3	19.6
529	Stairs	27.5	19.6
527.5-529	Tunnel	25.2	19.6
529-532	Tunnel	27.2	19.6
532	Stairs	26.7	19.6
532-601.5	MI-60	28.0	19.6
601.5-610.5	MI-60	26.7	19.6
610.5-612.5	Tunnel	25.6	19.6
612.5-613.5	Stairs	25.0	19.6
613.5-614	Tunnel	25.2	19.6
614-615	Tunnel	25.5	19.6
615-617	Tunnel	25.1	19.6
617-618	Tunnel	25.3	19.6
618-619	Tunnel	25.5	19.6
619-621.5	Tunnel	25.5	19.6
621.5-623.5	MI-62	24.4	19.6
624	Stairs	24.8	19.6
624-630	Tunnel	25.1	19.6
630-100	Tunnel	25.1	19.6
634	Culvert	24.1	19.6
402.5-406.5	**Abort** MI-40 Alcove	24.6	17.2
406.5-409	**Abort** Tunnel	25.0	17.2
403-407	MI-40 **Abort** Stub	24.6	17.2

N/A	MI-40 **Abort** Pipe	27.9	19.6
N/A	MI **Abort** Enclosure	24.7	17.2

Permanent Transverse Shielding

Cell or Transverse Station (ft)	Description	Current Shielding (efd)	Required (efd)
010	Tunnel US of MI-14	24.8	19.6
090	MI10 Stairway	26.1	19.6
110	MI-10	24.7	19.6
143	Near MI-12A Stairway	25.0	19.6
185	MI-14	25.3	19.6
200	MI-14	25.2	19.6
220	MI-14	25.0	19.6
265	MI-14	25.2	19.6
285	MI-14	25.0	19.6
315	MI-14 Driveway	24.9	19.6
435	Culvert	24.9	19.6
500	Culvert	23.4	19.6
560	Culvert	25.4	19.6
740	Stair Exit	25.2	19.6
825	Typical Sight Riser	24.8	19.6
855	Culvert	23.0	19.6
908	Intermediate Alcove	25.3	19.6
1211	Culvert	25.4	19.6
1236	Culvert	24.8	19.6
1256	Culvert	27.6	19.6
1300	Stair Exit	25.2	19.6
1643	MI-20 Stair	26.0	19.6
1995	Stair Exit	25.3	19.6
2445	Stair Exit	25.2	19.6
2585	Exhaust Air Fan	25.1	19.6
2965	Stair Exit	25.0	19.6
3075	Culvert	22.8	19.6
3520	MI-30 Stair	26.2	19.6
3577	MI-31 Tunnel	24.6	19.6
3612	MI-31 Pelletron	25.6	19.6
3650	MI-31	25.5	19.6
3980	Stair Exit	25.0	19.6

4075	Culvert, Stair Exit	23.0	19.6
4500	Stair Exit	24.9	19.6
4600	Exhaust Air Fan	25.0	19.6
4875	Culvert	27.4	19.6
5050	Stair Exit	25.0	19.6
5470	Tunnel US of MI-39	25.7	19.6
5480	MI-39	24.0	19.6
5500	MI-39	25.6	19.6
5525	MI-39	25.9	19.6
5545	MI-39	25.8	19.6
5615	MI-40	25.6	19.6
5707	Abort Stub, MI	25.0	19.6
5733	Abort Stub, MI	25.0	19.6
5800	MI near Abort Pipe	25.0	19.6
5834	Abort Enclosure, MI	25.0	19.6
5850	Abort Enclosure, MI	25.5	19.6
5862	Abort Enclosure, MI	25.7	19.6
5876	Abort Enclosure, MI	24.6	19.6
6072	Stair Exit	25.0	19.6
6352	Exhaust Air Fan	24.9	19.6
6527	Stair Exit	24.5	19.6
6690	Culvert	23.6	19.6
6902	Culvert	24.0	19.6
6936	Whittaker Road	25.4	19.6
6970	Culvert	23.8	19.6
7093	MI-50 walkway	24.2	19.6
7185	Culvert	23.8	19.6
7550	Stair Exit	25.6	19.6
7905	Enclosure under Road	25.3	19.6
8000	Enclosure under Road	25.1	19.6
8050	Retaining Wall	25.6	19.6
8115	MI-52 stair	27.9	19.6
8287	P150 Transition	25.3	19.6
8313	P150 Transition	24.6	19.6
8400	P150 Transition	24.3	19.6
8450	MI at P150 Transition	25.0	19.6
8475	MI at P150 Transition	25.3	19.6
8569	Stair Exit	23.5	19.6

8690	Stair Exit	26.8	19.6
8690	MI Enclosure	22.4	19.6
8703	MI Enclosure	27.4	19.6
8715	MI Enclosure	28.0	19.6
8735	MI Enclosure	27.8	19.6
8752	MI Enclosure	28.0	19.6
8769	MI Enclosure	26.5	19.6
8782	MI Enclosure	26.5	19.6
8792	MI Enclosure	26.5	19.6
8801	MI Enclosure	26.1	19.6
8811	MI Enclosure	26.5	19.6
8838	MI Enclosure	26.5	19.6
8863	MI Enclosure	26.3	19.6
8875	MI Enclosure	26.4	19.6
8912	MI Enclosure	26.4	19.6
8934	MI Enclosure	26.6	19.6
8967	MI Enclosure	26.6	19.6
8974	MI Enclosure	26.7	19.6
8985	MI Enclosure	26.6	19.6
9004	MI Enclosure	26.5	19.6
9010	MI Enclosure	26.5	19.6
9023	MI Enclosure	26.6	19.6
9041	MI Enclosure	26.5	19.6
9060	MI Enclosure	26.5	19.6
9131	MI Enclosure	26.4	19.6
9214	MI Enclosure	27.0	19.6
9243	MI-60 stairs Q609	21.6	19.6
9350	Stair Exit Q612	21.8	19.6
9495	MI on left	27.1	19.6
9629	Alongside NUMI Stub	28.3	19.6
9832	MI-62 stairs	24.5	19.6
9890	MI-62 overpass	24.1	19.6
10016	Culvert	23.4	19.6
10388	Stair Exit	25.9	19.6
10484	Culvert	24.2	19.6
10600	8 GeV Tunnel, MI beam	24.5	19.6
10752	8 GeV Merge, MI beam	25.4	19.6

10795	Stair Exit, MI beam	25.5	19.6
10837	Culvert, MI beam	23.4	19.6
5707	**Abort** Stub, Abort Line	25.0	17.2
5733	**Abort** Line	25.0	17.2
5800	Buried **Abort** Pipe	32.1	19.6
5834	**Abort** Enclosure, Abort Line	32.1	17.2
5850	**Abort** Enclosure, Abort Line	37.9	17.2
5862	**Abort** Enclosure, Abort Line	38.9	17.2
5876	**Abort** Enclosure, Abort Line	32.5	17.2

Movable Shielding

Location	Shielding Type	Quantity	Purpose	Preferred Method of Configuration (if specified)	Comments
MI-10 SB	Solid Poly & Poly Beads	6" thick solid poly box filled >24" deep with poly beads	Bus penetrations from SB crossover to tunnel alcove	Surrounded by aluminum enclosure	See PPH3-AIP08
MI-10 SB	Poly Beads	> 4' depth	Fill annulus between four 12" dia. carrier penetrations and LCW pipes		See PPH3-AIP09
MI-20 SB	Poly Beads	> 4' depth	Fill annulus between four 12" dia. carrier penetrations and LCW pipes	labels	See PPH3-AIP10
MI-20 SB	Solid Poly & Poly Beads	6" thick solid poly box filled >24" deep with poly beads	Bus penetrations from SB crossover to tunnel alcove	Surrounded by aluminum enclosure	See PPH3-AIP11
MI-30 SB	Solid Poly & Poly Beads	6" thick solid poly box filled >24" deep with poly beads	Bus penetrations from SB crossover to tunnel alcove	Surrounded by aluminum enclosure	See PPH3-AIP12
MI-30 SB	Poly Beads	> 4' depth	Fill annulus between four 12" dia. carrier	labels	See PPH3-AIP13

			penetrations and LCW pipes		
MI-40 SB	Solid Poly & Poly Beads	6" thick solid poly box filled >24" deep with poly beads	Bus penetrations from SB crossover to tunnel alcove	Surrounded by aluminum enclosure	See PPH3-AIP14
MI-40 SB	Poly Beads	> 4' depth	Fill annulus between four 12" dia. carrier penetrations and LCW pipes	labels	See PPH3-AIP15
MI-50 SB	Solid Poly & Poly Beads	6" thick solid poly box filled >24" deep with poly beads	Bus penetrations from SB crossover to tunnel alcove	Surrounded by aluminum enclosure	See PPH3-AIP16
MI-50 SB	Poly Beads	> 4' depth	Fill annulus between four 12" dia. carrier penetrations and LCW pipes	labels	See PPH3-AIP17
MI-52 SB	Solid Poly & Poly Beads	6" thick solid poly box filled >24" deep with poly beads	Bus penetrations from SB crossover to tunnel alcove	Surrounded by aluminum enclosure	See PPH3-AIP18
MI-52 SB	Poly Beads	> 4' depth	Fill one empty and annulus between three 12" dia. carrier penetrations and LCW pipes	labels	See PPH3-AIP19
MI-62 SB	Poly Beads	> 4' depth	Fill one empty and annulus between three 12" dia. carrier penetrations and LCW pipes	labels	See PPH3-AIP20
MI-31 Stub	Steel & Concrete	Many rods & blocks	Protect MI-31 from MI & Recycler		6' long steel rods inside two 6" dia. e-cooling carrier pipes & two 2' thick concrete walls (one wall on each end); this is in addition to the 7' of steel & 4.5'

					of concrete that was there when e-cooling was in use
P150	Concrete & Poly Beads	Many blocks	Protect F-sector from Recycler losses		In P150 tunnel, voids filled with bags of poly beads
A150	Concrete & Poly Beads	Many blocks	Protect F-sector from Recycler losses		In A150 tunnel, voids filled with bags of poly beads

Penetration Shielding

Location	Shielding Type	Quantity	Purpose	Preferred Method of Configuration (if specified)	Comments
MI-609	Steel and Poly	1	Site Riser penetration		a steel cylinder 11 5/8" dia x 62 5/8" long followed by a poly bead plug 11" dia. x 30" long
MI-601	Steel and Poly	1	Site Riser penetration		a steel cylinder 11 5/8" dia x 62 5/8" long followed by a poly bead plug 11" dia. x 30" long
MI-116.5	Steel and Poly	1	Site Riser penetration		a steel cylinder 11 5/8" dia x 62 5/8" long followed by a poly bead plug 11" dia. x 30" long
MI-633	Steel and Poly	1	Site Riser penetration		a steel cylinder 11 5/8" dia x 62 5/8" long followed by a

					poly bead plug 11” dia. x 30” long
MI-207	Steel and Poly	1	Site Riser penetration		Steel (11"dia. X 8' long cylinder, 2600 lb.) and one poly bead bomb (12" dia. X 3' long)
MI-301	Steel and Poly	1	Site Riser penetration		Steel (11"dia. X 8' long cylinder, 2600 lb.) and one poly bead bomb (12" dia. X 3' long)
MI-309	Steel and Poly	1	Site Riser penetration		Steel (11"dia. X 8' long cylinder, 2600 lb.) and one poly bead bomb (12" dia. X 3' long)
MI-332	Steel and Poly	1	Site Riser penetration		Steel (11"dia. X 8' long cylinder, 2600 lb.) and one poly bead bomb (12" dia. X 3' long)
MI-416	Steel and Poly	1	Site Riser penetration		Steel (11"dia. X 8' long cylinder, 2600 lb.) and one poly bead bomb (12" dia. X 3' long)
MI-507	Steel and Poly	1	Site Riser penetration		Steel (11"dia. X 8' long cylinder, 2600 lb.) and one poly bead bomb (12" dia. X 3' long)

MI-60 SB	Steel & Solid Poly	20 assemblies	20 single-leg RF penetrations in MI-60 RF gallery		Does not include the unused RF penetrations
MI-60 SB	Steel & Solid Poly	1 assembly	Long 8" dia. LCW penetration		"#2"; in Room 118
MI-60 SB	Steel & Solid Poly	1 assembly	Long 8" dia. LCW penetration		"#5"; in RF gallery
MI-60 SB	Steel & Solid Poly	1 assembly	Long 8" dia. LCW penetration		"#3"; in RF gallery
MI-60 SB	Steel & Solid Poly	1 assembly	Long 10" dia. LCW penetration		"#6"; in RF gallery
MI-60 SB	Steel & Solid Poly	1 assembly	Long 10" dia. LCW penetration		"#4"; in RF gallery
MI-60 SB	Steel & Solid Poly	1 assembly	Long 8" dia. LCW penetration		"#1"; in corner of RF gallery
MI-60 SB	Steel & Solid Poly	1 assembly	Short 8" dia. LCW penetration		"#1"; in Room 118
MI-60 SB	Steel & Solid Poly	1 assembly	Short 8" dia. LCW penetration		"#2"; in corner of RF gallery
MI-60 SB	Steel & Solid Poly	1 assembly on cart	K145A & K145B penetrations in Room 117	PAD-118 lock on cart	Cart has attached chipmunk
MI-60 SB	Steel & Solid Poly	1 assembly on cart	RF5A & RF5B penetrations in Room 118	PAD-118 lock on cart	Cart has attached chipmunk
MI-60 SB	Gravel & Solid Poly	13.2' of gravel & 4" of poly	Unused RF32 penetration in MI-60 RF gallery		
MI-60 SB	Gravel & Solid Poly	15.1' of gravel & 6.5" of poly	Unused RF71 penetration in MI-60 RF gallery		
MI-60 SB	Gravel & Solid Poly	15.1' of gravel & 6.5" of poly	Unused RF114 penetration in MI-60 RF gallery		
MI-62 SB	Solid Poly	1' thick	Three unused bus penetrations		
MI-14 SB	Sand	At least 15.4' in penetration	Two unused single-leg penetrations (#1 & #2)	PAD-118, MI Enter, and Confined Space locks	Penetrations end in vault outside of MI-14 SB
MI-14 SB	Solid Poly & Poly Beads	>3' beads at bottom; 1' solid at top of 1st leg; vault filled with beads	Two penetrations (#3 & #4) into MI-14 SB	PAD-118, MI Enter, and Confined Space locks	Penetrations pass through vault outside of MI-14 SB
MI-39 SB	Sand	At least 15.8' in penetration	Two unused single-leg	PAD-118 and Confined Space locks	Penetrations end in vault

			penetrations (#3 & #4)		outside of MI-39 SB
MI-39 SB	Poly Beads	3' beads at bottom; 3' of beads over penetrations in vault	Two penetrations (#1 & #2) into MI-39 SB	PAD-118 and Confined Space locks	Penetrations pass through vault outside of MI-39 SB

Compensatory Measure(s) In lieu of required shielding, temporary controls, such as guards, fencing, ropes, and/or postings, may be utilized as approved by the SRSO. Each use of a Compensatory Measure shall be documented using the USI Process.

Required Surveillance Required shielding shall be verified annually, not to exceed twelve (12) months.

Response Beam operation to the Recycler will be terminated. Beam operation to the Recycler will not resume until approval is received from the AD Associate Lab Director and the DOE Field Element Manager.

Passive – Fencing

Applicability During beam operations to the Recycler segment of the Fermilab Main Accelerator.

Basis Based on the Nominal Operating Intensity of 2.25e17 protons/hr, supported by the following Shielding Assessments, the shielding is required in the locations listed below.

Shielding Assessment(s):
- 2012 Recycler Ring Incremental 2.25e17 protons/hr [10]

Requirement Required fencing specified in the listed Shielding Assessments will be installed in its proper configuration during applicable beam operations.

Radiation Area Fencing
none

Controlled Area Fencing
none

Compensatory Measure(s) In lieu of required fencing, temporary controls, such as guards, ropes, and/or postings, may be utilized as approved by the SRSO. Each use of a Compensatory Measure shall be documented using the USI Process.

Required Surveillance Required fencing shall be verified annually, not to exceed twelve (12) months.

Response Beam operation to the Recycler will be terminated. Beam operation to the Recycler will not resume until approval is received from the AD Associate Lab Director and the DOE Field Element Manager.

Active Engineered – Radiation Safety Interlock System (RSIS)

Applicability During beam operations to the Recycler segment of the Fermilab Main Accelerator.

Basis Based on the Nominal Operating Intensity of 2.25e17 protons/hr, supported by the following Shielding Assessments, the RSIS is established with interlocked barriers around the Exclusion Area, as well as inclusion of required interlocked radiation monitors.

Shielding Assessment(s):
- 2012 Recycler Ring Incremental 2.25e17 protons/hr [10]
- 2018 Main Injector 1500kW Incremental Shielding Assessment [11]

Requirement The Radiation Safety Interlock System (RSIS) must prevent entry into the following Exclusion Area(s) during appliable beam operation:
- MI-10
- MI-20—MI62
- TeV F Sector
- MI/TeV Crossovers

Required components of the RSIS shall be specified in the Recycler's Operation Authorization Document.

The following components of the Radiation Safety Interlock System (RSIS) shall be in place, with no known loss of safety function, during applicable beam operations.

<u>Radiation Safety System – Interlocked Radiation Monitors</u>
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-10 SB LCW
Chipmunk	MI-20 SB LCW
Chipmunk	MI-30 SB LCW
Chipmunk	MI-40 SB LCW
Chipmunk	MI-50 SB LCW
Chipmunk	MI-52 SB LCW
Chipmunk	MI-62 SB LCW
Chipmunk	MI-60 South Rm 117 Pipe & BUS Pen
Chipmunk	MI-60 S Room 110 LCW Pens RF Gal
Chipmunk	MI-60 N Room 110 LCW Pens RF Gal

Chipmunk	MI-60 N Room 118 LCW Pen
Chipmunk	MI-60 N Room 118 Pen

Compensatory Measure(s) In lieu of required interlocked detectors, temporary controls, such as guards, fencing, ropes, and/or postings, may be utilized as approved by the SRSO. Each use of a Compensatory Measure shall be documented using the USI Process.

Required Surveillance The RSIS for the Recycler segment shall undergo certification annually, not to exceed twelve (12) months.

Response Beam operation to the Recycler will be terminated. Beam operation to the Recycler will not resume until approval is received from the AD Associate Lab Director and the DOE Field Element Manager.

Active Engineered – Oxygen Deficiency Hazard (ODH) Safety System

Applicability Not applicable

Basis Not applicable

Requirement none

Compensatory Measure(s) Not applicable

Required Surveillance none

Response none

Administrative – Operation Authorization Document

Applicability During beam operations to the Recycler segment of the Fermilab Main Accelerator.

Basis To summarize the bounding conditions for safe operation of the Recycler, and to provide explicit approval for operations of the Recycler.

Requirement An approved Recycler Beam Permit & Running Condition shall be issued prior to Recycler beam operations.

Compensatory Measure(s) none

Required Surveillance	The Recycler Beam Permit and Running Condition shall be verified annually, not to exceed twelve (12) months.
Response	Beam operation to the Recycler will be terminated. Beam operation to the Recycler will not resume until approval is received from the AD Associate Lab Director and the DOE Field Element Manager.

Administrative – Staffing

Applicability	During beam operations to the Recycler segment of the Fermilab Main Accelerator.
Basis	To ensure operations within bounding conditions specified in Operation Authorization Document, and to disable beam operation to the Recycler and initiate an immediate response in the event of a determined ASE violation.
Requirement	The following staffing shall be in place during applicable beam operation: • At least one member of the AD Operations Department who has achieved the rank of Operator II or higher shall be on shift. • At least one member of the AD Operations Department shall be present in the Main Control Room (MCR).
Compensatory Measure(s)	none
Required Surveillance	none
Response	Beam operation to the Recycler will be terminated. Beam operation to the Recycler will not resume until approval is received from the AD Associate Lab Director and the DOE Field Element Manager.

Administrative – Accelerator Operating Parameters

Applicability	During beam operations to the Recycler segment of the Fermilab Main Accelerator.
Basis	Longitudinal and Transverse spreadsheets were scaled using criteria 4 to find the weakest point in the shielding. Transverse spreadsheet Category 4 areas fail at 1.27×10^{18} protons/hour. Longitudinal spreadsheet Category 4 areas fail at 4.35×10^{18} protons/hour. Transverse spreadsheet is the limiting area, so the ASE limit is 1.27×10^{18} protons/hour.

Requirement

The Recycler segment will be operated within the following parameters:

Mode	Intensity	Energy
Transferred Beams	1.27e18 protons/hr	8 GeV

These parameters are further specified in the Operation Authorization Document.

Recycler intensity is monitored via: R:TOR853

Compensatory Measure(s)

Alternative methods of monitoring intensity may be used.

Required Surveillance

none

Response

Beam operation to the Recycler will be terminated. Beam operation to the Recycler will not resume until approval is received from the AD Associate Lab Director and the DOE Field Element Manager.

NuMI (Horn/Target Scan Mode) Credited Controls

Passive – Shielding

Applicability During beam operations to the NuMI segment of the Fermilab Main Accelerator during Horn/Target Scan Mode.

Basis Based on the Nominal Operating Intensity of 4.32e14 protons/hr, supported by the following Shielding Assessments, the shielding is required in the locations listed below.
Shielding Assessment(s):

- 2013 Neutrino at Main Inject (NuMI) Beam Line Shielding Assessment for 778 kilowatt (kW) Operation of Neutrino Off-axis Electron Neutrino (ve) Appearance (NOvA) Experiment [12]
- 2018 Addendum to the NuMI Beamline Shielding Assessment for 1MW Operation of the NOvA Experiment [13]
- 2016 Addressing Radiological Concerns for NuMI beam-based alignment special runs [14]

Requirement Required shielding specified in the listed Shielding Assessments will be installed in its proper configuration during applicable beam operations.

The listed Shielding Assessment(s) utilized the incremental shielding assessment methodology, required shielding is summarized here.

Permanent Longitudinal Shielding

Cell or Longitudinal Range (ft)	Description	Current Shielding (efd)	Required (efd)
0-482	NUMI Stub	24.8	18.8
482-514	Extraction Enclosure	31.7	18.8
514-929	Carrier Tunnel	41.5	16.2
929-1105	Pre-Target Tunnel	100.0	18.8
1105-1331	Target Hall	94.3	18.8
1288-1298	To MI-8 Tunnel	62.0	18.8
1331-3523	Decay Tunnel	138.1	21.1
3523-3577	Absorber Hall	264.8	18.8
3577-3587	Muon Alcove 1	266.7	18.8
3626-3636	Muon Alcove 2	270.5	18.8
3695-3705	Muon Alcove 3	274.3	18.8

3803-3813	Muon Alcove 4	280.0	18.8

Permanent Transverse Shielding

Cell or Transverse Station (ft)	Description	Current Shielding (efd)	Required (efd)
352	NUMI Stub	26.2	18.8
417	NUMI Stub	26.2	18.8
501	Extraction Enclosure	32.0	18.8
569	Carrier Tunnel	52.3	16.2
929	Pre-Target Tunnel	105.0	18.8
1123	Target Hall	94.0	18.8
1293	To MI-8 Tunnel	62.0	18.8
1361	Decay Tunnel	138.0	21.1
3535	Absorber Hall	265.0	18.8
3581	Muon Alcove 1	267.0	18.8
3631	Muon Alcove 2	270.0	18.8
3700	Muon Alcove 3	274.0	18.8
3808	Muon Alcove 4	280.0	18.8

Movable Shielding

Location	Shielding Type	Quantity	Purpose	Preferred Method of Configuration (if specified)	Comments
SR-1 z=488'	Concrete + Steel	1 plug	sight riser	None	3 ft of iron 1 ft of concrete
SR-2 z=990'	Concrete + Steel	1 plug	sight riser	None	2 ft of iron 1 ft of concrete
Target Hall	Concrete	Many R-Blocks	Shield Target and Horn Modules	PAD 118	See 9-6-7-4 drawing set
Absorber	Concrete	6 C, 2 D, 12 K Blocks	Shield Alcove 2 Entry	Pad 118 & Muon Alcove Enclosure Key	
Absorber	Concrete	Many Blocks (20) Handstack sand bags	Shield Labyrinth	None	

Penetration Shielding

none

Compensatory Measure(s) In lieu of required shielding, temporary controls, such as guards, fencing, ropes, and/or postings, may be utilized as approved by the SRSO. Each use of a Compensatory Measure shall be documented using the USI Process.

Required Surveillance Required shielding shall be verified annually, not to exceed twelve (12) months.

Response Beam operation to the NuMI will be terminated. Beam operation to the NuMI will not resume until approval is received from the AD Associate Lab Director and the DOE Field Element Manager.

Passive – Fencing

Applicability During beam operations to the NuMI segment of the Fermilab Main Accelerator during Horn/Target Scan Mode.

Basis Based on the Nominal Operating Intensity of 4.32e14 protons/hr, supported by the following Shielding Assessments, the shielding is required in the locations listed below.

Shielding Assessment(s):

- 2013 Neutrino at Main Inject (NuMI) Beam Line Shielding Assessment for 778 kilowatt (kW) Operation of Neutrino Off-axis Electron Neutrino (ve) Appearance (NOvA) Experiment [12]
- 2018 Addendum to the NuMI Beamline Shielding Assessment for 1MW Operation of the NOvA Experiment [13]
- 2016 Addressing Radiological Concerns for NuMI beam-based alignment special runs [14]

Requirement Required fencing specified in the listed Shielding Assessments will be installed in its proper configuration during applicable beam operations.

<u>Radiation Area Fencing</u>
none

<u>Controlled Area Fencing</u>
none

Compensatory Measure(s) In lieu of required fencing, temporary controls, such as guards, ropes, and/or postings, may be utilized as approved by the SRSO. Each use of a Compensatory Measure shall be documented using the USI Process.

Required Surveillance Required fencing shall be verified annually, not to exceed twelve (12) months.

Response Beam operation to the NuMI will be terminated. Beam operation to the NuMI will not resume until approval is received from the AD Associate Lab Director and the DOE Field Element Manager.

Active Engineered – Radiation Safety Interlock System (RSIS)

Applicability During beam operations to the NuMI segment of the Fermilab Main Accelerator during Horn/Target Scan Mode.

Basis Based on the Nominal Operating Intensity of 4.32e14 protons/hr, supported by the following Shielding Assessments, the RSIS is established with interlocked barriers around the Exclusion Area, as well as inclusion of required interlocked radiation monitors.

Shielding Assessment(s):

- 2013 Neutrino at Main Inject (NuMI) Beam Line Shielding Assessment for 778 kilowatt (kW) Operation of Neutrino Off-axis Electron Neutrino (ve) Appearance (NOvA) Experiment [12]
- 2018 Addendum to the NuMI Beamline Shielding Assessment for 1MW Operation of the NOvA Experiment [13]
- 2016 Addressing Radiological Concerns for NuMI beam-based alignment special runs [14]

Requirement The Radiation Safety Interlock System (RSIS) must prevent entry into the following Exclusion Area(s) during appliable beam operation:

- NuMI MI-65
- NuMI Decay Pipe Passageway
- NuMI MINOS Alcoves
- NuMI Absorber Area

Required components of the RSIS shall be specified in NuMI's Operation Authorization Document for Horn/Target Scan Mode.

The following components of the Radiation Safety Interlock System (RSIS) shall be in place, with no known loss of safety function, during applicable beam operations.

<u>Radiation Safety System – Interlocked Radiation Monitors</u>

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
Scarecrow	MI-65 Hobbit Door
Chipmunk	MI-65 Horn Power Supply Room

Compensatory Measure(s) In lieu of required interlocked detectors, temporary controls, such as guards, fencing, ropes, and/or postings, may be utilized as approved by the SRSO. Each use of a Compensatory Measure shall be documented using the USI Process.

Required Surveillance The RSIS for the NuMI segment shall undergo certification annually, not to exceed twelve (12) months.

Response Beam operation to the NuMI will be terminated. Beam operation to the NuMI will not resume until approval is received from the AD Associate Lab Director and the DOE Field Element Manager.

Active Engineered – Oxygen Deficiency Hazard (ODH) Safety System

Applicability Not applicable

Basis Not applicable

Requirement none

Compensatory Measure(s) Not applicable

Required Surveillance none

Response Not applicable

Administrative – Operation Authorization Document

Applicability During beam operations to the NuMI segment of the Fermilab Main Accelerator during Horn/Target Scan Mode.

Basis To summarize the bounding conditions for safe operation of NuMI, and to provide explicit approval for operations of NuMI.

Requirement	An approved NuMI Beam Permit & Running Condition for Horn/Target Scan Mode shall be issued prior to NuMI beam operations.
Compensatory Measure(s)	none
Required Surveillance	The NuMI Beam Permit and Running Condition for Horn/Target Scan Mode shall be verified annually, not to exceed twelve (12) months.
Response	Beam operation to the NuMI will be terminated. Beam operation to the NuMI will not resume until approval is received from the AD Associate Lab Director and the DOE Field Element Manager.

Administrative – Staffing

Applicability	During beam operations to the NuMI segment of the Fermilab Main Accelerator during Horn/Target Scan Mode.
Basis	To ensure operations within bounding conditions specified in Operation Authorization Document, and to disable beam operation to the NuMI and initiate an immediate response in the event of a determined ASE violation.
Requirement	The following staffing shall be in place during applicable beam operation: • At least one member of the AD Operations Department who has achieved the rank of Operator II or higher shall be on shift. • At least one member of the AD Operations Department shall be present in the Main Control Room (MCR).
Compensatory Measure(s)	none
Required Surveillance	none
Response	Beam operation to the NuMI will be terminated. Beam operation to the NuMI will not resume until approval is received from the AD Associate Lab Director and the DOE Field Element Manager.

Administrative – Accelerator Operating Parameters

Applicability	During beam operations to the NuMI segment of the Fermilab Main Accelerator during Horn/Target Scan Mode.

Basis

Longitudinal, Transverse, and Labyrinth and Penetration spreadsheets were scaled using criteria 2 and 3 to find the weakest point in the shielding. Beam on measurements were scaled using criteria 4.
The shielding assessment was done for 1.46×10^{17} protons/hour or 778 kW.
Upstream areas are the same as MI assessment since the beamline is in the MI enclosure. MI ASE limit is 7.45×10^{17} protons/hour. Longitudinal, Transverse, and Labyrinth and Penetration spreadsheets all pass with MI ASE limit.
Downstream measurements by Muon alcove 2 are 30 mrem/hour. Scaling to 500 mrem calculates a scaling factor of 500/30 or 16.6667. Using this scaling factor calculates a failure at
$1.46 \times 10^{17} * 16.6667 = 2.4333 \times ^{18}$ protons/hour.
Upstream berm limits maximum intensity, so the ASE limit is 7.45×10^{17} protons/hour.

Requirement

The NuMI segment of the Fermilab Main Accelerator during Horn/Target Scan Mode will be operated within the following parameters:

Mode	Intensity	Energy
NuMI Horn/Target Scan Mode	7.45e17 protons/hr	120 GeV

These parameters are further specified in the Operation Authorization Document.

NuMI intensity is monitored via: E:TOR101

Compensatory Measure(s)

Alternative methods of monitoring intensity may be used and should be documented in the MCR eLog.

Required Surveillance

none

Response

Beam operation to the NuMI will be terminated. Beam operation to the NuMI will not resume until approval is received from the AD Associate Lab Director and the DOE Field Element Manager.

NuMI (High Energy Physics (HEP) Operation Mode) Credited Controls

Passive – Shielding

Applicability During beam operations to the NuMI segment of the Fermilab Main Accelerator during High Energy Physics (HEP) Operation Mode.

Basis Based on the Nominal Operating Intensity of 2.25e17 protons/hr, supported by the following Shielding Assessments, the shielding is required in the locations listed below.

Shielding Assessment(s):

- 2013 Neutrino at Main Injector (NuMI) Beam Line Shielding Assessment for 778 kilowatt (kW) Operation of Neutrino Off-axis Electron Neutrino (νe) Appearance (NOvA) Experiment [12]
- 2018 Addendum to the NuMI Beamline Shielding Assessment for 1MW Operation of the NOvA Experiment [13]

Requirement Required shielding specified in the listed Shielding Assessments will be installed in its proper configuration during applicable beam operations.

The listed Shielding Assessment(s) utilized the incremental shielding assessment methodology, required shielding is summarized here.

Permanent Longitudinal Shielding

Cell or Longitudinal Range (ft)	Description	Current Shielding (efd)	Required (efd)
0-482	NUMI Stub	24.8	18.8
482-514	Extraction Enclosure	31.7	18.8
514-929	Carrier Tunnel	41.5	16.2
929-1105	Pre-Target Tunnel	100.0	18.8
1105-1331	Target Hall	94.3	18.8
1288-1298	To MI-8 Tunnel	62.0	18.8
1331-3523	Decay Tunnel	138.1	21.1
3523-3577	Absorber Hall	264.8	18.8
3577-3587	Muon Alcove 1	266.7	18.8
3626-3636	Muon Alcove 2	270.5	18.8
3695-3705	Muon Alcove 3	274.3	18.8
3803-3813	Muon Alcove 4	280.0	18.8

Permanent Transverse Shielding

Cell or Transverse Station (ft)	Description	Current Shielding (efd)	Required (efd)
352	NUMI Stub	26.2	18.8
417	NUMI Stub	26.2	18.8
501	Extraction Enclosure	32.0	18.8
569	Carrier Tunnel	52.3	16.2
929	Pre-Target Tunnel	105.0	18.8
1123	Target Hall	94.0	18.8
1293	To MI-8 Tunnel	62.0	18.8
1361	Decay Tunnel	138.0	21.1
3535	Absorber Hall	265.0	18.8
3581	Muon Alcove 1	267.0	18.8
3631	Muon Alcove 2	270.0	18.8
3700	Muon Alcove 3	274.0	18.8
3808	Muon Alcove 4	280.0	18.8

Movable Shielding

Location	Shielding Type	Quantity	Purpose	Preferred Method of Configuration (if specified)	Comments
SR-1 z=488'	Concrete + Steel	1 plug	sight riser	None	3 ft of iron 1 ft of concrete
SR-2 z=990'	Concrete + Steel	1 plug	sight riser	None	2 ft of iron 1 ft of concrete
z=1331'	Concrete	Many Blocks	Shield bottom of elevator shaft	MI-65 Reset Key (NS 11) & RSO Padlock	Two stacks of blocks in front of roll up door
Target Hall	Concrete	Many R-Blocks	Shield Target and Horn Modules	PAD 118	See 9-6-7-4 drawing set
Absorber	Concrete	6 C, 2 D, 12 K Blocks	Shield Alcove 2 Entry	Pad 118 & Muon Alcove Enclosure Key	
Absorber	Concrete	Many Blocks (20) Handstack sand bags	Shield Labyrinth	None	

Penetration Shielding

none

Compensatory Measure(s)	In lieu of required shielding, temporary controls, such as guards, fencing, ropes, and/or postings, may be utilized as approved by the SRSO. Each use of a Compensatory Measure shall be documented using the USI Process.
Required Surveillance	Required shielding shall be verified annually, not to exceed twelve (12) months.
Response	Beam operation to the NuMI will be terminated. Beam operation to the NuMI will not resume until approval is received from the AD Associate Lab Director and the DOE Field Element Manager.

Passive – Fencing

Applicability	During beam operations to the NuMI segment of the Fermilab Main Accelerator during HEP Operation Mode.
Basis	Based on the Nominal Operating Intensity of 2.25e17 protons/hr, supported by the following Shielding Assessments, the shielding is required in the locations listed below. Shielding Assessment(s): • 2013 Neutrino at Main Injector (NuMI) Beam Line Shielding Assessment for 778 kilowatt (kW) Operation of Neutrino Off-axis Electron Neutrino (ve) Appearance (NOvA) Experiment [12] • 2018 Addendum to the NuMI Beamline Shielding Assessment for 1MW Operation of the NOvA Experiment [13]
Requirement	Required fencing specified in the listed Shielding Assessments will be installed in its proper configuration during applicable beam operations. <u>Radiation Area Fencing</u> none <u>Controlled Area Fencing</u> none
Compensatory Measure(s)	In lieu of required fencing, temporary controls, such as guards, ropes, and/or postings, may be utilized as approved by the SRSO. Each use of a Compensatory Measure shall be documented using the USI Process.
Required Surveillance	Required fencing shall be verified annually, not to exceed twelve (12) months.

Response Beam operation to the NuMI will be terminated. Beam operation to the NuMI will not resume until approval is received from the AD Associate Lab Director and the DOE Field Element Manager.

Active Engineered – Radiation Safety Interlock System (RSIS)

Applicability During beam operations to the NuMI segment of the Fermilab Main Accelerator during HEP Operation Mode.

Basis Based on the Nominal Operating Intensity of 2.25e17 protons/hr, supported by the following Shielding Assessments, the RSIS is established with interlocked barriers around the Exclusion Area, as well as inclusion of required interlocked radiation monitors.

Shielding Assessment(s):

- 2013 Neutrino at Main Inject (NuMI) Beam Line Shielding Assessment for 778 kilowatt (kW) Operation of Neutrino Off-axis Electron Neutrino (ve) Appearance (NOvA) Experiment [12]
- 2018 Addendum to the NuMI Beamline Shielding Assessment for 1MW Operation of the NOvA Experiment [13]

Requirement The Radiation Safety Interlock System (RSIS) must prevent entry into the following Exclusion Area(s) during appliable beam operation:

- NuMI MI-65
- NuMI Decay Pipe Passageway
- NuMI MINOS Alcoves
- NuMI Absorber Area

Required components of the RSIS shall be specified in NuMI's Operation Authorization Document for Horn/Target Scan Mode.

The following components of the Radiation Safety Interlock System (RSIS) shall be in place, with no known loss of safety function, during applicable beam operations.

<u>Radiation Safety System – Interlocked Radiation Monitors</u>

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
Scarecrow	MI-65 Hobbit Door
Chipmunk	MI-65 Horn Power Supply Room

Compensatory Measure(s)	In lieu of required interlocked detectors, temporary controls, such as guards, fencing, ropes, and/or postings, may be utilized as approved by the SRSO. Each use of a Compensatory Measure shall be documented using the USI Process.
Required Surveillance	The RSIS for the NuMI segment shall undergo certification annually, not to exceed twelve (12) months.
Response	Beam operation to the NuMI will be terminated. Beam operation to the NuMI will not resume until approval is received from the AD Associate Lab Director and the DOE Field Element Manager.

Active Engineered – Oxygen Deficiency Hazard (ODH) Safety System

Applicability	Not applicable
Basis	Not applicable
Requirement	none
Compensatory Measure(s)	Not applicable
Required Surveillance	none
Response	Not applicable

Administrative – Operation Authorization Document

Applicability	During beam operations to the NuMI segment of the Fermilab Main Accelerator during HEP Operation Mode.
Basis	To summarize the bounding conditions for safe operation of the NuMI, and to provide explicit approval for operations of the NuMI.
Requirement	An approved NuMI Beam Permit & Running Condition for HEP Mode shall be issued prior to NuMI beam operations.
Compensatory Measure(s)	none
Required Surveillance	The NuMI Beam Permit and Running Condition for HEP Mode shall be verified annually, not to exceed twelve (12) months.

Response	Beam operation to NuMI will be terminated. Beam operation to NuMI will not resume until approval is received from the AD Associate Lab Director and the DOE Field Element Manager.

Administrative – Staffing

Applicability	During beam operations to the NuMI segment of the Fermilab Main Accelerator during HEP Operation Mode.
Basis	To ensure operations within bounding conditions specified in Operation Authorization Document, and to disable beam operation to the NuMI and initiate an immediate response in the event of a determined ASE violation.
Requirement	The following staffing shall be in place during applicable beam operation: • At least one member of the AD Operations Department who has achieved the rank of Operator II or higher shall be on shift. • At least one member of the AD Operations Department shall be present in the Main Control Room (MCR).
Compensatory Measure(s)	none
Required Surveillance	none
Response	Beam operation to the NuMI will be terminated. Beam operation to the NuMI will not resume until approval is received from the AD Associate Lab Director and the DOE Field Element Manager.

Administrative – Accelerator Operating Parameters

Applicability	During beam operations to the NuMI segment of the Fermilab Main Accelerator during HEP Operation Mode.
Basis	Longitudinal and Transverse spreadsheets were scaled using criteria 2 and 3 to find the weakest point in the shielding. Beam on measurements were scaled using criteria 4. The shielding assessment was done for 2.25×10^{17} protons/hour or 1200 kW. Upstream areas are the same as MI assessment since the beamline is in the MI enclosure. MI ASE limit is 7.45×10^{17} protons/hour. Longitudinal, Transverse, and Labyrinth and Penetration spreadsheets all pass with MI ASE limit.

Downstream measurements by Muon alcove 2 are 30 mrem/hour. Scaling to 500 mrem calculates a scaling factor of 500/30 or 16.6667. Using this scaling factor calculates a failure at
$2.25 \times 10^{17} * 16.6667 = 3.75 \times 10^{18}$ protons/hour.
Upstream berm limits maximum intensity, so the ASE limit is 7.45×10^{17} protons/hour.

Requirement

The NuMI segment of the Fermilab Main Accelerator during HEP Operation Mode will be operated within the following parameters:

Mode	Intensity	Energy
NuMI HEP Operation Mode	7.45e17 protons/hr	120 GeV

These parameters are further specified in the Operation Authorization Document.

NuMI intensity is monitored via: E:TOR101

Compensatory Measure(s)

Alternative methods of monitoring intensity may be used.

Required Surveillance

none

Response

Beam operation to the NuMI will be terminated. Beam operation to the NuMI will not resume until approval is received from the AD Associate Lab Director and the DOE Field Element Manager.

P1-P2 Beamline Credited Controls

Passive – Shielding

Applicability During beam operations to the P1-P2 Beamline segment of the Fermilab Main Accelerator.

Basis Based on the Nominal Operating Intensities of 5.41e16 protons/hr at 8 GeV and 1.25e15 protons/hr at 120 GeV, supported by the following Shielding Assessments, the shielding is required in the locations listed below.

Shielding Assessment(s):
- 2016 P1 and P2 Beamline Incremental Shielding Assessment [15]

Requirement Required shielding specified in the listed Shielding Assessments will be installed in its proper configuration during applicable beam operations.

The listed Shielding Assessment(s) utilized the incremental shielding assessment methodology, required shielding is summarized here.

Permanent Longitudinal Shielding

Cell or Longitudinal Range (ft)	Description	Current Shielding (efd)	Required (efd)
520-701	Tunnel	24.7	24.5
702-708	Tunnel	24.4	22.1
708-F0	Tunnel	26.7	22.1
F0	Tunnel	26.3	22.1
F0 - F13.5	Tunnel	28.2	22.1
F13.5 - F15	Tunnel	20.6	17.7
F15 Cryo Bldg	Tunnel	18.7	6.1
F15 – F18	Tunnel	20.6	17.7

Permanent Transverse Shielding

Cell or Transverse Station (ft)	Description	Current Shielding (efd)	Required (efd)
MI 8400	Tunnel	24.5	24.5
MI 8450	Tunnel	24.5	24.5
MI 8475	Tunnel	24.5	24.5
MI 8569	Tunnel	24.5	22.1
707 8650	Tunnel	25.2	22.1
707 8725	Tunnel	25.2	22.1
707 8740	Tunnel	33.2	22.1
E48-4	Tunnel	25.1	22.1

E48-7	Tunnel	27.7	22.1
E49-7	Tunnel	25.1	22.1
E49-9	Tunnel	30.0	22.1
F00-5	Tunnel	25.7	22.1
17270	Tunnel	24.4	22.1
17450	Tunnel	24.4	22.1
17657	Tunnel	19.0	17.7
17683	Tunnel	18.0	6.1
17707	Tunnel	19.0	17.7
17910	Tunnel	19.0	17.7
18100	Tunnel	19.0	17.7

Movable Shielding

Location	Shielding Type	Quantity	Purpose	Preferred Method of Configuration (if specified)	Comments
F23	Poly Beads	1	LCW pipes in duct		By Hogan 1991 Tev 99 SA 99-4
A0	Solid Poly	1	Site Riser		By Hogan 1991 Tev 99 SA 99-4
F0 RF Gallery	Lead	Six 6'x6' panels	Booster RF cavity test area	None	Shielding for residual radioactivity. See J. Reid memo 01 March, 2012.

Penetration Shielding

Location	Shielding Type	Quantity	Purpose	Preferred Method of Configuration (if specified)	Comments
TG9 ZP96	Solid Poly	Multiple rods	Penetration	none	multiple rods of various diameters
TG9 ZP93	Solid Poly	Multiple rods	Penetration	none	multiple rods of various diameters
TG9 ZP90	Solid Poly	Multiple rods	Penetration	none	multiple rods of various diameters

TG8 ZP83-84-85	Solid Poly	Multiple rods	Penetration	none	multiple rods of various diameters
TG6 ZP64	Solid Poly	Multiple rods	Penetration	none	multiple rods of various diameters
TG3 ZP30	Solid Poly	Multiple rods	Penetration	none	multiple rods of various diameters
TG4 ZP47	Solid Poly	Multiple rods	Penetration	none	multiple rods of various diameters
TG4	Solid Poly	Multiple rods	Penetration	none	multiple rods of various diameters
TGS-110	Poly Beads	Multiple	Penetration	none	
F13	Sand	Hand filled	To occlude the F13 cryo penetrations	Signs	For both Switchyard and Muon Campus running
F47-4	Sand	1	8" Cryo Pen		By Theilacker 1991 Tev 99 SA 99-4

Compensatory Measure(s) In lieu of required shielding, temporary controls, such as guards, fencing, ropes, and/or postings, may be utilized as approved by the SRSO. Each use of a Compensatory Measure shall be documented using the USI Process.

Required Surveillance Required shielding shall be verified annually, not to exceed twelve (12) months.

Response Beam operation to the P1-P2 Beamline will be terminated. Beam operation to the P1-P2 Beamline will not resume until approval is received from the AD Associate Lab Director and the DOE Field Element Manager.

Passive – Fencing

Applicability During beam operations to the P1-P2 Beamline segment of the Fermilab Main Accelerator.

Basis Based on the Nominal Operating Intensities of 5.41e16 protons/hr at 8 GeV and 1.25e15 protons/hr at 120 GeV, supported by the following Shielding Assessments, the shielding is required in the locations listed below.

Shielding Assessment(s):
- 2016 P1 and P2 Beamline Incremental Shielding Assessment [15]

Requirement Required fencing specified in the listed Shielding Assessments will be installed in its proper configuration during applicable beam operations.

Radiation Area Fencing

Fence Location	Required Posting	Gates (if applicable)	Configuration
South end at F13 across the berm	Radiation Area	NA	• 4 ft height • Standing upright between 60-120° • No missing or bent pieces creating a person-sized hole (~1ft^2)
West side of enclosure berm running between F13 to the east of M1 block house to the AP0 Building south side	Radiation Area	AP1PA1	• 4 ft height • Standing upright between 60-120° • No missing or bent pieces creating a person-sized hole (~1ft^2) • Gates locked with Rad Fence Padlock
East side of enclosure berm from F13 to F1 Refrigerator building	Radiation Area	F1PA1	• 4 ft height • Standing upright between 60-120° • No missing or bent pieces creating a person-sized hole (~1ft^2)

			• Gates locked with Rad Fence Padlock
F-1 Refrigerator building to F17 Kicker Building	Radiation Area	NA	• 4 ft height • Standing upright between 60-120° • No missing or bent pieces creating a person-sized hole (~1ft^2)
F17 Kicker building to F23 support building	Radiation Area	F17PA1	• 4 ft height • Standing upright between 60-120° • No missing or bent pieces creating a person-sized hole (~1ft^2) • Gates locked with Rad Fence Padlock
F23 Support Building to F2 Refrigerator Building	Radiation Area	F23PA1 F2PA1	• 4 ft height • Standing upright between 60-120° • No missing or bent pieces creating a person-sized hole (~1ft^2) • Gates locked with Rad Fence Padlock

F1 Refrigerator Building to F23 Support Building	Radiation Area	NA	• 4 ft height • Standing upright between 60-120° • No missing or bent pieces creating a person-sized hole (~1ft^2)
F23 Support Building to F3 Refrigerator Building	Radiation Area	F23PA1 F3PA1	• 4 ft height • Standing upright between 60-120° • No missing or bent pieces creating a person-sized hole (~1ft^2) • Gates locked with Rad Fence Padlock
F3 Refrigerator Building to F43 road crossover	Radiation Area	F43PA1	• 4 ft height • Standing upright between 60-120° • No missing or bent pieces creating a person-sized hole (~1ft^2) • Gates locked with Rad Fence Padlock
North end along F43 crossover road	Radiation Area	NA	• 4 ft height • Standing upright

			between 60-120° • No missing or bent pieces creating a person-sized hole (~1ft^2)
West side of berm from F43 crossover running south to Antiproton test pit.	Radiation Area	NA	• 4 ft height • Standing upright between 60-120° • No missing or bent pieces creating a person-sized hole (~1ft^2)
East to West north end of Antiproton test pit	Radiation Area	AP0PA2	• 4 ft height • Standing upright between 60-120° • No missing or bent pieces creating a person-sized hole (~1ft^2) • Gates locked with Rad Fence Padlock
Northwest corner of Antiproton test pit running south to the AP0 building north	Radiation Area	AP0PA1	• 4 ft height • Standing upright between 60-120° • No missing or bent pieces creating a

			person-sized hole (~1ft^2) • Gates locked with Rad Fence Padlock

Controlled Area Fencing
none

Compensatory Measure(s) In lieu of required fencing, temporary controls, such as guards, ropes, and/or postings, may be utilized as approved by the SRSO. Each use of a Compensatory Measure shall be documented using the USI Process.

Required Surveillance Required fencing shall be verified annually, not to exceed twelve (12) months.

Response Beam operation to the P1-P2 Beamline will be terminated. Beam operation to the P1-P2 Beamline will not resume until approval is received from the AD Associate Lab Director and the DOE Field Element Manager.

Active Engineered – Radiation Safety Interlock System (RSIS)

Applicability During beam operations to the P1-P2 Beamline segment of the Fermilab Main Accelerator.

Basis Based on the Nominal Operating Intensities of 5.41e16 protons/hr at 8 GeV and 1.25e15 protons/hr at 120 GeV, supported by the following Shielding Assessments, the RSIS is established with interlocked barriers around the Exclusion Area, as well as inclusion of required interlocked radiation monitors.

Shielding Assessment(s):
- 2016 P1 and P2 Beamline Incremental Shielding Assessment [15]

Requirement The Radiation Safety Interlock System (RSIS) must prevent entry into the following Exclusion Area(s) during appliable beam operation:
- F Sector
- Muon Campus Pre-Target

Required components of the RSIS shall be specified in the P1-P2 Beamline's Operation Authorization Document.

The following components of the Radiation Safety Interlock System (RSIS) shall be in place, with no known loss of safety function, during applicable beam operations.

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	F1 Refrigerator Building
Chipmunk	F0 Service Building Penetration #1
Chipmunk	F0 Service Building Penetration #2
Chipmunk	F0 Service Building Penetration #3
Chipmunk	F0 Service Building Penetration #4
Chipmunk	F0 Service Building Penetration #5
Chipmunk	F0 Service Building Penetration #6
Chipmunk	F0 Service Building Penetration #7
Chipmunk	F0 Service Building Penetration #8

Compensatory Measure(s) In lieu of required interlocked detectors, temporary controls, such as guards, fencing, ropes, and/or postings, may be utilized as approved by the SRSO. Each use of a Compensatory Measure shall be documented using the USI Process.

Required Surveillance The RSIS for the P1-P2 Beamline segment shall undergo certification annually, not to exceed twelve (12) months.

Response Beam operation to the P1-P2 Beamline will be terminated. Beam operation to the P1-P2 Beamline will not resume until approval is received from the AD Associate Lab Director and the DOE Field Element Manager.

Active Engineered – Oxygen Deficiency Hazard (ODH) Safety System

Applicability Not applicable

Basis Not applicable

Requirement none

Compensatory Measure(s) Not applicable

Required Surveillance none

Response Beam operation to the P1-P2 Beamline will be terminated. Beam operation to the P1-P2 Beamline will not resume until approval is received from the AD Associate Lab Director and the DOE Field Element Manager.

Administrative – Operation Authorization Document

Applicability	During beam operations to the P1-P2 Beamline segment of the Fermilab Main Accelerator.
Basis	To summarize the bounding conditions for safe operation of the P1-P2 Beamline, and to provide explicit approval for operations of the P1-P2 Beamline.
Requirement	An approved P1-P2 Beamline Beam Permit & Running Condition shall be issued prior to P1-P2 Beamline beam operations.
Compensatory Measure(s)	none
Required Surveillance	The P1-P2 Beamline Beam Permit and Running Condition shall be verified annually, not to exceed twelve (12) months.
Response	Beam operation to the P1-P2 Beamline will be terminated. Beam operation to the P1-P2 Beamline will not resume until approval is received from the AD Associate Lab Director and the DOE Field Element Manager.

Administrative – Staffing

Applicability	During beam operations to the P1-P2 Beamline segment of the Fermilab Main Accelerator.
Basis	To ensure operations within bounding conditions specified in Operation Authorization Document, and to disable beam operation to the P1-P2 Beamline and initiate an immediate response in the event of a determined ASE violation.
Requirement	The following staffing shall be in place during applicable beam operation: • At least one member of the AD Operations Department who has achieved the rank of Operator II or higher shall be on shift. • At least one member of the AD Operations Department shall be present in the Main Control Room (MCR).
Compensatory Measure(s)	none
Required Surveillance	none

Response Beam operation to the P1-P2 Beamline will be terminated. Beam operation to the P1-P2 Beamline will not resume until approval is received from the AD Associate Lab Director and the DOE Field Element Manager.

Administrative – Accelerator Operating Parameters

Applicability During beam operations to the P1-P2 Beamline segment of the Fermilab Main Accelerator.

Basis At 8 GeV, Longitudinal and Transverse spreadsheets were scaled using criteria 4 to find the weakest point in the shielding.
Transverse spreadsheet Category 4 areas fail at 1.11×10^{18} protons/hour.
Longitudinal spreadsheet Category 4 areas fail at 3.38×10^{18} protons/hour.
At 120 GeV, Longitudinal and Transverse spreadsheets were scaled using criteria 4 to find the weakest point in the shielding.
Transverse spreadsheet Category 4 areas fail at 1.27×10^{17} protons/hour.
Longitudinal spreadsheet Category 4 areas fail at 3.79×10^{17} protons/hour.
Transverse spreadsheet at 120 GeV is the limiting area, so the ASE limit is 1.27×10^{17} protons/hour.

Requirement The P1-P2 Beamline segment will be operated within the following parameters:

Mode	Intensity	Energy
Beam to F17 – 8 GeV for Muon Campus Operations	1.11e18 protons/hr	8 GeV
Beam to F17 – 120 GeV for Switchyard Operations	1.27e17 protons/hr	120 GeV

These parameters are further specified in the Operation Authorization Document.

P1-P2 Beamline intensity is monitored via: R:TOR703 for 8 GeV Operations
P1-P2 Beamline intensity is monitored via: I:BEAM for 120 GeV Operations

Compensatory Measure(s) Alternative methods of monitoring intensity may be used.

Required Surveillance none

Response Beam operation to the P1-P2 Beamline will be terminated. Beam operation to the P1-P2 Beamline will not resume until approval is received from the AD Associate Lab Director and the DOE Field Element Manager.

Muon Campus (On Target/g-2 Experimental Mode) Credited Controls

Passive – Shielding

Applicability	During beam operations to the Muon Campus segment of the Fermilab Main Accelerator during On Target/g-2 Experimental Mode.
Basis	Based on the Nominal Operating Intensity of 4.32e16 protons/hr, supported by the following Shielding Assessments, the shielding is required in the locations listed below. Shielding Assessment(s): • 2017 Muon g-2 Shielding assessment [16] • 2020 Muon Campus Shielding Assessment for 8 GeV Beam Transmission to the Diagnostic Absorber [19]
Requirement	Required shielding specified in the listed Shielding Assessments will be installed in its proper configuration during applicable beam operations. The listed Shielding Assessment(s) utilized the more current Monte Carlo simulation methodology, required shielding is found in the listed Shielding Assessment(s).
Compensatory Measure(s)	In lieu of required shielding, temporary controls, such as guards, fencing, ropes, and/or postings, may be utilized as approved by the SRSO. Each use of a Compensatory Measure shall be documented using the USI Process.
Required Surveillance	Required shielding shall be verified annually, not to exceed twelve (12) months.
Response	Beam operation to the Muon Campus will be terminated. Beam operation to the Muon Campus will not resume until approval is received from the AD Associate Lab Director and the DOE Field Element Manager.

Passive – Fencing

Applicability	During beam operations to the Muon Campus segment of the Fermilab Main Accelerator during On Target/g-2 Experimental Mode.
Basis	Based on the Nominal Operating Intensity of 4.32e16 protons/hr, supported by the following Shielding Assessments, the shielding is required in the locations listed below. Shielding Assessment(s): • 2017 Muon g-2 Shielding assessment [16] • 2020 Muon Campus Shielding Assessment for 8 GeV Beam Transmission to the Diagnostic Absorber [19]
Requirement	Required fencing specified in the listed Shielding Assessments will be installed in its proper configuration during applicable beam operations.

Radiation Area Fencing

Fence Location	Required Posting	Gates (if applicable)	Configuration
South end at F13 across the berm	Radiation Area	NA	• 4 ft height • Standing upright between 60-120° • No missing or bent pieces creating a person-sized hole (~1ft^2)
West side of enclosure berm running between F13 to the east of M1 block house to AP0 Building south	Radiation Area	AP1PA1	• 4 ft height • Standing upright between 60-120° • No missing or bent pieces creating a person-sized hole (~1ft^2) • Gates locked with Rad Fence Padlock
East side of enclosure berm from F13 to F1 Refrigerator building	Radiation Area	F1PA1	• 4 ft height • Standing upright between 60-120° • No missing or bent pieces creating a person-sized hole (~1ft^2) • Gates locked with Rad Fence Padlock

F-1 Refrigerator building to F17 Kicker Building	Radiation Area	NA	• 4 ft height • Standing upright between 60-120° • No missing or bent pieces creating a person-sized hole (~1ft^2)
F17 Kicker building to F23 support building	Radiation Area	F17PA1	• 4 ft height • Standing upright between 60-120° • No missing or bent pieces creating a person-sized hole (~1ft^2) • Gates locked with Rad Fence Padlock
F23 Support Building to F2 Refrigerator Building	Radiation Area	F23PA1 F2PA1	• 4 ft height • Standing upright between 60-120° • No missing or bent pieces creating a person-sized hole (~1ft^2) • Gates locked with Rad Fence Padlock
F1 Refrigerator Building to F23 Support Building	Radiation Area	NA	• 4 ft height • Standing upright

			between 60-120° • No missing or bent pieces creating a person-sized hole (~1ft^2)
F23 Support Building to F3 Refrigerator Building	Radiation Area	F23PA1 F3PA1	• 4 ft height • Standing upright between 60-120° • No missing or bent pieces creating a person-sized hole (~1ft^2) • Gates locked with Rad Fence Padlock
F3 Refrigerator Building to F43 road crossover	Radiation Area	F43PA1	• 4 ft height • Standing upright between 60-120° • No missing or bent pieces creating a person-sized hole (~1ft^2) • Gates locked with Rad Fence Padlock
North end along F43 crossover road	Radiation Area	NA	• 4 ft height • Standing upright between 60-120° • No missing or bent pieces

			creating a person-sized hole (~1ft^2)
West side of berm from F43 crossover running south to Antiproton test pit.	Radiation Area	NA	• 4 ft height • Standing upright between 60-120° • No missing or bent pieces creating a person-sized hole (~1ft^2)
East to West north end of Antiproton test pit	Radiation Area	AP0PA2	• 4 ft height • Standing upright between 60-120° • No missing or bent pieces creating a person-sized hole (~1ft^2) • Gates locked with Rad Fence Padlock
Northwest corner of Antiproton test pit running south to the north side of AP0 building	Radiation Area	AP0PA1	• 4 ft height • Standing upright between 60-120° • No missing or bent pieces creating a person-sized hole (~1ft^2) • Gates locked with Rad Fence Padlock

Controlled Area Fencing
none

Compensatory Measure(s) In lieu of required fencing, temporary controls, such as guards, ropes, and/or postings, may be utilized as approved by the SRSO. Each use of a Compensatory Measure shall be documented using the USI Process.

Required Surveillance Required fencing shall be verified annually, not to exceed twelve (12) months.

Response Beam operation to the Muon Campus will be terminated. Beam operation to the Muon Campus will not resume until approval is received from the AD Associate Lab Director and the DOE Field Element Manager.

Active Engineered – Radiation Safety Interlock System (RSIS)

Applicability During beam operations to the Muon Campus segment of the Fermilab Main Accelerator during On Target/g-2 Experimental Mode.

Basis Based on the Nominal Operating Intensity of 4.32e16 protons/hr, supported by the following Shielding Assessments, the RSIS is established with interlocked barriers around the Exclusion Area, as well as inclusion of required interlocked radiation monitors.

Shielding Assessment(s):
- 2017 Muon g-2 Shielding assessment [16]
- 2020 Muon Campus Shielding Assessment for 8 GeV Beam Transmission to the Diagnostic Absorber [19]

Requirement The Radiation Safety Interlock System (RSIS) must prevent entry into the following Exclusion Area(s) during appliable beam operation:
- Muon Campus Pre-Target
- Muon Campus Pre-Vault
- Muon Campus Transport US/DS
- Muon Campus Transport Mid
- Muon Campus Delivery Ring
- Muon Campus Extraction Enclosure & Stub
- MC-1 Hall
- M4

Required components of the RSIS shall be specified in Muon Campus's Operation Authorization Document for On Target/g-2 Experimental Mode.

The following components of the Radiation Safety Interlock System (RSIS) shall be in place, with no known loss of safety function, during applicable beam operations.

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
TLM	Muon Campus Prevault
Chipmunk	AP-1 Entrance – PreTarget Access Hutch
Chipmunk	AP0 South Vault Wall
Chipmunk	AP0 South Building Wall
Chipmunk	Transport DS/Delivery Ring Gate
Chipmunk	AP-10 North Door
Chipmunk	AP-10 A17R05
Chipmunk	AP-10 A16R07
Chipmunk	AP-10 A16R03
Chipmunk	AP-10 D:QS
Chipmunk	AP-10 D:QD
Chipmunk	AP-10 A14R03
Chipmunk	AP-10 A14R0Y
Chipmunk	AP-10 MCR SW Door
Chipmunk	AP-10 Bay A13 South
Chipmunk	AP-10 Bay A12 North
Chipmunk	AP-10 A2R01
Chipmunk	AP-10 SW Rollup Door
Chipmunk	AP-10 South Door
Chipmunk	AP-30 South Door
Chipmunk	AP-30 S Rollup Door
Chipmunk	AP-30 D:H744
Chipmunk	AP-30 D:QT303
Chipmunk	AP-30 A35R07
Chipmunk	AP-30 A35R01
Chipmunk	AP-30 D:ISEP
Chipmunk	AP-30 A34R03
Chipmunk	AP-30 A33R07
Chipmunk	AP-30 A33R01
Chipmunk	AP-30 D:ELAM
Chipmunk	AP-30 D:V906
Chipmunk	AP-30 NE Rollup Door
Chipmunk	AP-30 North Door
Chipmunk	AP-50 West Door
Chipmunk	AP-50 A57R07
Chipmunk	AP-50 A57R01
Chipmunk	AP-50 A56R04
Chipmunk	AP-50 A55R08
Chipmunk	AP-50 A55R02 RFPA
Chipmunk	AP-50 D:SEXFV
Chipmunk	AP-50 D:VA03
Chipmunk	AP-50 A53R07
Chipmunk	AP-50 A53R01
Chipmunk	AP-50 Abort Kicker
Chipmunk	AP-50 D:ASEP
Chipmunk	AP-50 East Rollup Door
Chipmunk	AP-50 East Door

Chipmunk	MC-1 DS of Q023
Chipmunk	MC-1 g-2 Ring Center

Compensatory Measure(s) In lieu of required interlocked detectors, temporary controls, such as guards, fencing, ropes, and/or postings, may be utilized as approved by the SRSO. Each use of a Compensatory Measure shall be documented using the USI Process.

Required Surveillance The RSIS for the Muon Campus segment shall undergo certification annually, not to exceed twelve (12) months.

Response Beam operation to the Muon Campus will be terminated. Beam operation to the Muon Campus will not resume until approval is received from the AD Associate Lab Director and the DOE Field Element Manager.

Active Engineered – Oxygen Deficiency Hazard (ODH) Safety System

Applicability During personnel access into the G-2 Storage Ring

Basis Based on the ODH Analysis, the ODH Safety System is established with specified required components.

Requirement The following components of the Oxygen Deficiency Hazard (ODH) Safety System shall be in place, with no known loss of safety function, during personnel access into applicable areas.

- 2 area/fixed oxygen monitors (one high, one low)
- Backup generator
- Louvers

Compensatory Measure(s) Temporary updated ODH postings and associated requirements and/or restrictions may be implemented following a component failure to allow reentry to fix failed components based on either: (1) an existing and approved out-of-service policy, or (2) an updated ODH analysis approved by the Cryogenic Safety Subcommittee (CSS).

Required Surveillance

- Testing area/fixed oxygen monitors every 1 year per established procedure

Response Beam operation to the Neutrino Muon will be terminated. Beam operation to the Neutrino Muon will not resume until approval is received from the AD Associate Lab Director and the DOE Field Element Manager.

Active Engineered – Fluorinert System Filter

Applicability	During beam operations to the Muon Campus segment of the Fermilab Main Accelerator during On Target/g-2 Experimental Mode.
Basis	To ensure removal of contaminants produced from fluorinert use in prompt radiation environments.
Requirement	The fluorinert system filter is installed.
Compensatory Measure(s)	none
Required Surveillance	The fluorinert system filter shall be verified annually, not to exceed twelve (12) months.
Response	Beam operation to the Muon Campus will be terminated. Beam operation to the Muon Campus will not resume until approval is received from the AD Associate Lab Director and the DOE Field Element Manager.

Administrative – Operation Authorization Document

Applicability	During beam operations to the Muon Campus segment of the Fermilab Main Accelerator during On Target/g-2 Experimental Mode.
Basis	To summarize the bounding conditions for safe operation of the Muon Campus during On-Target/g-2 Experimental Mode operation, and to provide explicit approval for operations of the Muon Campus for On-Target/g-2 Experimental Mode.
Requirement	An approved Muon Campus Beam Permit & Running Condition for On Target/g-2 Experimental Mode shall be issued prior to Muon Campus beam operations.
Compensatory Measure(s)	none
Required Surveillance	The Muon Beam Permit and Running Condition for On Target/g-2 Experimental Mode shall be verified annually, not to exceed twelve (12) months.
Response	Beam operation to the Muon Campus will be terminated. Beam operation to the Muon Campus segment of the Fermilab Main Accelerator during On Target/g-2 Experimental Mode will not resume until approval is received from the AD Associate Lab Director and the DOE Field Element Manager.

Administrative – Staffing

Applicability	During beam operations to the Muon Campus segment of the Fermilab Main Accelerator during On Target/g-2 Experimental Mode.
Basis	To ensure operations within bounding conditions specified in Operation Authorization Document, and to disable beam operation to the Muon Campus and initiate an immediate response in the event of a determined ASE violation.
Requirement	The following staffing shall be in place during applicable beam operation: • At least one member of the AD Operations Department who has achieved the rank of Operator II or higher shall be on shift. • At least one member of the AD Operations Department shall be present in the Main Control Room (MCR).
Compensatory Measure(s)	none
Required Surveillance	none
Response	Beam operation to the Muon Campus will be terminated. Beam operation to the Muon Campus will not resume until approval is received from the AD Associate Lab Director and the DOE Field Element Manager.

Administrative – Accelerator Operating Parameters

Applicability	During beam operations to the Muon Campus segment of the Fermilab Main Accelerator during On Target/g-2 Experimental Mode.
Basis	The Muon Campus g-2 shielding assessment was completed partially by reviewing the 2000 Antiproton Source assessment [16] and comparing against the beam power needed for the g-2 experiment in the MC-1 Experimental Hall. The results of this comparison show that the beam power needed for the g-2 experiment are less than that already assessed for antiproton production and storage during the Tevatron Collider era. Hence, the majority of the Muon Campus will continue to use the 2000 Antiproton Source shielding assessment. The remaining areas, the new M4 and M5 extraction enclosures and the MC-1 Experimental Hall were analyzed. The M5 and MC-1 Experimental Hall only see the secondary muon beam and hence have no ability to create a 500 mrem/hr accident condition. As such, the previous safety envelope calculation from the Antiproton Source below remains valid.

The Muon Campus Shielding Assessment for 8 GeV Beam Transmission to the Diagnostic Absorber was completed for primary beam operations down the M4 beamline. This assessment was performed in addition to the above assessment for Muon Campus/g-2 operations. The worst case accident scenario for beam operations in the M4 beamline to the Diagnostic Absorber results in dose rates below accident scenarios in upstream beamlines described in the previous assessment. As such, the current safety envelope calculation, derived from the Antiproton Source below, continues to remain valid.

The Antiproton Source assessment was done using the Cossairt Criteria to determine shielding thickness or via beam loss measurements. The standard spreadsheets were not used to allow for easy scaling and changes to the category. The assessment was reviewed to find the most conservative loss point and then scaled to a 500 mrem accident condition. In many cases this is simply scaling from a Cossairt category 3 to a category 4 using criteria 2. In this case, the scaling is a factor of 5. No attempt was made to also include the additional shielding available when scaling between categories 3 and 4. Areas protected by interlocked detectors were scaled to a 500 mrem accident condition even though the detector protects the area with a credited control using criteria 1. The most conservative scaling was for a shift from Cossairt category 3 to 4 which is a scale factor of 5.

Using the scaling factor of 5 the Antiproton Source 8 GeV ASE limit is $3.6 \times 10^{13} * 5 = 1.8 \times 10^{14}$ protons/hour.

Using the scaling factor of 5 the Antiproton Source 120 GeV ASE limit is $1.8 \times 10^{16} * 5 = 9.0 \times 10^{16}$ protons/hour.

Using power scaling from the 120 GeV ASE limit to 8 Gev is a factor of 15. $9.0 \times 10^{16} * 15 = 1.35 \times 10^{18}$ protons/hour.

Requirement

The Muon Campus segment will be operated within the following parameters during On Target/g-2 Experimental Mode:

Mode	Intensity	Energy
8 GeV Primary beam to AP-0 Target, 3 GeV secondary beam to Delivery Ring & MC-1	1.35e18 protons/hr	8 GeV

These parameters are further specified in the Operation Authorization Document.

Muon Campus intensity for On Target/g-2 Experimental Mode is monitored via: M:TOR107

Compensatory Measure(s)

Alternative methods of monitoring intensity may be used.

Required Surveillance	none
Response	Beam operation to the Muon Campus will be terminated. Beam operation to the Muon Campus will not resume until approval is received from the AD Associate Lab Director and the DOE Field Element Manager.

Muon Campus (Off Target/Mu2e Experimental Mode) Credited Controls

Passive – Shielding

Applicability	During beam operations to the Muon Campus segment of the Fermilab Main Accelerator during Off Target/Mu2e Experimental Mode.
Basis	Based on the Nominal Operating Intensity of 3.60e13 protons/hr, supported by the following Shielding Assessments, the shielding is required in the locations listed below. Shielding Assessment(s): • 2017 Muon g-2 Shielding assessment [17] • 2020 Muon Campus Shielding Assessment for 8 GeV Beam Transmission to the Diagnostic Absorber [18]
Requirement	Required shielding specified in the listed Shielding Assessments will be installed in its proper configuration during applicable beam operations. The listed Shielding Assessment(s) utilized the more current Monte Carlo simulation methodology, required shielding is found in the listed Shielding Assessment(s).
Compensatory Measure(s)	In lieu of required shielding, temporary controls, such as guards, fencing, ropes, and/or postings, may be utilized as approved by the SRSO. Each use of a Compensatory Measure shall be documented using the USI Process.
Required Surveillance	Required shielding shall be verified annually, not to exceed twelve (12) months.
Response	Beam operation to the Muon Campus will be terminated. Beam operation to the Muon Campus will not resume until approval is received from the AD Associate Lab Director and the DOE Field Element Manager.

Passive – Fencing

Applicability	During beam operations to the Muon Campus segment of the Fermilab Main Accelerator during Off Target/Mu2e Experimental Mode.
Basis	Based on the Nominal Operating Intensity of 3.60e13 protons/hr, supported by the following Shielding Assessments, the shielding is required in the locations listed below. Shielding Assessment(s): • 2017 Muon g-2 Shielding assessment [17] • 2020 Muon Campus Shielding Assessment for 8 GeV Beam Transmission to the Diagnostic Absorber [18]
Requirement	Required fencing specified in the listed Shielding Assessments will be installed in its proper configuration during applicable beam operations.

Radiation Area Fencing

Fence Location	Required Posting	Gates (if applicable)	Configuration
South end at F13 across the berm	Radiation Area	NA	• 4 ft height • Standing upright between 60-120° • No missing or bent pieces creating a person-sized hole (~1ft^2)
West side of enclosure berm running between F13 to the east of M1 block house to the south side the AP0 Building	Radiation Area	AP1PA1	• 4 ft height • Standing upright between 60-120° • No missing or bent pieces creating a person-sized hole (~1ft^2) • Gates locked with Rad Fence Padlock
East side of enclosure berm from F13 to F1 Refrigerator building	Radiation Area	F1PA1	• 4 ft height • Standing upright between 60-120° • No missing or bent pieces creating a person-sized hole (~1ft^2) • Gates locked with Rad Fence Padlock

F-1 Refrigerator building to F17 Kicker Building	Radiation Area	NA	• 4 ft height • Standing upright between 60-120° • No missing or bent pieces creating a person-sized hole (~1ft^2)
F17 Kicker building to F23 support building	Radiation Area	F17PA1	• 4 ft height • Standing upright between 60-120° • No missing or bent pieces creating a person-sized hole (~1ft^2) • Gates locked with Rad Fence Padlock
F23 Support Building to F2 Refrigerator Building	Radiation Area	F23PA1 F2PA1	• 4 ft height • Standing upright between 60-120° • No missing or bent pieces creating a person-sized hole (~1ft^2) • Gates locked with Rad Fence Padlock
F1 Refrigerator Building to F23 Support Building	Radiation Area	NA	• 4 ft height • Standing upright

			between 60-120° • No missing or bent pieces creating a person-sized hole (~1ft^2)
F23 Support Building to F3 Refrigerator Building	Radiation Area	F23PA1 F3PA1	• 4 ft height • Standing upright between 60-120° • No missing or bent pieces creating a person-sized hole (~1ft^2) • Gates locked with Rad Fence Padlock
F3 Refrigerator Building to F43 road crossover	Radiation Area	F43PA1	• 4 ft height • Standing upright between 60-120° • No missing or bent pieces creating a person-sized hole (~1ft^2) • Gates locked with Rad Fence Padlock
North end along F43 crossover road	Radiation Area	NA	• 4 ft height • Standing upright between 60-120° • No missing or bent pieces

			creating a person-sized hole (~1ft^2)
West side of berm from F43 crossover running south to Antiproton test pit.	Radiation Area	NA	• 4 ft height • Standing upright between 60-120° • No missing or bent pieces creating a person-sized hole (~1ft^2)
East to West north end of Antiproton test pit	Radiation Area	AP0PA2	• 4 ft height • Standing upright between 60-120° • No missing or bent pieces creating a person-sized hole (~1ft^2) • Gates locked with Rad Fence Padlock
Northwest corner of Antiproton test pit running south to north side of the AP0 building	Radiation Area	AP0PA1	• 4 ft height • Standing upright between 60-120° • No missing or bent pieces creating a person-sized hole (~1ft^2) • Gates locked with Rad Fence Padlock

Controlled Area Fencing
none

Compensatory Measure(s) In lieu of required fencing, temporary controls, such as guards, ropes, and/or postings, may be utilized as approved by the SRSO. Each use of a Compensatory Measure shall be documented using the USI Process.

Required Surveillance Required fencing shall be verified annually, not to exceed twelve (12) months.

Response Beam operation to the Muon Campus will be terminated. Beam operation to the Muon Campus will not resume until approval is received from the AD Associate Lab Director and the DOE Field Element Manager.

Active Engineered – Radiation Safety Interlock System (RSIS)

Applicability During beam operations to the Muon Campus segment of the Fermilab Main Accelerator during Off Target/Mu2e Experimental Mode.

Basis Based on the Nominal Operating Intensity of 3.60e13 protons/hr, supported by the following Shielding Assessments, the RSIS is established with interlocked barriers around the Exclusion Area, as well as inclusion of required interlocked radiation monitors.

Shielding Assessment(s):
- 2017 Muon g-2 Shielding assessment [17]
- 2020 Muon Campus Shielding Assessment for 8 GeV Beam Transmission to the Diagnostic Absorber [18]

Requirement The Radiation Safety Interlock System (RSIS) must prevent entry into the following Exclusion Area(s) during appliable beam operation:
- Muon Campus Pre-Target
- Muon Campus Pre-Vault
- Muon Campus Transport US/DS
- Muon Campus Transport Mid
- Muon Campus Delivery Ring
- Muon Campus Extraction Enclosure & Stub
- M4

Required components of the RSIS shall be specified in Muon Campus's Operation Authorization Document for On Target/g-2 Experimental Mode.

The following components of the Radiation Safety Interlock System (RSIS) shall be in place, with no known loss of safety function, during applicable beam operations.

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
TLM	Muon Campus Prevault
Chipmunk	AP-1 Entrance – PreTarget Access Hutch
Chipmunk	AP0 South Vault Wall
Chipmunk	AP0 South Building Wall
Chipmunk	Transport DS/Delivery Ring Gate
Chipmunk	AP-10 North Door
Chipmunk	AP-10 A17R05
Chipmunk	AP-10 A16R07
Chipmunk	AP-10 A16R03
Chipmunk	AP-10 D:QS
Chipmunk	AP-10 D:QD
Chipmunk	AP-10 A14R03
Chipmunk	AP-10 A14R0Y
Chipmunk	AP-10 MCR SW Door
Chipmunk	AP-10 Bay A13 South
Chipmunk	AP-10 Bay A12 North
Chipmunk	AP-10 A2R01
Chipmunk	AP-10 SW Rollup Door
Chipmunk	AP-10 South Door
Chipmunk	AP-30 South Door
Chipmunk	AP-30 S Rollup Door
Chipmunk	AP-30 D:H744
Chipmunk	AP-30 D:QT303
Chipmunk	AP-30 A35R07
Chipmunk	AP-30 A35R01
Chipmunk	AP-30 D:ISEP
Chipmunk	AP-30 A34R03
Chipmunk	AP-30 A33R07
Chipmunk	AP-30 A33R01
Chipmunk	AP-30 D:ELAM
Chipmunk	AP-30 D:V906
Chipmunk	AP-30 NE Rollup Door
Chipmunk	AP-30 North Door
Chipmunk	AP-50 West Door
Chipmunk	AP-50 A57R07
Chipmunk	AP-50 A57R01
Chipmunk	AP-50 A56R04
Chipmunk	AP-50 A55R08
Chipmunk	AP-50 A55R02 RFPA
Chipmunk	AP-50 D:SEXFV
Chipmunk	AP-50 D:VA03
Chipmunk	AP-50 A53R07
Chipmunk	AP-50 A53R01
Chipmunk	AP-50 Abort Kicker
Chipmunk	AP-50 D:ASEP
Chipmunk	AP-50 East Rollup Door
Chipmunk	AP-50 East Door

Chipmunk	M4 7 foot drop Gate
Chipmunk	MC-1 Hall Extraction Stub Gate

Compensatory Measure(s) In lieu of required interlocked detectors, temporary controls, such as guards, fencing, ropes, and/or postings, may be utilized as approved by the SRSO. Each use of a Compensatory Measure shall be documented using the USI Process.

Required Surveillance The RSIS for the Muon Campus segment shall undergo certification annually, not to exceed twelve (12) months.

Response Beam operation to the Muon Campus will be terminated. Beam operation to the Muon Campus will not resume until approval is received from the AD Associate Lab Director and the DOE Field Element Manager.

Active Engineered – Oxygen Deficiency Hazard (ODH) Safety System

Applicability Not applicable

Basis Not applicable

Requirement none

Compensatory Measure(s) Not applicable

Required Surveillance none

Response Not applicable

Active Engineered – Fluorinert System Filter

Applicability During beam operations to the Muon Campus segment of the Fermilab Main Accelerator during Off Target/Mu2e Experimental Mode.

Basis To ensure removal of contaminants produced from fluorinert use in prompt radiation environments.

Requirement The fluorinert system filter is installed.

Compensatory Measure(s) none

Required Surveillance	The fluorinert system filter shall be verified annually, not to exceed twelve (12) months.
Response	Beam operation to the Muon Campus will be terminated. Beam operation to the Muon Campus will not resume until approval is received from the AD Associate Lab Director and the DOE Field Element Manager.

Administrative – Operation Authorization Document

Applicability	During beam operations to the Muon Campus segment of the Fermilab Main Accelerator during Off Target/Mu2e Experimental Mode.
Basis	To summarize the bounding conditions for safe operation of the Muon Campus during On-Target/g-2 Experimental Mode operation, and to provide explicit approval for operations of the Muon Campus for On-Target/g-2 Experimental Mode.
Requirement	An approved Muon Campus Beam Permit & Running Condition for Off Target/Mu2e Experimental Mode shall be issued prior to Muon Campus beam operations.
Compensatory Measure(s)	none
Required Surveillance	The Muon Beam Permit and Running Condition for Off Target/Mu2e Experimental Mode shall be verified annually, not to exceed twelve (12) months.
Response	Beam operation to the Muon Campus will be terminated. Beam operation to the Muon Campus segment of the Fermilab Main Accelerator during On Target/g-2 Experimental Mode will not resume until approval is received from the AD Associate Lab Director and the DOE Field Element Manager.

Administrative – Staffing

Applicability	During beam operations to the Muon Campus segment of the Fermilab Main Accelerator during Off Target/Mu2e Experimental Mode.
Basis	To ensure operations within bounding conditions specified in Operation Authorization Document, and to disable beam operation to the Muon Campus and initiate an immediate response in the event of a determined ASE violation.

Requirement	The following staffing shall be in place during applicable beam operation: • At least one member of the AD Operations Department who has achieved the rank of Operator II or higher shall be on shift. • At least one member of the AD Operations Department shall be present in the Main Control Room (MCR).
Compensatory Measure(s)	none
Required Surveillance	none
Response	Beam operation to the Muon Campus will be terminated. Beam operation to the Muon Campus will not resume until approval is received from the AD Associate Lab Director and the DOE Field Element Manager.

Administrative – Accelerator Operating Parameters

Applicability	During beam operations to the Muon Campus segment of the Fermilab Main Accelerator during for Off Target/Mu2e Experimental Mode.
Basis	The Muon Campus g-2 shielding assessment was completed partially by reviewing the 2000 Antiproton Source assessment [16] and comparing against the beam power needed for the g-2 experiment in the MC-1 Experimental Hall. The results of this comparison show that the beam power needed for the g-2 experiment are less than that already assessed for antiproton production and storage during the Tevatron Collider era. Hence, the majority of the Muon Campus will continue to use the 2000 Antiproton Source shielding assessment. The remaining areas, the new M4 and M5 extraction enclosures and the MC-1 Experimental Hall were analyzed. The M5 and MC-1 Experimental Hall only see the secondary muon beam and hence have no ability to create a 500 mrem/hr accident condition. As such, the previous safety envelope calculation from the Antiproton Source below remains valid. The Muon Campus Shielding Assessment for 8 GeV Beam Transmission to the Diagnostic Absorber was completed for primary beam operations down the M4 beamline. This assessment was performed in addition to the above assessment for Muon Campus/g-2 operations. The worst case accident scenario for beam operations in the M4 beamline to the Diagnostic Absorber results in dose rates below accident scenarios in upstream beamlines described in the previous assessment. As such, the current safety envelope calculation, derived from the Antiproton Source below, continues to remain valid. The Antiproton Source assessment was done using the Cossairt Criteria to determine shielding thickness or via beam loss measurements. The standard

spreadsheets were not used to allow for easy scaling and changes to the category. The assessment was reviewed to find the most conservative loss point and then scaled to a 500 mrem accident condition. In many cases this is simply scaling from a Cossairt category 3 to a category 4 using criteria 2. In this case, the scaling is a factor of 5. No attempt was made to also include the additional shielding available when scaling between categories 3 and 4. Areas protected by interlocked detectors were scaled to a 500 mrem accident condition even though the detector protects the area with a credited control using criteria 1. The most conservative scaling was for a shift from Cossairt category 3 to 4 which is a scale factor of 5.
Using the scaling factor of 5 the Antiproton Source 8 GeV ASE limit is 3.6 x 10^{13} * 5 = 1.8 x 10^{14} protons/hour.
Using the scaling factor of 5 the Antiproton Source 120 GeV ASE limit is 1.8 x 10^{16} * 5 = 9.0 x 10^{16} protons/hour.
Using power scaling from the 120 GeV ASE limit to 8 Gev is a factor of 15. 9.0 x 10^{16} * 15 = 1.35 x 10^{18} protons/hour.

Requirement

The Muon Campus segment will be operated within the following parameters during Off Target/Mu2e Experimental Mode:

Mode	Intensity	Energy
8 GeV Primary beam around AP-0 target, through Delivery Ring to Diagnostic Absorber (DA)	1.80e14 protons/hr	8 GeV

These parameters are further specified in the Operation Authorization Document.

Muon Campus intensity for Off Target/Mu2e Experimental Mode is monitored via: M:TOR704

Compensatory Measure(s)

Alternative methods of monitoring intensity may be used.

Required Surveillance

none

Response

Beam operation to the Muon Campus will be terminated. Beam operation to the Muon Campus will not resume until approval is received from the AD Associate Lab Director and the DOE Field Element Manager.

P3-Switchyard 120 Credited Controls

Passive – Shielding

Applicability During beam operations to the P3-Switchyard 120 segment of the Fermilab Main Accelerator.

Basis Based on the Nominal Operating Intensity of 6.00e14 protons/hr, supported by the following Shielding Assessments, the shielding is required in the locations listed below.

Shielding Assessment(s):

- 2017 P3 to SY Absorber Incremental Shielding Assessment [19]
- 2019 P3 to SY Absorber Incremental Shielding Assessment for IERC [20]

Requirement Required shielding specified in the listed Shielding Assessments will be installed in its proper configuration during applicable beam operations.

The listed Shielding Assessment(s) utilized the incremental shielding assessment methodology, required shielding is summarized here.

Permanent Longitudinal Shielding

Cell or Longitudinal Range (ft)	Description	Current Shielding (efd)	Required (efd)
17880-18550	Tevatron Tunnel	20.6	14.4
18550-18600	F2 Fridge Bldg	17.7	3.0
18600-19332	Tunnel	20.6	14.4
19332-19345	F3 Fridge Bldg	15.2	3.0
19345-19815	Tunnel	20.6	14.4
19815-19867	S Booster Road	20.1	18.8
19867-20114	Tunnel	20.6	14.4
20114-20128	F4 Fridge Bldg	17.9	3.0
20128-20313	Tunnel	20.6	14.4
20313-20370	Transfer Hall	17.6	14.4
20370-20376	A0 Crossover	15.5	7.2
20376-00130	Transfer Hall	17.5	14.4
130-175	Transfer Hall TLM1	16.6	7.2
175-215	Transfer Hall TLM1	17.5	7.2
215-265	Crossover Road	16.7	7.2
265-360	TH Ext. to Enc. B	21.0	7.2
360-740	Enclosure B	20.7	9.5
740-750	Enc B Cryo Vent	22.2	5.1
750-807	Enclosure B	22.4	9.5

807-920	Berm Pipe	23.0	21.2
920-1250	Enclosure C TLM2	20.6	9.5
1250-1265	Enclosure C TLM2	19.8	9.5
1265-1290	Road D/Pine Street	19.8	16.6
1290-1333	Road D Culvert	18.8	16.8
1333-1495	NC Pipe	21.5	21.2
1495-1520	SY Absorber	23.0	21.2

Permanent Transverse Shielding

Cell or Transverse Station (ft)	Description	Current Shielding (efd)	Required (efd)
17910	TeV Tunnel F17	20.0	18.8
18100	TeV Tunnel	22.0	14.4
18302	TeV Tunnel	22.0	14.4
18355	TeV Tunnel F23	15.3	14.4
18410	TeV Tunnel	20.0	14.4
18535	TeV Tunnel	18.9	14.4
18569	TeV Tunnel F2	18.5	3.0
18605	TeV Tunnel	19.3	14.4
18695	TeV Tunnel	19.8	14.4
18753	TeV Tunnel F27	15.3	14.4
18811	TeV Tunnel	21.0	14.4
19050	TeV Tunnel	20.8	14.4
19317	TeV Tunnel	18.6	14.4
19342	TeV Tunnel F3	18.6	3.0
19367	TeV Tunnel	18.6	14.4
19650	TeV Tunnel	19.8	14.4
19750	TeV Tunnel	17.6	14.4
19842	S. Booster Road	18.0	16.8
19925	TeV Tunnel	18.5	14.4
20098	TeV Tunnel	21.0	14.4
20122	TeV Tunnel F4	15.4	3.0
20148	TeV Tunnel	21.0	14.4
20390	Transfer Hall	12.0	7.2
0	Transfer Hall A0	17.8	7.2
85	TH PFN Pit	20.8	14.4
124	TG Annex	12.7	7.2
175	C-2 Manhole	58.0	7.2
184	P-8 Manhole	46.3	7.2
200	Transfer Hall	19.0	7.2

236	Transfer Hall	16.5	7.2
251	C-3A Manhole	57.7	7.2
260	P-65 Manhole	34.7	7.2
273	WH-C-1 Manhole	13.5	7.2
300	Trans. Hall Ext.	20.1	7.2
385	P-65A Manhole	24.0	9.5
400	Encl. B	22.4	9.5
438	C-3B Manhole	31.9	9.5
500	Encl. B	22.4	9.5
600	Encl. B	22.0	9.5
700	Encl. B	22.0	9.5
800	Encl. B	22.0	9.5
814	C-3C Manhole	38.3	21.2
900	Pipe	23.5	21.2
948	P-64 Manhole	28.3	9.5
986	P-64A Manhole	18.2	9.5
1000	Encl. C	22.0	9.5
1100	Encl. C	22.0	9.5
1200	Encl. C	22.0	9.5
1280	Road D	20.5	16.8
1330	Pipe	22.2	21.2
1510	SY Absorber	25.6	21.2

Movable Shielding

Location	Shielding Type	Quantity	Purpose	Preferred Method of Configuration (if specified)	Comments
TG9 ZP96	Solid Poly	Multiple rods	Penetration	none	multiple rods of various diameters
TG9 ZP93	Solid Poly	Multiple rods	Penetration	none	multiple rods of various diameters
TG9 ZP90	Solid Poly	Multiple rods	Penetration	none	multiple rods of various diameters
TG8 ZP83-84-85	Solid Poly	Multiple rods	Penetration	none	multiple rods of various diameters
TG6 ZP64	Solid Poly	Multiple rods	Penetration	none	multiple rods of various diameters

TG3 ZP30	Solid Poly	Multiple rods	Penetration	none	multiple rods of various diameters
TG4 ZP47	Solid Poly	Multiple rods	Penetration	none	multiple rods of various diameters
TG4	Solid Poly	Multiple rods	Penetration	none	multiple rods of various diameters
TGS-110	Poly Beads	Multiple	Penetration	none	
F13	Sand	Hand filled	To occlude the F13 cryo penetrations	Signs	For both Switchyard and Muon Campus running
F47-4	Sand	1	8" Cryo Pen		By Theilacker 1991 Tev 99 SA 99-4

Penetration Shielding

Location	Shielding Type	Quantity	Purpose	Preferred Method of Configuration (if specified)	Comments
z=2327'	Sand	14.7'	4 of 8 cable penetrations to G2 Service Bldg.		see PWKS-NM31

Compensatory Measure(s) In lieu of required shielding, temporary controls, such as guards, fencing, ropes, and/or postings, may be utilized as approved by the SRSO. Each use of a Compensatory Measure shall be documented using the USI Process.

Required Surveillance Required shielding shall be verified annually, not to exceed twelve (12) months.

Response Beam operation to the P3-Switchyard 120 will be terminated. Beam operation to the P3-Switchyard 120 will not resume until approval is received from the AD Associate Lab Director and the DOE Field Element Manager.

Passive – Fencing

Applicability During beam operations to the P3-Switchyard 120 segment of the Fermilab Main Accelerator.

Basis

Based on the Nominal Operating Intensity of 6.00e14 protons/hr, supported by the following Shielding Assessments, the shielding is required in the locations listed below.

Shielding Assessment(s):

- 2017 P3 to SY Absorber Incremental Shielding Assessment [19]
- 2019 P3 to SY Absorber Incremental Shielding Assessment for IERC [20]

Requirement

Required fencing specified in the listed Shielding Assessments will be installed in its proper configuration during applicable beam operations.

Radiation Area Fencing

Fence Location	Required Posting	Gates (if applicable)	Configuration
South end at F13 across the berm	Radiation Area	NA	• 4 ft height • Standing upright between 60-120° No missing or bent pieces creating a person-sized hole (~1ft^2)
West side of enclosure berm running between F13 to the east of M1 block house AP0 Building	Radiation Area	AP1PA1	• 4 ft height • Standing upright between 60-120° • No missing or bent pieces creating a person-sized hole (~1ft^2) • Gates locked with Rad Fence Padlock
East side of enclosure berm from F13 to F1 Refrigerator building	Radiation Area	F1PA1	• 4 ft height • Standing upright between 60-120°

			• No missing or bent pieces creating a person-sized hole (~1ft^2) • Gates locked with Rad Fence Padlock
F-1 Refrigerator building to F17 Kicker Building	Radiation Area	NA	• 4 ft height • Standing upright between 60-120° • No missing or bent pieces creating a person-sized hole (~1ft^2)
F17 Kicker building to F23 support building	Radiation Area	F17PA1	• 4 ft height • Standing upright between 60-120° • No missing or bent pieces creating a person-sized hole (~1ft^2) • Gates locked with Rad Fence Padlock
F23 Support Building to F3 Refrigerator Building	Radiation Area	F23PA1 F3PA1	• 4 ft height • Standing upright between 60-120° • No missing or bent pieces creating a

			person-sized hole (~1ft^2) • Gates locked with Rad Fence Padlock
F3 Refrigerator Building to F43 road crossover	Radiation Area	F43PA1	• 4 ft height • Standing upright between 60-120° • No missing or bent pieces creating a person-sized hole (~1ft^2) • Gates locked with Rad Fence Padlock
North end along F43 crossover road	Radiation Area	NA	• 4 ft height • Standing upright between 60-120° • No missing or bent pieces creating a person-sized hole (~1ft^2)
West side of berm from F43 crossover running south to Antiproton test pit.	Radiation Area	NA	• 4 ft height • Standing upright between 60-120° • No missing or bent pieces creating a person-sized hole (~1ft^2)
East to West north end of	Radiation Area	AP0PA2	• 4 ft height • Standing upright

Antiproton test pit			between 60-120° • No missing or bent pieces creating a person-sized hole (~1ft^2) • Gates locked with Rad Fence Padlock
Northwest corner of Antiproton test pit running south to AP0	Radiation Area	AP0PA1	• 4 ft height • Standing upright between 60-120° • No missing or bent pieces creating a person-sized hole (~1ft^2) • Gates locked with Rad Fence Padlock
North side of F43 crossover along the road	Radiation Area	NA	• 4 ft height • Standing upright between 60-120° • No missing or bent pieces creating a person-sized hole (~1ft^2)
West side of enclosure berm running north from F43 crossover to Booster period 12 fan room	Radiation Area	NA	• 4 ft height • Standing upright between 60-120° • No missing or bent pieces

			creating a person-sized hole (~1ft^2)
East side of berm running north from F43 crossover to F4 Refrigerator building	Radiation Area	F43PA2 F4PA1	• 4 ft height • Standing upright between 60-120° • No missing or bent pieces creating a person-sized hole (~1ft^2) • Gates locked with Rad Fence Padlock
F4 Refrigerator Building to A0 ramp	Radiation Area	F4PA2 A0PAS1	• 4 ft height • Standing upright between 60-120° • No missing or bent pieces creating a person-sized hole (~1ft^2) • Gates locked with Rad Fence Padlock
A0 ramp east side of berm running north to Transfer Hall crossover road	Radiation Area	A0PA2	• 4 ft height • Standing upright between 60-120° • No missing or bent pieces creating a person-sized hole (~1ft^2)

			• Gates locked with Rad Fence Padlock
South side of A0 crossover road running east to west to the Transfer Gallery Annex	Radiation Area	A0PA1	• 4 ft height • Standing upright between 60-120° • No missing or bent pieces creating a person-sized hole (~1ft^2) • Gates locked with Rad Fence Padlock

Controlled Area Fencing
none

Compensatory Measure(s) In lieu of required fencing, temporary controls, such as guards, ropes, and/or postings, may be utilized as approved by the SRSO. Each use of a Compensatory Measure shall be documented using the USI Process.

Required Surveillance Required fencing shall be verified annually, not to exceed twelve (12) months.

Response Beam operation to the P3-Switchyard 120 will be terminated. Beam operation to the P3-Switchyard 120 will not resume until approval is received from the AD Associate Lab Director and the DOE Field Element Manager.

Active Engineered – Radiation Safety Interlock System (RSIS)

Applicability During beam operations to the P3-Switchyard 120 segment of the Fermilab Main Accelerator.

Basis Based on the Nominal Operating Intensity of 6.00e14 protons/hr, supported by the following Shielding Assessments, the RSIS is established with interlocked barriers around the Exclusion Area, as well as inclusion of required interlocked radiation monitors.

Shielding Assessment(s):
- 2017 P3 to SY Absorber Incremental Shielding Assessment [19]

- 2019 P3 to SY Absorber Incremental Shielding Assessment for IERC [20]

Requirement

The Radiation Safety Interlock System (RSIS) must prevent entry into the following Exclusion Area(s) during appliable beam operation:

- Transfer Hall
- Enclosure B
- Enclosures C, D, E & G1 Stub

Required components of the RSIS shall be specified in the P3-Switchyard 120's Operation Authorization Document.

The following components of the Radiation Safety Interlock System (RSIS) shall be in place, with no known loss of safety function, during applicable beam operations.

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	A0 Ramp
Chipmunk	Transfer Hall Head House N Addition #2
Chipmunk	Transfer Hall Head House N Addition #1
Chipmunk	A0 Kicker Room South
Chipmunk	A0 Kicker Room Middle
Chipmunk	A0 Kicker Room North
Chipmunk	F4 Refrigerator Building
Chipmunk	F3 Refrigerator Building
Chipmunk	F23 Kicker Building
Chipmunk	F2 Refrigerator Building
TLM	Swyd Enc B TLM
TLM	Swyd Enc C TLM

Compensatory Measure(s)

In lieu of required interlocked detectors, temporary controls, such as guards, fencing, ropes, and/or postings, may be utilized as approved by the SRSO. Each use of a Compensatory Measure shall be documented using the USI Process.

Required Surveillance

The RSIS for the P3-Switchyard 120 segment shall undergo certification annually, not to exceed twelve (12) months.

Response

Beam operation to the P3-Switchyard 120 will be terminated. Beam operation to the P3-Switchyard 120 will not resume until approval is received from the AD Associate Lab Director and the DOE Field Element Manager.

Active Engineered – Oxygen Deficiency Hazard (ODH) Safety System

Applicability	Not applicable
Basis	Not applicable
Requirement	none
Compensatory Measure(s)	Not applicable
Required Surveillance	none
Response	none

Administrative – Operation Authorization Document

Applicability	During beam operations to the P3-Switchyard 120 segment of the Fermilab Main Accelerator.
Basis	To summarize the bounding conditions for safe operation of the P3-Switchyard 120, and to provide explicit approval for operations of the P3-Switchyard 120.
Requirement	An approved P3-Switchyard 120 Beam Permit & Running Condition shall be issued prior to P3-Switchyard 120 beam operations.
Compensatory Measure(s)	none
Required Surveillance	The P3-Switchyard 120 Beam Permit and Running Condition shall be verified annually, not to exceed twelve (12) months.
Response	Beam operation to the P3-Switchyard 120 will be terminated. Beam operation to the P3-Switchyard 120 will not resume until approval is received from the AD Associate Lab Director and the DOE Field Element Manager.

Administrative – Staffing

Applicability	During beam operations to the P3-Switchyard 120 segment of the Fermilab Main Accelerator.

Basis	To ensure operations within bounding conditions specified in Operation Authorization Document, and to disable beam operation to the P3-Switchyard 120 and initiate an immediate response in the event of a determined ASE violation.
Requirement	The following staffing shall be in place during applicable beam operation: • At least one member of the AD Operations Department who has achieved the rank of Operator II or higher shall be on shift. • At least one member of the AD Operations Department shall be present in the Main Control Room (MCR).
Compensatory Measure(s)	none
Required Surveillance	none
Response	Beam operation to the P3-Switchyard 120 will be terminated. Beam operation to the P3-Switchyard 120 will not resume until approval is received from the AD Associate Lab Director and the DOE Field Element Manager.

Administrative – Accelerator Operating Parameters

Applicability	During beam operations to the P3-Switchyard 120 segment of the Fermilab Main Accelerator.
Basis	Longitudinal, Transverse, and Labyrinth and Penetration spreadsheets were scaled using criteria 2 and 3 to find the weakest point in the shielding. Transverse spreadsheet GK-03 category 2 and 3 areas changed to 4 fail at 1.61 x 10^{16} protons/hour. Transverse spreadsheet GK-07 category 4 areas fail at 3.10 x 10^{15} protons/hour. Apply scaling of 100 for a fenced area, 3.1 x 10^{15} * 100 = 3.1 x 10^{17} protons/hour. Transverse spreadsheet GK-07 category 2 and 3 areas changed to 4 fail at 1.49 x 10^{17} protons/hour. Transverse spreadsheet GK-10 category 4 areas fail at 1.24 x 10^{16} protons/hour. Apply scaling of 100 for a fenced area, 1.24 x 10^{16} * 100 = 1.24 x ^{18} protons/hour. Longitudinal spreadsheet GK-04 category 2 and 3 areas changed to 4 fail at 1.03 x 10^{16} protons/hour. Longitudinal spreadsheet GK-08 category 4 areas fail at 2.48 x 10^{15} protons/hour. Apply scaling of 100 for a fenced area. 2.48 x 10^{15} * 100 = 2.48 x 10^{17} protons/hour. Longitudinal spreadsheet GK-08 category 2 and 3 areas changed to 4 fail at 9.56 x 10^{16} protons/hour. Longitudinal spreadsheet GK-11 category 4 areas fail at 1.86 x 10^{16} protons/hour. Apply scaling of 100 for a fenced area, 1.86 x 10^{16} * 100 = 1.86 x ^{18} protons/hour.

Penetration spreadsheet GK-09 category 2 and 3 areas changed to 4 fail at 7.70 x 10^{16} protons/hour.
Penetration spreadsheet GK-09 category 4 area fails at 6.58 x 10^{15} protons/hour.
Apply scaling of 100 for a fenced area 6.58 x 10^{15} * 100 = 6.58 x 10^{17} protons/hour.
Penetration spreadsheet GK-05 category 2 and 3 areas changed to 4 fail at 1.24 x 10^{16} protons/hour.
Penetration spreadsheet GK-05 category 4 area fails at 1.20 x 10^{16} protons/hour.
Apply scaling of 100 for a fenced area 1.20 x 10^{16} * 100 = 1.2 x ^{18} protons/hour.
Penetration spreadsheet GK-02
F1, 2, 3, 4 Personnel Access labyrinths dose is 9.72 mrem/hour with 2.483 x 10^{15} protons/hour. Scaling to 500 mrem/hour accident condition is a factor of 51.44 higher, 2.483 x 10^{15} * 51.44 = 1.277 x 10^{17} protons/hour.
A0 Survey riser is the penetration with the largest calculated dose/pulse that is not protected by an interlocked detector. The calculated dose is 2.2e-2 mrem/pulse. This would yield a dose rate of 27.3 mrem/hour. Scaling to a 500 mrem accident condition is a factor of 18.3 higher,
2.483 x 10^{15} * 18.3 = 4.544 x 10^{16} protons/hour.
The limiting area is the longitudinal spreadsheet GK-04, the ASE is set to 1.03 x 10^{16} protons/hour.

Requirement

The P3-Switchyard 120 segment will be operated within the following parameters:

Mode	Intensity	Energy
Beam to Switchyard Absorber	1.03e16 protons/hr	120 GeV

These parameters are further specified in the Operation Authorization Document.

P3-Switchyard 120 intensity is monitored via: S:SYDINT

Compensatory Measure(s)

Alternative methods of monitoring intensity may be used.

Required Surveillance

none

Response

Beam operation to the P3-Switchyard 120 will be terminated. Beam operation to the P3-Switchyard 120 will not resume until approval is received from the AD Associate Lab Director and the DOE Field Element Manager.

Meson Primary Credited Controls

Passive – Shielding

Applicability During beam operations to the Meson Primary segment of the Fermilab Main Accelerator.

Basis Based on the Nominal Operating Intensity of 1.68e14 protons/hr, supported by the following Shielding Assessments, the shielding is required in the locations listed below.

Shielding Assessment(s):

- 2003 Shielding Assessment for the SY120 Project [22]
- 2017 P3 to SY Absorber Incremental Shielding Assessment [19]
- 2017 Further Explanation of Assessed Beam Intensity for P3 to SY Absorber. [21]

Requirement Required shielding specified in the listed Shielding Assessments will be installed in its proper configuration during applicable beam operations.

The listed Shielding Assessment(s) utilized the incremental shielding assessment methodology, required shielding is summarized here.

Permanent Longitudinal Shielding

Cell or Longitudinal Range (ft)	Description	Current Shielding (efd)	Required (efd)
900-1237	Encl C	21.7	16.9
1237-1335	Road D	18.8	14.9
1335-1615	Encl C	22.1	16.9
1615-1635	Hatch	20.0	13.1
1635-2058	Enc. C	21.0	16.9
2058-2130	Enc. C	21.0	16.9
2130-2308	Pipe	21.6	16.9
2308-2350	F1	19.3	14.9
2350-2370	F1 Hatch	19.2	13.1
2370-2413	G2 Road	19.9	14.9

2413-2480	F1	21.0	16.9
2480-2850	Road B	21.3	13.1
2850-2950	Substation	20.6	16.9
2950-3005	F2 manhole	18.0	11.6
3005-3350	Substation	14.8	11.6
3347-3475	pipe	18.1	14.0
3475-3558	F3	18.7	14.0
3558-3950	4' pipe	17.7	14.0
3950-3967	4' pipe	18.6	14.0
3967-4003	M01	15.7	11.6
4003-4062	M01	16.5	11.6
4062-4160	M01	20.4	11.6
4160-4300	M01	16.4	11.6
4300-4340	targ. tube	25.8	11.6

Permanent Transverse Shielding

Cell or Transverse Station (ft)	Description	Current Shielding (efd)	Required (efd)
M001000	Enc. C	20.3	14.9
M001100	Enc. C	20.0	14.9
M001200	Enc. C	20.2	14.9
M001280	Road D	18.5	14.9
M001330	Enc. C	20.0	14.9
M001500	Swyd Dump	20.5	14.9
M001600	Enc. C	20.4	14.9
M001620	Enc. C Hatch	20.5	11.6

M001640	X Tunnel	20.1	10.1
M002050	Enc. C Laby.	21.0	17.1
M002100	Enc. C	20.8	17.1
M002200	Pipe	22.5	19.1
M002340	F1 Laby.	20.3	17.1
M002360	F1 Hatch	20.0	11.6
M002400	G2 Road	20.7	16.9
M002600	Pipe	21.8	13.1
M002750	Road B	22.2	16.9
M002950	F2 Laby.	18.3	14.9
M003200	Pipe	15.1	11.6
ME13353	10"Pipe	17.8	14.0
ME13400	10"Pipe	17.0	14.0
ME13450	10"Pipe	18.2	14.0
ME13500	F3 manhole	18.3	14.0
ME13550	F3 manhole	17.4	14.0
ME13552	F3 manhole	17.3	14.0
ME13600	4' B. Pipe	17.7	14.0
ME13650	4' B. Pipe	18.3	14.0
ME13700	4' B. Pipe	19.0	14.0
ME13750	4' B. Pipe	17.4	14.0
ME13800	4' B. Pipe	18.0	14.0
ME13850	4' B. Pipe	17.3	14.0
ME13900	4' B. Pipe	18.4	14.0
ME13950	4' B. Pipe	17.5	14.0

ME13975	M01	15.8	11.6
ME14000	M01	15.7	11.6
MC14035	M01	20.7	11.6
ME14050	M01	21.3	11.6
ME24250	M01	19.0	11.6

Movable/Penetration Shielding

Location	Shielding Type	Quantity	Purpose	Preferred Method of Configuration (if specified)	Comments
z = 5115'	Concrete	Many blocks	M03 west exit labyrinth		Blocks arranged to create additional labyrinth leg
z = 5160'	Concrete	Many blocks	MTest second primary target	Chained & locked	Target in M03 for low-energy pion mode
z = 5200'	Concrete	Many blocks	MTest low-energy pion mode dump in M03		Absorbs uninteracted 120 GeV protons
z = 5100'	Sand	5.5' high	Duct in ceiling of DS exit labyrinth to MS3		
z = 4010'	Concrete & Sand	Many blocks	M01 rail spur plug		89" heavy concrete on cart; 13' sand in gap underneath
z = 4128'	Steel & Concrete	1.7' steel; 2.5' concrete	Four 5" dia. cable ducts between M01 and MS1		Steel before mouths, concrete after exits of ducts
z = 4144'	Steel & Concrete	1.7' steel; 2.5' concrete	Four 5" dia. cable ducts between M01 and MS1		Steel before mouths, concrete after exits of ducts
z = 4158'	Steel & Concrete	1.7' steel; 2.5' concrete	Four 5" dia. cable ducts		Steel before mouths, concrete

			between M01 and MS1		after exits of ducts
z = 4350'	Sand	19.5'	Unused 8" dia. vent duct		Completely filled with sand
z ~ 4438'	Steel & Concrete	1.7' steel; 1.5' concrete	Four 5" dia. cable ducts between M02 and MS2		Steel before mouths, concrete after exits of ducts
z ~ 4467'	Steel & Concrete	1.7' steel; 1.5' concrete	Four 5" dia. cable ducts between M02 and MS2		Steel before mouths, concrete after exits of ducts
z ~ 4475'	Steel & Concrete	1.7' steel; 1.5' concrete	Four 5" dia. cable ducts between M02 and MS2		Steel before mouths, concrete after exits of ducts
z = 4545'	Sand	33'	M02 old cryo labyrinth		Sand confined by cinder block walls
z = 4550'	Concrete	12'	M02 & MS2 east downstream labyrinth		12' blocks at rollup door plus 4' fence shield from MC & MT losses
z = 4550'	Sand	20'	M02 sight riser		In crossover above MW beam
z = 4750'	Sand	20.5'	M03 sight riser		In crossover between MW and MC beams
z = 4975'	Concrete	12'	M03 rollup door near MS3		
z = 4975'	Concrete	2 D blocks 1.5' x 3' x 6'	M03 labyrinth into MS3 short circuit		
z = 4985'	Sand	16.5'	M03 sight riser		

Compensatory Measure(s)

In lieu of required shielding, temporary controls, such as guards, fencing, ropes, and/or postings, may be utilized as approved by the SRSO. Each use of a Compensatory Measure shall be documented using the USI Process.

Required Surveillance Required shielding shall be verified annually, not to exceed twelve (12) months.

Response Beam operation to the Meson Primary will be terminated. Beam operation to the Meson Primary will not resume until approval is received from the AD Associate Lab Director and the DOE Field Element Manager.

Passive – Fencing

Applicability During beam operations to the Meson Primary segment of the Fermilab Main Accelerator.

Basis Based on the Nominal Operating Intensity of 1.68e14 protons/hr, supported by the following Shielding Assessments, the shielding is required in the locations listed below.

Shielding Assessment(s):

- 2003 Shielding Assessment for the SY120 Project [22]
- 2017 P3 to SY Absorber Incremental Shielding Assessment [19]
- 2017 Further Explanation of Assessed Beam Intensity for P3 to SY Absorber. [21]

Requirement Required fencing specified in the listed Shielding Assessments will be installed in its proper configuration during applicable beam operations.

Radiation Area Fencing

Fence Location	Required Posting	Gates (if applicable)	Configuration
F1 Manhole Drop Hatch	Radiation Area		• 4 ft height • Standing upright between 60-120° • No missing or bent pieces creating a person-sized hole (~1ft^2) • Gates locked with Rad Fence Padlock

Master Substation Running north south along discovery road	Radiation Area	NA	• Metal Fence used for electrical hazard protection
North end of Master Sub Station running east west from Discover Road over enclosure to F3 Manhole access road	Radiation Area	NA	• Metal fence used for electrical hazard protection
West side of berm running north south from F3 Manhole access road to the Master Substation control building	Radiation Area	F2MPA3 F2MPA2	• 4 ft height • Standing upright between 60-120° • No missing or bent pieces creating a person-sized hole (~1ft^2) • Gates locked with Rad Fence Padlock
Master Station Building running east west to near Discovery Road	Radiation Area	F2MVA1	• Metal fence used for electrical Hazard protection • Gates locked with Rad Fence Padlock
From Master Substation east side of Meson berm running north south to MS1 Service Building	Radiation Area	M01PAE	• 4 ft height • Standing upright between 60-120° • No missing or bent pieces

			creating a person-sized hole (~1ft^2) • Gates locked with Rad Fence Padlock
MS1 Service Building to MS2 Service Building	Radiation Area	M02PAE	• 4 ft height • Standing upright between 60-120° • No missing or bent pieces creating a person-sized hole (~1ft^2) • Gates locked with Rad Fence Padlock
MS2 Service Building to MS3 Service Building	Radiation Area	M02VAE2 M03VAE M03PAE1	• 4 ft height • Standing upright between 60-120° • No missing or bent pieces creating a person-sized hole (~1ft^2) • Gates locked with Rad Fence Padlock
M03Service Building to MDB	Radiation Area	M03PAE2 M04PAE M04VAE	• 4 ft height • Standing upright between 60-120° • No missing or bent pieces creating a

			person-sized hole (~1ft^2) • Gates locked with Rad Fence Padlock
From Meson Service Building 4 west side of berm running north south by West Batavia Road to Meson Central Cryo	Radiation Area	M05PA1 M04VAW	• 4 ft height • Standing upright between 60-120° • No missing or bent pieces creating a person-sized hole (~1ft^2) • Gates locked with Rad Fence Padlock
Meson Central Cryo running north south to Master Substation	Radiation Area	M02VAW2 M02VAW1 M01PAW	• 4 ft height • Standing upright between 60-120° • No missing or bent pieces creating a person-sized hole (~1ft^2) Gates locked with Rad Fence Padlock

Controlled Area Fencing
none

Compensatory Measure(s)

In lieu of required fencing, temporary controls, such as guards, ropes, and/or postings, may be utilized as approved by the SRSO. Each use of a Compensatory Measure shall be documented using the USI Process.

Required Surveillance

Required fencing shall be verified annually, not to exceed twelve (12) months.

Response Beam operation to the Meson Primary will be terminated. Beam operation to the Meson Primary will not resume until approval is received from the AD Associate Lab Director and the DOE Field Element Manager.

Active Engineered – Radiation Safety Interlock System (RSIS)

Applicability During beam operations to the Meson Primary segment of the Fermilab Main Accelerator.

Basis Based on the Nominal Operating Intensity of 1.68e14 protons/hr, supported by the following Shielding Assessments, the RSIS is established with interlocked barriers around the Exclusion Area, as well as inclusion of required interlocked radiation monitors.

Shielding Assessment(s):
- 2003 Shielding Assessment for the SY120 Project [22]
- 2017 P3 to SY Absorber Incremental Shielding Assessment [19]
- 2017 Further Explanation of Assessed Beam Intensity for P3 to SY Absorber. [21]

Requirement The Radiation Safety Interlock System (RSIS) must prevent entry into the following Exclusion Area(s) during appliable beam operation:
- F1
- F2
- F3
- M01
- M02
- M03
- M04
- M05

Required components of the RSIS shall be specified in the Meson Primary's Operation Authorization Document.

The following components of the Radiation Safety Interlock System (RSIS) shall be in place, with no known loss of safety function, during applicable beam operations.

<u>Radiation Safety System – Interlocked Radiation Monitors</u>
None required

Compensatory Measure(s)	In lieu of required interlocked detectors, temporary controls, such as guards, fencing, ropes, and/or postings, may be utilized as approved by the SRSO. Each use of a Compensatory Measure shall be documented using the USI Process.
Required Surveillance	The RSIS for the Meson Primary segment shall undergo certification annually, not to exceed twelve (12) months.
Response	Beam operation to the Meson Primary will be terminated. Beam operation to the Meson Primary will not resume until approval is received from the AD Associate Lab Director and the DOE Field Element Manager.

Active Engineered – Oxygen Deficiency Hazard (ODH) Safety System

Applicability	During personnel access into the Meson (M02, M03, M04, M05)
Basis	Based on the ODH Analysis, the ODH Safety System is established with specified required components.
Requirement	The following components of the Oxygen Deficiency Hazard (ODH) Safety System shall be in place, with no known loss of safety function, during personnel access into applicable areas. • One (1) area/fixed oxygen monitor
Compensatory Measure(s)	Temporary updated ODH postings and associated requirements and/or restrictions may be implemented following a component failure to allow reentry to fix failed components based on either: (1) an existing and approved out-of-service policy, or (2) an updated ODH analysis approved by the Cryogenic Safety Subcommittee (CSS).
Required Surveillance	• Testing area/fixed oxygen monitors every six (6) months per established procedure
Response	Beam operation to the Neutrino Muon will be terminated. Beam operation to the Neutrino Muon will not resume until approval is received from the AD Associate Lab Director and the DOE Field Element Manager.

Administrative – Operation Authorization Document

Applicability	During beam operations to the Meson Primary segment of the Fermilab Main Accelerator.
Basis	To summarize the bounding conditions for safe operation of the Meson Primary, and to provide explicit approval for operations of the Meson Primary.

Requirement	An approved Meson Primary Beam Permit & Running Condition shall be issued prior to Meson Primary beam operations.
Compensatory Measure(s)	none
Required Surveillance	The Meson Primary Beam Permit and Running Condition shall be verified annually, not to exceed twelve (12) months.
Response	Beam operation to the Meson Primary will be terminated. Beam operation to the Meson Primary will not resume until approval is received from the AD Associate Lab Director and the DOE Field Element Manager.

Administrative – Staffing

Applicability	During beam operations to the Meson Primary segment of the Fermilab Main Accelerator.
Basis	To ensure operations within bounding conditions specified in Operation Authorization Document, and to disable beam operation to the Meson Primary and initiate an immediate response in the event of a determined ASE violation.
Requirement	The following staffing shall be in place during applicable beam operation: • At least one member of the AD Operations Department who has achieved the rank of Operator II or higher shall be on shift. • At least one member of the AD Operations Department shall be present in the Main Control Room (MCR).
Compensatory Measure(s)	none
Required Surveillance	none
Response	Beam operation to the Meson Primary will be terminated. Beam operation to the Meson Primary will not resume until approval is received from the AD Associate Lab Director and the DOE Field Element Manager.

Administrative – Accelerator Operating Parameters

Applicability During beam operations to the Meson Primary segment of the Fermilab Main Accelerator.

Basis Longitudinal and Transverse spreadsheets were scaled using criteria 2 and 3 to find the weakest point in the shielding.
Transverse spreadsheet category 4 areas fail at 6.54×10^{15} protons/hour.
Longitudinal spreadsheet category 4 areas fail at 1.02×10^{16} protons/hour.
Transverse spreadsheet is the limiting area, so the ASE limit is 6.54×10^{15} protons/hour.

Requirement The Meson Primary segment will be operated within the following parameters:

Mode	Intensity	Energy
Beam to the M01 Target Train	6.54e15 protons/hr	120 GeV

These parameters are further specified in the Operation Authorization Document.

Meson Primary intensity is monitored via: S:F1SEM and/or F:MC1SEM

Compensatory Measure(s) Alternative methods of monitoring intensity may be used.

Required Surveillance none

Response Beam operation to the Meson Primary will be terminated. Beam operation to the Meson Primary will not resume until approval is received from the AD Associate Lab Director and the DOE Field Element Manager.

Meson Test Credited Controls

Passive – Shielding

Applicability During beam operations to the Meson Test segment of the Fermilab Main Accelerator during Low Energy Pion Mode, Diffracted Proton Mode, and/or High Energy Pion Mode.

Basis Based on the Nominal Operating Intensity of 1.20e13 protons/hr, supported by the following Shielding Assessments, the shielding is required in the locations listed below.

Shielding Assessment(s):

- 2003 Shielding Assessment for the SY120 Project [21]
- 2017 P3 to SY Absorber Incremental Shielding Assessment [19]
- "Post Assessment Document" to the 2003 SY 120 Shielding Assessment to Enable a Low Energy Pion Mode of Operation in the MTest Beamline [23]
- MTest 2016 Post Assessment for Operation of 32 GeV in Low Energy Pion Mode [24]
- Meson Test Operating Limits based on Operational Experience [25]

Requirement Required shielding specified in the listed Shielding Assessments will be installed in its proper configuration during applicable beam operations.

The listed Shielding Assessment(s) utilized the incremental shielding assessment methodology, required shielding is summarized here.

Permanent Longitudinal Shielding

Cell or Longitudinal Range (ft)	Description	Current Shielding (efd)	Required (efd)
4300-4340	Targ. Tube	25.9	11.6
4340-4605	M02	19.3	10.1
4605-4710	PIPE	25.3	11.6
4710-4716	M02	18.2	10.1
4716-4841	PIPE	23.5	11.6
4841-4889	M03	15.5	8.1

4889-4989	PIPE	17.7	11.6
4989-4995	M03	11.9	10.1
4995-5043	PIPE	17.4	11.6
5043-5164	M03	11.9	10.1
5164-5590	M03,4,5	11.9	3.0
5590-5618	M05	6.9	3.0

Permanent Transverse Shielding

Cell or Transverse Station (ft)	Description	Current Shielding (efd)	Required (efd)
ME24375	M02	21.6	10.1
MC24480	M02	22.3	10.1
MC24540	M02	21.6	10.1
MC24550	M02	17.4	10.1
MC34775	M02	22.2	11.6
MC34973	M03	18.1	11.6
MC34985	M03	13.1	10.1
ME35003	M03	19.8	11.6
ME35005	M03	19.8	11.6
MC35025	M03	17.3	11.6
MC35065	M03	13.6	10.1
MC45297	M04	12.7	3.0
MC55520	M05	14.3	3.0

Movable/Penetration Shielding

Location	Shielding Type	Quantity	Purpose	Preferred Method of Configuration (if specified)	Comments
z = 5620'	Steel & Poly	See comments	Empty cable ducts from MT6 Sec. 1 west alcove to MW		At least 2' steel and 1' poly rods in unused ducts
MT6.1 & MT6.2	Concrete	Many blocks	Construct MT6.1 and MT6.2 enclosures		
MT6.2	Concrete	Many Blocks	MTest downstream absorber		

Compensatory Measure(s) In lieu of required shielding, temporary controls, such as guards, fencing, ropes, and/or postings, may be utilized as approved by the SRSO. Each use of a Compensatory Measure shall be documented using the USI Process.

Required Surveillance Required shielding shall be verified annually, not to exceed twelve (12) months.

Response Beam operation to the Meson Test will be terminated. Beam operation to the Meson Test will not resume until approval is received from the AD Associate Lab Director and the DOE Field Element Manager.

Passive – Fencing

Applicability During beam operations to the Meson Test segment of the Fermilab Main Accelerator during Low Energy Pion Mode, Diffracted Proton Mode, and/or High Energy Pion Mode.

Basis Based on the Nominal Operating Intensity of 1.20e13 protons/hr, supported by the following Shielding Assessments, the shielding is required in the locations listed below.

Shielding Assessment(s):

- 2003 Shielding Assessment for the SY120 Project [21]
- 2017 P3 to SY Absorber Incremental Shielding Assessment [19]

- "Post Assessment Document" to the 2003 SY 120 Shielding Assessment to Enable a Low Energy Pion Mode of Operation in the MTest Beamline [23]
- MTest 2016 Post Assessment for Operation of 32 GeV in Low Energy Pion Mode [24]
- Meson Test Operating Limits based on Operational Experience [25]

Requirement Required fencing specified in the listed Shielding Assessments will be installed in its proper configuration during applicable beam operations.

Radiation Area Fencing
none

Controlled Area Fencing
none

Compensatory Measure(s) In lieu of required fencing, temporary controls, such as guards, ropes, and/or postings, may be utilized as approved by the SRSO. Each use of a Compensatory Measure shall be documented using the USI Process.

Required Surveillance Required fencing shall be verified annually, not to exceed twelve (12) months.

Response Beam operation to the Meson Test will be terminated. Beam operation to the Meson Test will not resume until approval is received from the AD Associate Lab Director and the DOE Field Element Manager.

Active Engineered – Radiation Safety Interlock System (RSIS)

Applicability During beam operations to the Meson Test segment of the Fermilab Main Accelerator during Low Energy Pion Mode, Diffracted Proton Mode, and/or High Energy Pion Mode.

Basis Based on the Nominal Operating Intensity of 1.20e13 protons/hr, supported by the following Shielding Assessments, the RSIS is established with interlocked barriers around the Exclusion Area, as well as inclusion of required interlocked radiation monitors.

Shielding Assessment(s):
- 2003 Shielding Assessment for the SY120 Project [21]
- 2017 P3 to SY Absorber Incremental Shielding Assessment [19]

- "Post Assessment Document" to the 2003 SY 120 Shielding Assessment to Enable a Low Energy Pion Mode of Operation in the MTest Beamline [23]
- MTest 2016 Post Assessment for Operation of 32 GeV in Low Energy Pion Mode [24]
- Meson Test Operating Limits based on Operational Experience [25]

Requirement

The Radiation Safety Interlock System (RSIS) must prevent entry into the following Exclusion Area(s) during appliable beam operation:

- MT6 Section 1
- MT6 Section 2

Required components of the RSIS shall be specified in the Meson Test's Operation Authorization Document.

The following components of the Radiation Safety Interlock System (RSIS) shall be in place, with no known loss of safety function, during applicable beam operations.

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	MT3 Cryo Labyrinth
Chipmunk	MS4 Service Building Gate
Chipmunk	MT6 West Side Gas House
Chipmunk	MT6 Section 2 for Portakamp
Chipmunk	MT6 Section 2 Beam Dump
Chipmunk	MT6 Section 2 on Blocks
Chipmunk	MT6 Section 2 US West Wall
Chipmunk	MT6 Section 2 DS West Wall CALICE

Compensatory Measure(s)

In lieu of required interlocked detectors, temporary controls, such as guards, fencing, ropes, and/or postings, may be utilized as approved by the SRSO. Each use of a Compensatory Measure shall be documented using the USI Process.

Required Surveillance

The RSIS for the Meson Test segment shall undergo certification annually, not to exceed twelve (12) months.

Response

Beam operation to the Meson Test will be terminated. Beam operation to the Meson Test will not resume until approval is received from the AD Associate Lab Director and the DOE Field Element Manager.

Active Engineered – Oxygen Deficiency Hazard (ODH) Safety System

Applicability	Not applicable
Basis	Not applicable
Requirement	none
Compensatory Measure(s)	Not applicable.
Required Surveillance	none
Response	Not applicable

Administrative – Operation Authorization Document

Applicability	During beam operations to the Meson Test segment of the Fermilab Main Accelerator during Low Energy Pion Mode, Diffracted Proton Mode, and/or High Energy Pion Mode.
Basis	To summarize the bounding conditions for safe operation of the Meson Test, and to provide explicit approval for operations of the Meson Test.
Requirement	At least one approved Meson Test Beam Permit & Running Condition for Low Energy Pion Mode, Diffracted Proton Mode, and/or High Energy Pion Mode shall be issued prior to Meson Test beam operations.
Compensatory Measure(s)	none
Required Surveillance	The Meson Test Beam Permit and Running Condition shall be verified annually, not to exceed twelve (12) months.
Response	Beam operation to the Meson Test will be terminated. Beam operation to the Meson Test will not resume until approval is received from the AD Associate Lab Director and the DOE Field Element Manager.

Administrative – Staffing

Applicability	During beam operations to the Meson Test segment of the Fermilab Main Accelerator during Low Energy Pion Mode, Diffracted Proton Mode, and/or High Energy Pion Mode.

Basis To ensure operations within bounding conditions specified in Operation Authorization Document, and to disable beam operation to the Meson Test and initiate an immediate response in the event of a determined ASE violation.

Requirement The following staffing shall be in place during applicable beam operation:
- At least one member of the AD Operations Department who has achieved the rank of Operator II or higher shall be on shift.
- At least one member of the AD Operations Department shall be present in the Main Control Room (MCR).

Compensatory Measure(s) none

Required Surveillance none

Response Beam operation to the Meson Test will be terminated. Beam operation to the Meson Test will not resume until approval is received from the AD Associate Lab Director and the DOE Field Element Manager.

Administrative – Accelerator Operating Parameters

Applicability During beam operations to the Meson Test segment of the Fermilab Main Accelerator during Low Energy Pion Mode, Diffracted Proton Mode, and/or High Energy Pion Mode.

Basis Longitudinal, Transverse, Labyrinth, and Penetration spreadsheets were scaled using criteria 2 and 3 to find the weakest point in the shielding.
Penetration spreadsheet GK-06 category 4 area fails at 6.58 x 10^{15} protons/hour.
Apply scaling of 100 for a fenced area, 6.58 x 10^{15} * 100 = 6.58 x 10^{17} protons/hour.
Penetration spreadsheet category 2 and 3 areas changed to 4 fail at 7.7 x 10^{16} protons/hour.
The most conservative area in Switchyard 120 area is longitudinal spreadsheet GK-04 that fails at 1.03 x 10^{16} protons/hour at the F3 refrigerator building. Although this is upstream of the MTest beamline, it is a reasonable bounding limitation for MTest as it was originally assessed, as there are no failures in MTest at a lower intensity. The ASE is set to 1.03 x 10^{16} protons/hour.

Requirement The Meson Test segment will be operated within the following parameters:

Mode	Intensity	Energy
Low Energy Pion Mode	1.03e16 protons/hr	120 GeV
Diffracted Proton Mode	1.03e16 protons/hr	120 GeV

High Energy Pion Mode	1.03e16 protons/hr	120 GeV

These parameters are further specified in the Operation Authorization Document.

Meson test intensity is monitored via: F:MW1SEM

Compensatory Measure(s) Alternative methods of monitoring intensity may be used.

Required Surveillance none

Response Beam operation to the Meson Test will be terminated. Beam operation to the Meson Test will not resume until approval is received from the AD Associate Lab Director and the DOE Field Element Manager.

Meson Center Credited Controls

Passive – Shielding

Applicability During beam operations to the Meson Center segment of the Fermilab Main Accelerator.

Basis Based on the Nominal Operating Intensity of 1.02e12 protons/hr, supported by the following Shielding Assessments, the shielding is required in the locations listed below.

Shielding Assessment(s):

- 2003 Shielding Assessment for the Switchyard 120 Project [21]
- 2013 Addendum to the SY120 Shielding Assessment for the Continued Operation of the Meson Center Beamline [23]
- 2018 "MC7 NOvA Beam Intensity Limit" Memo

Requirement Required shielding specified in the listed Shielding Assessments will be installed in its proper configuration during applicable beam operations.

The listed Shielding Assessment(s) utilized the incremental shielding assessment methodology, required shielding is summarized here.

Permanent Longitudinal Shielding

Cell or Longitudinal Range (ft)	Description	Current Shielding (efd)	Required (efd)
4300-4340	Targ. Tube	25.8	11.6
4340-4566	M02	18.6	11.6
4566-4656	M02	18.9	11.6
4656-4709	M02	21.5	11.6
4709-4936	PIPE	24.3	14.0
4936-4986	M03	17.5	11.6
4986-5297	PIPE	19.1	14.0
5297-5353	M04	15.1	9.1
5353-5518	PIPE	18.9	14.0
5518-5603	M05	15.5	11.6

5603-5662	MC6	15.0	11.6
5662-5733	MC6	7.8	3.0
5733-5790	MC6	6.6	3.0
5790-5793	MC6	3.3	3.0
5793-5798	MC6	0.0	0.0

Permanent Transverse Shielding

Transverse Station	Description	Current Shielding (efd)	Required (efd)
MC24520	M02	21.7	11.6
MC24550	M02	16.7	11.6
MC34985	M03	19.7	11.6
ME35003	M03	22.3	11.6
ME35005	M03	22.3	11.6
MC65655	MC6	16.9	11.6
MC65662-E	MC6	28.0	20.8
MC65662-W	MC6	39.1	20.8
MC65664-E	MC6	22.2	20.8
MC65670-W	MC6	29.7	20.8
MC65673-W	MC6	48.2	20.8
MC65679-W	MC6	26.4	20.8
MC65682-W	MC6	16.5	9.2
MC65685-W	MC6	13.2	9.2
MC65701-W	MC6	16.5	9.2
MC65715-W	MC6	9.9	9.2
MC65719-W	MC6	13.2	9.2
MC65722-W	MC6	9.9	9.2
MC65728-W	MC6	9.9	9.2
MC65733-E	MC6	26.5	9.2

MC65734-W	MC6	16.5	9.2
MC65735-W	MC6	13.2	9.2
MC65739-W	MC6	16.5	9.2
MC65741-E	MC6	24.9	9.2
MC65742-W	MC6	11.6	9.2
MC65743-W	MC6	14.9	9.2
MC65747-W	MC6	19.8	9.2
MC65749-E	MC6	26.5	9.2
MC65750-W	MC6	14.9	9.2
MC65754-W	MC6	19.8	9.2
MC65755-W	MC6	16.5	9.2
MC65757-W	MC6	11.6	9.2
MC65759-E	MC6	24.9	9.2
MC65759-W	MC6	11.6	9.2
MC65765-W	MC6	13.6	9.2
MC65767-E	MC6	18.2	9.2
MC65775-E	MC6	8.3	3.0
MC65788-E	MC6	11.6	3.0
MC65790-W	MC6	3.3	3.0
MC65791-E	MC6	8.3	3.0

Movable/Penetration Shielding

Location	Shielding Type	Quantity	Purpose	Preferred Method of Configuration (if specified)	Comments
MC6	Concrete	Many blocks	MC6 target enclosure	Roof blocks chained with PAD118 & MC6 Enter	
MC6	Spare MR Magnets	8 magnets in 3 stacks	MDB west of MC6 enclosure	Each stack chained with MC6 Enter & PAD118	Required by shielding

					assessment MARS model
z = 5790'	Concrete	5 C- & 2 B-blocks	MCenter control room in MWest tunnel	Top B-blocks chained with PAD118 & MC6 Enter	
z = 6075'	Steel & Concrete	Many blocks	MCenter Secondary Beam Absorber		AKA the "batting cage"; see drawing for details
z = 5300'	Sand	13' high	Sight riser in ceiling of 1000' crossover		Valve for emptying is not locked
z = 5510'	Sand	15' high	Sight riser in ceiling of 1200' crossover		No valve
z = 5300'	Concrete	14.5' thick	M04 east exit labyrinth rollup door		Shielding is in 1000' crossover tunnel west of ME
z = 5610'	Concrete	At least 6'	Protects MP6 from losses in MC5 and MT5		
z = 5517'	Concrete	At least 3'	Wall in 1200' crossover between MC & MP beamlines		Likely more than 3', but records are unavailable
z = 5517'	Concrete	At least 3'	Wall in 1200' crossover between ME & MP beamlines		Likely more than 3', but records are unavailable
MC7 NOvA Absorber	Concrete	3 "B" Blocks	NOvA Absorber	Posted as movable shielding	Per NOvA Shielding Assessment
MC7-2	Steel	Many Blocks	Secondary Target Shielding	Posted as movable shielding	Can be easily taken apart
z = 5410'	Sand	15' high	Cryo penetrations in MP4 tunnel		Sand is in two out of the three cryo penetrations
z = 5614'	Sand	13' high	Two penetrations in MP6 ceiling		

Compensatory Measure(s) In lieu of required shielding, temporary controls, such as guards, fencing, ropes, and/or postings, may be utilized as approved by the SRSO. Each use of a Compensatory Measure shall be documented using the USI Process.

Required Surveillance Required shielding shall be verified annually, not to exceed twelve (12) months.

Response Beam operation to the Meson Center will be terminated. Beam operation to the Meson Center will not resume until approval is received from the AD Associate Lab Director and the DOE Field Element Manager.

Passive – Fencing

Applicability During beam operations to the Meson Center segment of the Fermilab Main Accelerator.

Basis Based on the Nominal Operating Intensity of 1.02e12 protons/hr, supported by the following Shielding Assessments, the shielding is required in the locations listed below.

Shielding Assessment(s):

- 2003 Shielding Assessment for the Switchyard 120 Project [21]
- 2013 Addendum to the SY120 Shielding Assessment for the Continued Operation of the Meson Center Beamline [23]
- 2018 LArIAT Tertiary Beamline Post Assessment [27]
- 2023 TOAD MC7 Post Assessment [28]
- 2018 “MC7 NOvA Beam Intensity Limit” Memo

Requirement Required fencing specified in the listed Shielding Assessments will be installed in its proper configuration during applicable beam operations.

Radiation Area Fencing

Fence Location	Required Posting	Gates (if applicable)	Configuration
MC7 Batting cage	High Radiation Area	NA	• 8 ft height • Standing upright between 60-120° • No missing or bent pieces creating a

			person-sized hole (~1ft^2)
MC7 fence running east west between MC8 and MP enclosure	Radiation Area	MC7VAE	• 4 ft height • Standing upright between 60-120° • No missing or bent pieces creating a person-sized hole (~1ft^2) • Gates locked with Rad Fence Padlock
MC8 fence running east west between north end of MC8 and MW enclosure	Radiation Area	MC8MVAW	• 4 ft height • Standing upright between 60-120° • No missing or bent pieces creating a person-sized hole (~1ft^2) • Gates locked with Rad Fence Padlock

Controlled Area Fencing
none

Compensatory Measure(s)

In lieu of required fencing, temporary controls, such as guards, ropes, and/or postings, may be utilized as approved by the SRSO. Each use of a Compensatory Measure shall be documented using the USI Process.

Required Surveillance

Required fencing shall be verified annually, not to exceed twelve (12) months.

Response Beam operation to the Meson Center will be terminated. Beam operation to the Meson Center will not resume until approval is received from the AD Associate Lab Director and the DOE Field Element Manager.

Active Engineered – Radiation Safety Interlock System (RSIS)

Applicability During beam operations to the Meson Center segment of the Fermilab Main Accelerator.

Basis Based on the Nominal Operating Intensity of 1.02e12 protons/hr, supported by the following Shielding Assessments, the RSIS is established with interlocked barriers around the Exclusion Area, as well as inclusion of required interlocked radiation monitors.

Shielding Assessment(s):

- 2003 Shielding Assessment for the Switchyard 120 Project [21]
- 2013 Addendum to the SY120 Shielding Assessment for the Continued Operation of the Meson Center Beamline [23]
- 2018 LArIAT Tertiary Beamline Post Assessment [27]
- 2023 TOAD MC7 Post Assessment [28]

Requirement The Radiation Safety Interlock System (RSIS) must prevent entry into the following Exclusion Area(s) during appliable beam operation:

- MC6
- MC7
- MB7

Required components of the RSIS shall be specified in the Meson Center's Operation Authorization Document.

The following components of the Radiation Safety Interlock System (RSIS) shall be in place, with no known loss of safety function, during applicable beam operations.

<u>Radiation Safety System – Interlocked Radiation Monitors</u>

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	MC6 Target
Chipmunk	MC6 Absorber
Chipmunk	MC6 Catwalk
Chipmunk	MC6 Upstream West
Chipmunk	MC6 Midstream West
Chipmunk	MC6 Downstream West

Chipmunk	MC7-1 Experimental Area
Chipmunk	MC7-1 Downstream
Chipmunk	M05/ME6 Gate

Compensatory Measure(s) In lieu of required interlocked detectors, temporary controls, such as guards, fencing, ropes, and/or postings, may be utilized as approved by the SRSO. Each use of a Compensatory Measure shall be documented using the USI Process.

Required Surveillance The RSIS for the Meson Center segment shall undergo certification annually, not to exceed twelve (12) months.

Response Beam operation to the Meson Center will be terminated. Beam operation to the Meson Center will not resume until approval is received from the AD Associate Lab Director and the DOE Field Element Manager.

Active Engineered – Oxygen Deficiency Hazard (ODH) Safety System

Applicability Not applicable

Basis Not applicable

Requirement none

Compensatory Measure(s) Not applicable

Required Surveillance none

Response Not applicable

Administrative – Operation Authorization Document

Applicability During beam operations to the Meson Center segment of the Fermilab Main Accelerator.

Basis To summarize the bounding conditions for safe operation of the Meson Center, and to provide explicit approval for operations of the Meson Center.

Requirement An approved Meson Center Beam Permit & Running Condition shall be issued prior to Meson Center beam operations.

Compensatory Measure(s)	none
Required Surveillance	The Meson Center Beam Permit and Running Condition shall be verified annually, not to exceed twelve (12) months.
Response	Beam operation to the Meson Center will be terminated. Beam operation to the Meson Center will not resume until approval is received from the AD Associate Lab Director and the DOE Field Element Manager.

Administrative – Staffing

Applicability	During beam operations to the Meson Center segment of the Fermilab Main Accelerator.
Basis	To ensure operations within bounding conditions specified in Operation Authorization Document, and to disable beam operation to the Meson Center and initiate an immediate response in the event of a determined ASE violation.
Requirement	The following staffing shall be in place during applicable beam operation: • At least one member of the AD Operations Department who has achieved the rank of Operator II or higher shall be on shift. • At least one member of the AD Operations Department shall be present in the Main Control Room (MCR).
Compensatory Measure(s)	none
Required Surveillance	none
Response	Beam operation to the Meson Center will be terminated. Beam operation to the Meson Center will not resume until approval is received from the AD Associate Lab Director and the DOE Field Element Manager.

Administrative – Accelerator Operating Parameters

Applicability	During beam operations to the Meson Center segment of the Fermilab Main Accelerator.
Basis	Longitudinal, Transverse, and Labyrinth and Penetration spreadsheets were scaled using criteria 2 and 3 to find the weakest point in the shielding. MARS simulations were scaled using criteria 5.

Under normal operating conditions, the dose rate on top of the shield pile is calculated to be 20 mrem/hour. This is a fenced area that is allowed to go to 100 mrem during normal operations. The scaling factor is 100/20 = 5. The assessment was completed for 6.0 x 10^{14} protons/hour, applying the scaling factor of 25, 6.0 x 10^{14} * 5 = 3.0 x 10^{15} protons per hour. Applying the second scaling factor of 100 for the dose on the outside of a fenced area, 3.0 x 10^{15} * 100 = 3.0 x 10^{17} protons/hour.
Longitudinal spreadsheet category 4 area fails at 7.8 x 10^{15} protons/hour. Apply scaling of 100 for a fenced area, 7.8 x 10^{15} * 100 = 7.8 x 10^{17} protons/hour.
There are no category 1-3 areas on the longitudinal spreadsheet. Category 9 areas are ignored due to the interlocked detectors.
Transverse spreadsheet category 4 area fails at 6.0 x 10^{15} protons/hour. Apply scaling of 100 for a fenced area, 6.0 x 10^{15} * 100 = 6.0 x 10^{17} protons/hour.
Transverse spreadsheet category 2 and 3 areas changed to 4 fail at 7.2 x 10^{17} protons/hour.
Penetration category 4 area fails at 4.32 x 10^{15} protons/hour. Apply scaling of 100 for a fenced area,
4.32 x 10^{15} * 100 = 4.32 x 10^{17} protons/hour.
Penetrations category 2 and 3 areas changed to 4 fail at 9.6 x 10^{16} protons/hour.
Penetration spreadsheet is the limiting area; ASE limit is 9.6 x 10^{16} protons/hour.

Requirement

The Meson Center segment will be operated within the following parameters:

Mode	Intensity	Energy
Pion Mode	9.60e16 protons/hr	120 GeV

These parameters are further specified in the Operation Authorization Document.

Meson Center intensity is monitored via: F:MC6IC

Compensatory Measure(s)

Alternative methods of monitoring intensity may be used.

Required Surveillance

none

Response

Beam operation to the Meson Center will be terminated. Beam operation to the Meson Center will not resume until approval is received from the AD Associate Lab Director and the DOE Field Element Manager.

Neutrino Muon Credited Controls

Passive – Shielding

Applicability During beam operations to the Neutrino Muon segment of the Fermilab Main Accelerator.

Basis Based on the Nominal Operating Intensity of 6.00e14 protons/hr, supported by the following Shielding Assessments, the shielding is required in the locations listed below.

Shielding Assessment(s):
- 2012 Neutrino Muon Beam Line Shielding Assessment [29]
- 2019 Neutrino Muon Beamline Shielding Assessment Addendum for E1039 [30]

Requirement Required shielding specified in the listed Shielding Assessments will be installed in its proper configuration during applicable beam operations.

The listed Shielding Assessment(s) utilized the incremental shielding assessment methodology, required shielding is summarized here.

Permanent Longitudinal Shielding

Cell or Longitudinal Range (ft)	Enclosure Type	Current (e.f.d.)	Required (e.f.d.)
920-1250	SY Encl. C	20.5	16.9
1250-1333	SY Encl. C	19	16.9
1333-1494	Beam Pipe	21.5	18.9
1494-1520	Beam Dump	18.5	18.9
1520-1536	Beam Pipe	18.5	18.9
1536-1633	Beam Pipe	19.5	15.0
1633-1708	SY Encl. G1	17.8	12.5
1708-1752	Beam Pipe	19	15.0
1752-2070	Beam Pipe	21	18.9
2070-2224	SY Encl. G2	17.7	13.5
2224-2285	SY Encl. G2	18.4	13.5
2285-2390	SY Encl. G2	16.5	13.5
2390-2417	G2 Hatch	16.5	13.5
2417-2420	SY Encl. G2	17	13.5
2420-2430	Beam Pipe	21	15.0
2430-2690	Beam Pipe	27	18.9
2690-2763	Beam Pipe	24	21.0
2763-3090	Beam Pipe	29	15.0
3090-3110	Beam Pipe	21.9	15.0

3110-3146	Beam Pipe	30	15.0
3146-3179	Beam Pipe	24.4	15.0
3179-3216	NM1	19.6	13.5
3216-3620	Beam Pipe	22	15.0
3620-3829	NM2	18	13.5
3829-3929	NM2	15.5	13.5
3929-4060	NM2	17.5	13.5
4060-4113	Beam Pipe	30.8	15.0
4113-4230	NM3	21	13.5
4230-4334	NM3	21.3	12.5
4334-4348	NM3	12.5	12.5
4348-4353	NM3	11.3	6.8
4353-4357	NM3 collimator	17.5	3
4357-4360	NM3	11.4	3
4360-4368	Target Cave	11.7	3
4368-4373	Target Wall	29.9	14
4373-4374	Pre-FMAG	31.4	14
4374-4378	FMAG US	31	16.4
4378-4381	FMAG US	28.8	16.4
4382-4388	FMAG DS	26	16.4
4388-4389	FMAG DS	22.4	16.4
4389-4390	FMAG DS	28.5	16.4
4390-4391	Post-FMAG	3.5	3
4391-4392	Post-FMAG	8.9	3
4392-4394	Post-FMAG	3.5	3
4394-4454	NM4	0	3
4454-4490	NM4	7.1	3
4490-4503	NM4	8.9	3

Permanent Transverse Shielding

Cell or Transverse Station (ft)	Enclosure Type	Current (e.f.d.)	Required (e.f.d.)
1330	SY Encl. C	21.15	16.9
1510	Beam Dump	16.83	16.9
1700	SY Encl. G1	17.22	13.5
1800	Beam Pipe	20.75	18.9
1900	Beam Pipe	20.75	18.9
2180	SY Encl. G2	19.13	13.5
2260	SY Encl. G2	18.60	13.5
2285	SY Encl. G2	18.85	13.5
2400	G2 Hatch	16.50	13.5
2460	Beam Pipe	25.00	18.9

2600	Beam Pipe	25.25	18.9
2720	Beam Pipe	23.80	21.0
3176	N01	26.6	13.5
3208	N01	21.8	13.5
3673	NM2	19.0	13.5
3827	NM2	19.5	13.5
3882	NM2	19.0	13.5
4009	NM2	25.5	13.5
4028	NM2	17.9	13.5
4100	Beam Pipe	31.4	15.0
4120	NM3	18.4	13.5
4125	NM3	21.7	13.5
4150	NM3	21.7	12.5
4168	NM3	21.2	12.5
4245	NM3	21.3	12.5
4354-W	NM3 Collimator	17.5	3
4354-E	NM3 Collimator	17.5	3
4357-W	NM3	16.9	3
4357-E	NM3	16.9	3
4360-W	Target Cave	4	3
4360-E(dn)	Target Cave	19.8	18.4
4360-E(up)	Target Cave	5	3
4361-W	Target Cave	8.4	3
4361-E(dn)	Target Cave	23.6	18.4
4361-E(up)	Target Cave	11.4	3
4364-W	Cryo Line	11	3
4364-E(dn)	Cryo Line	23.6	18.4
4364-E(up)	Cryo Line	11.4	3
4367-W	Target Cave	6.7	3
4367-E(dn)	Target Cave	32.6	18.4
4367-E(up)	Target Cave	11.4	3
4368-W	Target Cave	18.5	3
4368-E(dn)	Target Cave	33.5	3
4368-E(up)	Target Cave	20.3	3
4370-W	Target Wall	22.9	3
4370-E(dn)	Target Wall	32.8	18.4
4370-E(up)	Target Wall	20.5	14
4373-W	Pre-FMAG	25.9	4.7
4373-E(dn)	Pre-FMAG	29.4	20.8
4373-E(up)	Pre-FMAG	24.3	16.4
4376-W	FMAG Face	31	16.4
4376-E(dn)	FMAG Face	37.4	20.8

4376-E(up)	FMAG Face	31	16.4
4378-W	FMAG	28.8	16.4
4378-E(dn)	FMAG	39.9	20.8
4378-E(up)	FMAG	28.8	16.4
4380-W	FMAG	26	16.4
4380-E(dn)	FMAG	39.9	20.8
4380-E(up)	FMAG	26	16.4
4382-W	FMAG	26	16.4
4382-E(dn)	FMAG	33.9	20.8
4382-E(up)	FMAG	26	16.4
4388-W	FMAG	22.4	16.4
4388-E(dn)	FMAG	37.7	20.8
4388-E(up)	FMAG	22.4	16.4
4389-W	FMAG	26.1	16.4
4389-E(dn)	FMAG	37	20.8
4389-E(up)	FMAG	26.1	16.4
4390-W	Post-FMAG	2.5	3
4390-E(dn)	Post-FMAG	16.9	3
4390-E(up)	Post-FMAG	2.2	3
4392-W	Post-FMAG	10.4	3
4392-E(dn)	Post-FMAG	24.6	3
4392-E(up)	Post-FMAG	10.1	3
4394-W	Post-FMAG	2.2	3
4394-E(dn)	Post-FMAG	16.9	3
4394-E(up)	Post-FMAG	2.2	3
4411-E(dn)	Post-FMAG	12.4	3
4411-E(up)	Post-FMAG	0	3
4411-W	Post-FMAG	0	3
4482-E(dn)	Post-FMAG	16.4	3
4482-E(up)	Post-FMAG	6.6	3
4482-W	Post-FMAG	6.6	3
4502-E(dn)	Post-FMAG	14.8	3
4502-E(up)	Post-FMAG	7.7	3
4502-W	Post-FMAG	7.7	3

Movable Shielding

Location	Shielding Type	Quantity	Purpose	Preferred Method of Configuration (if specified)	Comments
Z=3897'	Concrete	Many Blocks	NM2 Magnet Hatch		
Z=4160'	Concrete	Many Blocks	NM3 Magnet Hatch		Secondary beamline enclosure converted to primary
Z=4238'	Steel and Concrete	8' steel; 4' concrete	Site Riser SR1		NM20 11" diameter steel 10" concrete
Z=4112'	Steel and Concrete	8' steel; 4' concrete	Site Riser SR5		NM19 11" diameter steel 10" concrete
Z=4360'	Sand	11'	Site Riser SR6		NM21 11" diameter of sand
Z=3928'	Steel and Concrete	6'9" steel; 4' concrete	Site Riser SR3		NM29 11" diameter steel 10" concrete
Z=4058'	Steel and Concrete	6'9" steel; 4' concrete	Site Riser SR4		NM30 11" diameter steel 10" concrete
Z=3837'	Steel and Concrete	6'9" steel; 4' concrete	Site Riser SR2		NM28 11" diameter steel 10" concrete
Z=4373'	Concrete and Steel	Many blocks	FMAG Shielding Pile in NM4		Radiation Safety Drawings 9-8-6-12 C-1 through C-17

Z=3897'	Steel	Many blocks	Old NM2 target pile		Old target pile of yellow steel
Z=4059'	Solid Poly	10"	Old NM2 alignment pipe cover		Old AMG sight pipe
Z=4454'	Concrete	48 G blocks	NM4 Loading Dock		Secondary beamline needed for floor space and north shielding
Z=4374'	Concrete	4 C and 1 B block	NM4 East Side Parking Lot		Added next to building
Z=2800'	Concrete	Many blocks	TSB Spur		75' away from TSB door

Penetration Shielding

Station (ft)	Enclosure Type	Current (e.f.d.)	Required (e.f.d.)	Preferred Method of Configuration (if specified)
1640	SY Encl. D: west pen to SSB	see worksheet NM34	--	
1640	SY Encl. D: east pen to SSB	see worksheet NM37	--	
2327	SY Encl. G2: (8) cable pens to G2 SB	15	14	
2333	SY Encl. G2: cryo pen	see worksheet NM63	--	
2337	SY Encl. G2: cryo pen	see worksheet NM64	--	
3837	NM2: SR2	23.3	5	
3883	NM2: large hatch	13.2	6.6	
3928	NM2: SR3	23.3	6.6	
4058	NM2: SR4	23.3	7.25	
4112	NM3: SR5	26.8	6.5	

4168	NM3: hatch	9.9	6.6	
4238	NM3: SR1	26.8	4.9	
4355	NM3: SR6	11	2.2	

Compensatory Measure(s) In lieu of required shielding, temporary controls, such as guards, fencing, ropes, and/or postings, may be utilized as approved by the SRSO. Each use of a Compensatory Measure shall be documented using the USI Process.

Required Surveillance Required shielding shall be verified annually, not to exceed twelve (12) months.

Response Beam operation to the Neutrino Muon will be terminated. Beam operation to the Neutrino Muon will not resume until approval is received from the AD Associate Lab Director and the DOE Field Element Manager.

Passive – Fencing

Applicability During beam operations to the Neutrino Muon segment of the Fermilab Main Accelerator.

Basis Based on the Nominal Operating Intensity of 6.00e14 protons/hr, supported by the following Shielding Assessments, the shielding is required in the locations listed below.

Shielding Assessment(s):
- 2012 Neutrino Muon Beam Line Shielding Assessment [29]
- 2019 Neutrino Muon Beamline Shielding Assessment Addendum for E1039 [30]

Requirement Required fencing specified in the listed Shielding Assessments will be installed in its proper configuration during applicable beam operations.

Radiation Area Fencing

Fence Location	Required Posting	Gates (if applicable)	Configuration
Running East-West on the North side of B Road across NM berm	Radiation Area	• N01VAS2	• 4 ft height • Standing upright between 60-120° • No missing or bent pieces creating a

			person-sized hole (~1ft^2) • Gates locked with Rad Fence Padlock
Running North-South on the West side of C Road West to the South corner of the NM4 Service Building	Radiation Area	• N01PAE1 • N01PAR2 • N01VAE • N02PAE1 • N02PAE2 • N02PAE3 • NM4PA1 • NM4PA2	• 4 ft height • Standing upright between 60-120° • No missing or bent pieces creating a person-sized hole (~1ft^2) • Gates locked with Rad Fence Padlock
Running East-West across the NM berm between the NM4 Service Building and the NS2 Service Building	Radiation Area	none	• 4 ft height • Standing upright between 60-120° • No missing or bent pieces creating a person-sized hole (~1ft^2)
Running North-South on the East side of Discovery Road from the South end of the NS2 Service Building parking lot to the NS0 Service building and B Road	Radiation Area	• NW3VAW • NW2VAW • N01VAW2 • N01PAW2 • N01VAW1 • N01PAW1	• 4 ft height • Standing upright between 60-120° • No missing or bent pieces creating a person-sized hole (~1ft^2) • Gates locked with Rad Fence Padlock

Controlled Area Fencing

Fence Location	Required Posting	Gates (if applicable)	Configuration
NM4 South Parking lot	Controlled Area		• 4 ft height • Standing upright between 60-120° • No missing or bent pieces creating a person-sized hole (~1ft^2)

Compensatory Measure(s) In lieu of required fencing, temporary controls, such as guards, ropes, and/or postings, may be utilized as approved by the SRSO. Each use of a Compensatory Measure shall be documented using the USI Process.

Required Surveillance Required fencing shall be verified annually, not to exceed twelve (12) months.

Response Beam operation to the Neutrino Muon will be terminated. Beam operation to the Neutrino Muon will not resume until approval is received from the AD Associate Lab Director and the DOE Field Element Manager.

Active Engineered – Radiation Safety Interlock System (RSIS)

Applicability During beam operations to the Neutrino Muon segment of the Fermilab Main Accelerator.

Basis Based on the Nominal Operating Intensity of 6.00e14 protons/hr, supported by the following Shielding Assessments, the RSIS is established with interlocked barriers around the Exclusion Area, as well as inclusion of required interlocked radiation monitors.

Shielding Assessment(s):
- 2012 Neutrino Muon Beam Line Shielding Assessment [29]
- 2019 Neutrino Muon Beamline Shielding Assessment Addendum for E1039 [30]

Requirement The Radiation Safety Interlock System (RSIS) must prevent entry into the following Exclusion Area(s) during appliable beam operation:

- G2
- N01 (NM1)
- NM2
- NM3
- NM4

Required components of the RSIS shall be specified in the Neutrino Muon's Operation Authorization Document.

The following components of the Radiation Safety Interlock System (RSIS) shall be in place, with no known loss of safety function, during applicable beam operations.

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	NM3 berm doghouse south of NM4
Chipmunk	NM4 SW corner doghouse
Chipmunk	NM4 North Highbay Ledge
Chipmunk	NM4 North Highbay
Chipmunk	NM4 Utility Room East side
Chipmunk	NM4 South Counting House
Chipmunk	NM4 North Counting House
Chipmunk	NM4 Control Room

Compensatory Measure(s) In lieu of required interlocked detectors, temporary controls, such as guards, fencing, ropes, and/or postings, may be utilized as approved by the SRSO. Each use of a Compensatory Measure shall be documented using the USI Process.

Required Surveillance The RSIS for the Neutrino Muon segment shall undergo certification annually, not to exceed twelve (12) months.

Response Beam operation to the Neutrino Muon will be terminated. Beam operation to the Neutrino Muon will not resume until approval is received from the AD Associate Lab Director and the DOE Field Element Manager.

Active Engineered – Oxygen Deficiency Hazard (ODH) Safety System

Applicability During personnel access into the NM4

Basis Based on the ODH Analysis, the ODH Safety System is established with specified required components.

Requirement	The following components of the Oxygen Deficiency Hazard (ODH) Safety System shall be in place, with no known loss of safety function, during personnel access into applicable areas. • 2 area/fixed oxygen monitors (one high, one low) • ODH fans • Fail closed isolation valve on the Liquid Nitrogen supply
Compensatory Measure(s)	Temporary updated ODH postings and associated requirements and/or restrictions may be implemented following a component failure to allow reentry to fix failed components based on either: (1) an existing and approved out-of-service policy, or (2) an updated ODH analysis approved by the Cryogenic Safety Subcommittee (CSS).
Required Surveillance	• Testing area/fixed oxygen monitors every 1 year per established procedure • Test ODH fans every six months per established procedure • Test fail closed isolation valve on the Liquid Nitrogen supply every 1 year per established procedure
Response	Beam operation to the Neutrino Muon will be terminated. Beam operation to the Neutrino Muon will not resume until approval is received from the AD Associate Lab Director and the DOE Field Element Manager.

Administrative – Operation Authorization Document

Applicability	During beam operations to the Neutrino Muon segment of the Fermilab Main Accelerator.
Basis	To summarize the bounding conditions for safe operation of the Neutrino Muon, and to provide explicit approval for operations of the Neutrino Muon.
Requirement	An approved Neutrino Muon Beam Permit & Running Condition shall be issued prior to Neutrino Muon beam operations.
Compensatory Measure(s)	none
Required Surveillance	The Neutrino Muon Beam Permit and Running Condition shall be verified annually, not to exceed twelve (12) months.

Response	Beam operation to the Neutrino Muon will be terminated. Beam operation to the Neutrino Muon will not resume until approval is received from the AD Associate Lab Director and the DOE Field Element Manager.

Administrative – Staffing

Applicability	During beam operations to the Neutrino Muon segment of the Fermilab Main Accelerator.
Basis	To ensure operations within bounding conditions specified in Operation Authorization Document, and to disable beam operation to the Neutrino Muon and initiate an immediate response in the event of a determined ASE violation.
Requirement	The following staffing shall be in place during applicable beam operation: • At least one member of the AD Operations Department who has achieved the rank of Operator II or higher shall be on shift. • At least one member of the AD Operations Department shall be present in the Main Control Room (MCR).
Compensatory Measure(s)	none
Required Surveillance	none
Response	Beam operation to the Neutrino Muon will be terminated. Beam operation to the Neutrino Muon will not resume until approval is received from the AD Associate Lab Director and the DOE Field Element Manager.

Administrative – Accelerator Operating Parameters

Applicability	During beam operations to the Neutrino Muon segment of the Fermilab Main Accelerator.
Basis	Longitudinal, Transverse, and Labyrinth and Penetration spreadsheets were scaled using criteria 2 and 3 to find the weakest point in the shielding. Most areas already fenced allowing up to a 500 mrem accident condition or use interlocked detectors set to 5 mrem. Longitudinal spreadsheet category 4 area fails at 1.26×10^{15} protons/hour. Apply scaling of 100 for a fenced area, $1.26 \times 10^{15} * 100 = 1.26 \times 10^{17}$ protons/hour. Longitudinal spreadsheet category 2 and 3 areas changed to 4 fail at 5.34×10^{16} protons/hour.

Transverse spreadsheet category 4 area fails at 6.0 x 10^{14} protons/hour. Apply scaling of 100 for a fenced area, 6.0 x 10^{14} * 100 = 6.0 x 10^{16} protons/hour.
Transverse spreadsheet category 2 and 3 areas changed to 4 fail at 4.68 x 10^{16} protons/hour.
Penetration category 4 area fails at 1.38 x 10^{15} protons/hour. Apply scaling of 100 for a fenced area,
1.38 x 10^{15} * 100 = 1.38 x 10^{17} protons/hour.
Penetrations category 2 and 3 areas changed to 4 fail at 8.64 x 10^{15} protons/hour.
Penetration spreadsheet is the limiting area; ASE limit is set to 8.64 x 10^{15} protons/hour.

Requirement

The Neutrino Muon segment will be operated within the following parameters:

Mode	Intensity	Energy
Beam to NM3 Target/Absorber	8.64e15 protons/hr	120 GeV

These parameters are further specified in the Operation Authorization Document.

Neutrino Muon intensity is monitored via: S:G2SEM and/or F:NM3ION

Compensatory Measure(s)

Alternative methods of monitoring intensity may be used.

Required Surveillance

none

Response

Beam operation to the Neutrino Muon will be terminated. Beam operation to the Neutrino Muon will not resume until approval is received from the AD Associate Lab Director and the DOE Field Element Manager.

Section 8. References

[1] 1993 Radiation Shielding Assessment of Linac High Energy Enclosure Following the 1993 Upgrade Installation & Low Intensity Commissioning. Web link: https://fermipoint.fnal.gov/org/eshq/sa/Shared%20Documents/Linac%20Shielding%20Assessment/LINAC%201993%20SHIELDING%20ASSESSMENT.pdf
[2] 1992 Neutron Therapy Facility 1992 Shielding Assessment.
[3] Shielding Assessment Document for the MeV Test Area at the Fermilab Linac Endstation, August 24, 2020. Web link: https://fermipoint.fnal.gov/org/eshq/sa/Shared%20Documents/MTA%20Shielding%20Assessment/Shielding_Assessment_Document_for_the_MeV_Test_Area_Rev8.pdf
[4] MTA Air Exchange Post-Assessment Memo.
[5] Booster Shielding Assessment, January 17, 2017. Web link: https://fermipoint.fnal.gov/org/eshq/sa/Shared%20Documents/Booster%20Shielding%20Assessment/Booster%20Shielding%20Assessment%20v6%20011717.pdf
[6] 2002 Shielding Assessment Document for the 8 GeV Fixed Target Facility.
[7] 2010 Post-Assessment Memo “8 GeV Beamline & MiniBooNE Beamline NOvA-Era Operational Limits”.
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