# 400 MEV TEST AREA

## SECTION III CHAPTER 02
## OF THE FERMILAB SAD

Revision 4 March 1, 2024

This Chapter of the Fermilab Safety Assessment Document (SAD) contains a summary of the results of the Safety Analysis for the 400 MeV Test Area (MTA) segment of the Fermilab Main Accelerator that are pertinent to understanding the risks to the workers, the public, and the environment due to its operation.

This page is intentionally blank.

# SAD Chapter Review

This Section III Chapter 02 of the Fermi National Accelerator Laboratory (Fermilab) Safety Assessment Document (SAD), *400 MeV Test Area*, was prepared and reviewed by the staff of the External Beam Delivery Department in conjunction with the Environment, Safety, & Health Division (ES&H) Accelerator Safety Department.

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

☐ ____________________________________________
Line Organization Owner

☐ ____________________________________________
Accelerator Safety Department Head

☐ ____________________________________________
SAD Review Subcommittee Chair

This page is intentionally blank.

## Revision History

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

| Author | Rev. No. | Date | Description of Change |
|---|---|---|---|
| S. McGimpsey<br>C. Johnstone | 4 | March 1, 2024 | • Increased credited control limit for radiation monitors consistent with MCI analysis<br>• Addressed minor editorial suggestions including specifying risk level in text in addition to existing tables<br>• Reorganized Section III-2.5 Summary of Defense-in-Depth Controls<br>• Updated Sections III-2.2.2.4 Liquid Scintillator Oil and III-2.2.8.1 Fringe Fields |
| S. McGimpsey<br>C. Johnstone | 3 | December 21, 2023 | Incorporation of the maximum credible incident for a radiological hazard and a description of the Credited Controls that mitigate it, along with any elements that are considered defense in depth.<br>Address comments from the IRR Committee |
| T. Kobilarcik<br>E. Niner | 1 | August 25, 2020 | Updated to align with new shielding assessment, infrastructure modifications, and repurposing as the MeV Test Area (MTA) for studies of the effects of radiation on components and materials. |
| Herman B. White | 0 | January 20, 2011 | Initial release of the MuCool Test Area Chapter for the Fermi National Accelerator Safety Assessment Document (SAD) |

This page is intentionally blank.

# Table of Contents

## Acronyms and Abbreviations

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

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

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

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

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

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

# III-2. 400 MeV Test Area

## III-2.1. Introduction

This Section III Chapter 02 of the Fermi National Accelerator Laboratory (Fermilab) Safety Assessment Document (SAD) covers the 400 MeV Test Area (MTA) segment of the Fermilab Main Accelerator.

### III-2.1.1 Purpose/Function

The purpose of the MTA is to provide 400 MeV H- or protons to the MTA. The MTA was originally designed to test the feasibility of ionization cooling of the high-power ionizing beam from the Fermilab Linac, passing through a liquid hydrogen energy absorber. The beam line, and associated experimental hall, have been repurposed for studying the effects of radiation on various components and materials.

### III-2.1.2 Current Status

The MTA segment of the Fermilab Main Accelerator is currently: **operational**.

### III-2.1.3 Description

The MTA enclosure is located southwest of the Linac accelerator (see Figure 1). The MTA beam line begins with two C magnets that extract beam from the downstream portion of the Linac. A four-dipole bend string then directs beam through a shield wall, separating the Linac tunnel and the MTA enclosure, and then into the MTA enclosure.

In the MTA enclosure, beam emerges at the end of the beam line through a titanium vacuum window and continues through air, passing down the center of a shielding cave constructed of concrete shielding blocks. The cave offers a passage three feet across and three feet high, with at least three feet of shielding block material all around. Target material can be irradiated at the center of this volume. The shielding cave floor extends an additional three feet toward the vacuum window, making a “front porch” area that serves as another position for target material. Beam that does not interact with target materials is absorbed in the final beam absorber located beyond the downstream wall of the experimental hall.

Several multiwire beam profile monitors, beam loss monitors, and diagnostic beam toroids are installed along the beamline to assess the beam’s trajectory. A full intensity beam absorber is located at the downstream end of the facility.

The experimental area will be used by experimenters to study the effects of radiation on components and materials placed in the MTA beamline. These experiments may make use of motion tables, cooling units, power supplies, and fluence monitoring to control and monitor samples under test. The character of the hazards associated with these planned experiments is similar but may vary in magnitude. New experiments are screened for hazards through the operational readiness clearance (ORC) process coordinated by the ORC chairperson for the respective area prior to approval. Such experiments would be similar in ES&H impact to those described here.

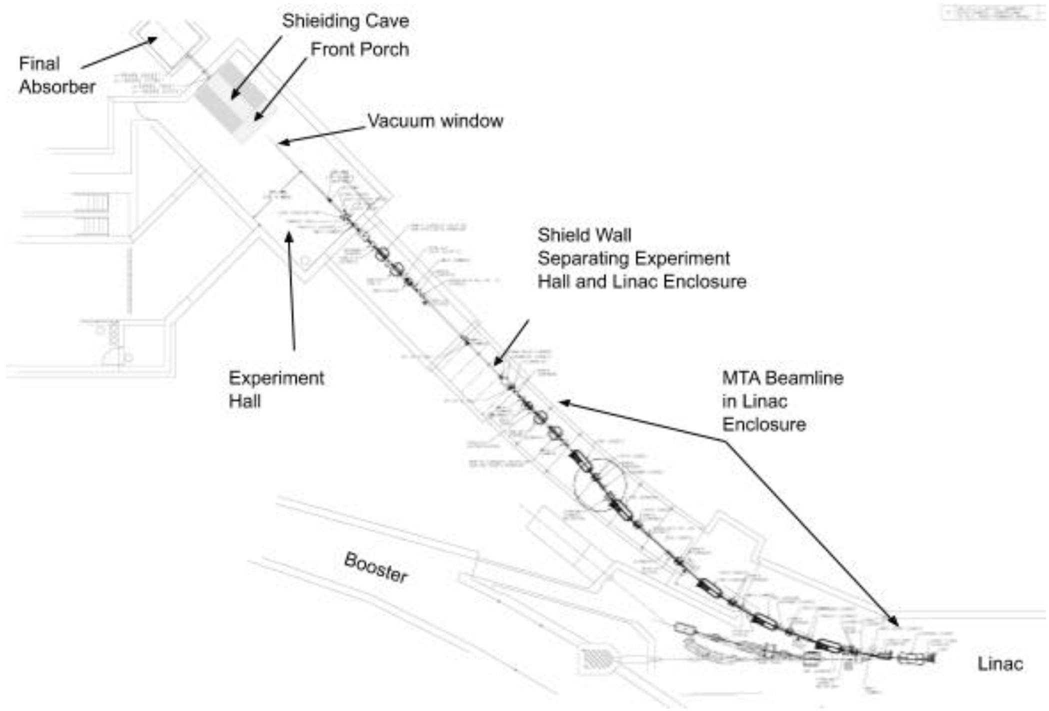

*Figure 1. MTA Experimental Hall*

### III-2.1.4 Location

The MTA segment enclosure is located on the Fermilab site in Batavia, Ill, beyond Obvious and Operating Barriers to ensure only authorized access. These barriers are located at: Wilson Hall West, Wilson Hall East, and Site 55..

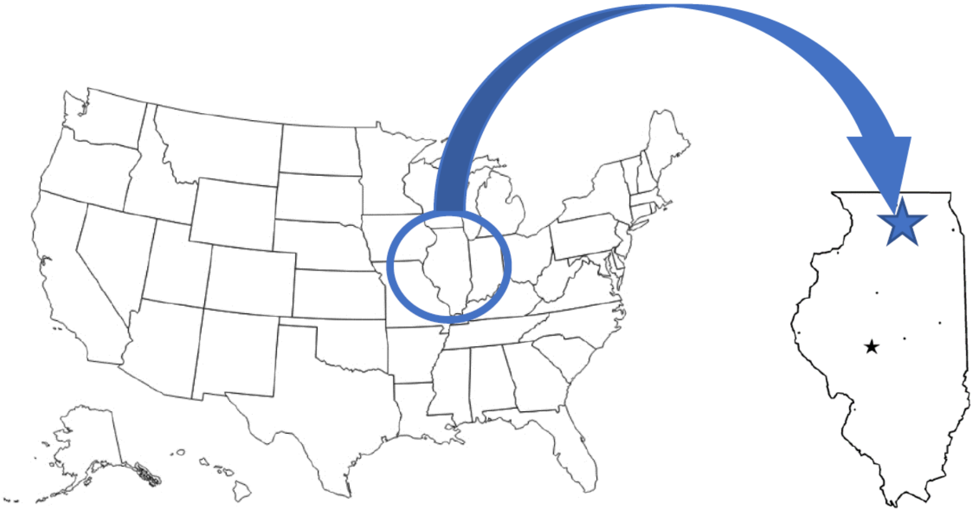

*Figure 2. Regional view showing the location of the Fermilab site in Batavia, IL.*

The MTA is located in the central campus on the Fermilab site. Members of the public are not invited to the MTA.

*Figure 3. Aerial view of the Fermilab site, indicating the location of the MTA.*

*Figure 4. Location of Obvious and Operating Barriers.*

### III-2.1.5 Management Organization

The MTA facility is owned and operated by the Accelerator Directorate. The Irradiation Test Area (ITA), managed by the Particle Physics Division, conducts experiments within the MTA experimental hall.

### III-2.1.6 Operating Modes

The “Shielding Assessment Document for the MeV Test Area at the Fermilab Linac End station”[2] (the shielding assessment) demonstrates that the MTA is capable of receiving 400 MeV ions from the end of the Linac at an intensity of 2.7E15 protons per hour average flux. The MTA supports two modes of operation: H- and protons.

In proton mode, the stripping foil is inserted in the beamline upstream of the final bend. The stripping foil removes electrons from the H- ion. The final bend then directs protons to the test apparatus. Stripped electrons and neutral hydrogen are absorbed above the beamline. Protons which do not interact with the test apparatus continue to the final absorber.

In H- mode, the stripping foil is retracted from the beamline, and the final bend directs H- to the test apparatus. Particles which do not interact with the test apparatus continue to the final absorber.

The MTA can deliver one or eight pulses per minute at 15 Hz, with a variable pulse length of 7us to 32us.

### III-2.1.7 Inventory of Hazards

The following table lists all the identified hazards found in the MTA enclosure and support buildings. Section III-2.9 *Appendix – Risk Matrices* describes the baseline risk (i.e., unmitigated risk), any preventative controls and/or mitigative controls in place to reduce the risk, and residual risk (i.e., mitigated risk) for a facility worker, co-located worker, and maximally exposed offsite individual (MOI) (i.e., members of the public). A summary of these controls is described within Section III-2.2 *Safety Assessment.*

Prompt ionizing and oxygen deficiency hazards due to cryogenic systems within accelerator enclosures have been identified as accelerator-specific hazards, and as such their controls are identified as Credited Controls. The analysis of these hazards and their Credited Controls will be discussed within this SAD Chapter, and their Credited Controls summarized in the Accelerator Safety Envelope for the Fermilab Main Accelerator. Accelerator-specific controls are identified as **purple/bold** throughout this Chapter.

All other hazards present in the MTA are safely managed by other DOE approved applicable safety and health programs and/or processes, and their analyses have been performed according to applicable DOE requirements as flowed down through the Fermilab Environment, Safety and Health Manual (FESHM). These hazards are non-accelerator-specific hazards (NASH), and their analysis will be summarized in this SAD Chapter.

*Table 1. Hazard Inventory for MTA.*

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

## III-2.2. Safety Assessment

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

### III-2.2.1 Radiological Hazards

The MTA presents radiological hazards in the form of prompt ionizing radiation, residual activation, groundwater activation, surface water activation, radioactive air activation, soil interactions, radioactive waste, contamination, beryllium-7, and radioactive sources. A detailed shielding assessment [2] addresses these hazards and provide a detailed analysis of the facility demonstrating the required shielding, controls, and interlocks to comply with the Fermilab Radiological Control Manual (FRCM) [1]. Radiation safety has been carefully considered in the design of the MTA. There are two predominant radiation hazards. The first hazard is due to the interaction of beam particles in the materials surrounding the beam pipes, beam line elements, and test equipment. The second is caused by the interaction of beam particles in the test components and the subsequent interactions of the secondaries with their surrounding material.

There are three categories of beam-induced radiation hazards:

1. Prompt radiation levels inside and surrounding the enclosure that are present during beam transport. These include protons, neutrons, muons, and other energetic particles.
2. Residual radiation due to activation of beamline components, and experimental devices which can give rise to radiation exposure to personnel during accesses to the beam enclosure and experimental facility for repair, maintenance, inspection, and operation activities; and
3. Environmental radioactivity due to the operation of the beam transport system, such as the activation of air, soil, and groundwater.

A detailed shielding assessment [2] has been compiled and reviewed to address these concerns. The assessment provides a detailed analysis of this facility, demonstrating the required overburden, use of signs, fences, and active interlocks to comply with the Fermilab Radiological Control Manual (FRCM)[1]. Residual activation of components makes a substantial impact on the ability to occupy the experimental hall where recurring access is required for routine experimental equipment changes. The shielding assessment has analyzed the beam line areas from the Linac extraction through the MTA experimental enclosure.

### III-2.2.1.1 Prompt Ionizing Radiation

When beam is transported through the MTA Beamline, prompt ionizing radiation is a significant radiation hazard. In order to protect workers and the general public, the enclosure and beam pipes are surrounded by sufficient amounts of shielding or networks of interlocked detectors. Prompt radiation is kept within acceptable levels. Operation of the area conforms to the FRCM and to maintain exposures for operating personnel as-low-as-reasonably-achievable (ALARA).

This hazard has been evaluated via a Maximum Credible Incident (MCI) analysis that is described in Section III-2.3.1.1. This analysis specifies that Fermilab uses Credited Controls that flow down to the ASE to mitigate the consequences of the MCI to at or below the acceptable dose levels described in SAD Section I Chapter 4. A detailed description of each of the Credited Controls and their function is provided in Section III-2.4. The conclusion of these analyses is that the mitigated dose level associated with prompt ionizing radiation due to beam loss is acceptable.

### III-2.2.1.2 Residual Activation

High intensity beam delivery in the MTA will produce activated materials inside the enclosure. Exposure is kept ALARA by a combination of shielding (provided by the shielding cave) and cool off time.

The residual dose at the exterior surface of the shielding cave has been calculated for 12 hours of operating at 5E12 protons per second (average). The residual dose is less than 30 mrem/hr after one hour of cool-off and less than 5 mrem/hr after one day of cool-off. (Note: 5E12 protons per second was chosen for ease of scaling and is in excess of the expected 2.7E15 protons per hour, or 7.5E11 protons per second, average flux).

Access to activated components in the experimental area is tightly controlled. All potential residual activation hazards are handled operationally as in all other primary beam enclosures. These controls include verification of training, centralized authorization, and key entry. The level of control depends on the level of residual radiation. In addition, no access into the MTA enclosure is permitted until the air monitor (G: RD0236) is reading less than 400 cpm. The controls will follow the administrative controls and safety guidelines found in the radiological work permit (RWP) and running condition. In most cases, the typical RWP for accesses will suffice. A job-specific RWP and an ALARA plan will be required for work on any highly activated equipment or work within the posted Contamination Area. RWPs and ALARA plans must be written and followed in accordance with the FRCM requirements. Results of risk assessment have been demonstrated that baseline risk has reduced from a value of I to a residual risk of IV when preventive and mitigative measures are considered.

#### III-2.2.1.3 Groundwater Activation

Radioactivity induced by the interaction of high-energy particles with the soil that surrounds a proton target is addressed in this section. The production of tritium and sodium-22 poses the greatest concern, since the product of the production rate, leachability into the water flowing through the soil, and decay half-lives of these nuclides may be large. Fermilab standards pertaining to groundwater activation are provided in FRCM Chapters 3 and 11[1], and methodologies for estimating groundwater activation are given in Environmental Protection Notes 8 and 17. The methodology is designed to achieve a conservative estimate of groundwater activation. Additionally, the annual integrated intensity used in the calculations is estimated well above the practical beam delivery limits.

As discussed in the shielding assessment [2], the simulation program MARS[4] has been used to estimate the surface water and groundwater activation concentrations in the vicinity of the final beam absorber. The shielding assessment demonstrates that the operation of beam to the absorber will be well within any limits set by surface or ground water activity.

Additional calculations were performed to determine the annual integrated intensity limits for the facility for surface and ground water activation. The shielding assessment determined that 1.3E18 protons per year could be sent to the final beam absorber without exceeding the FRCM ground water limits. Since Fermilab has mandatory shutdown every Summer, typically lasting 12-15 weeks, MTA is not operational for a full calendar year. MTA is typically operational for about 40 weeks/year. Results of risk assessment, Tables 6.1 thorough 6.3, have been demonstrated that baseline risk has been reduced from a value of I to a residual risk of III or IV when preventive and mitigative measures are considered.

#### III-2.2.1.4 Surface Water Activation

See groundwater activation section above.

#### III-2.2.1.5 Radioactive Water (RAW) Systems

N/A

#### III-2.2.1.6 Air Activation

Illinois state regulations and the Fermilab registration in Registration of Smaller Sources (ROSS) program, administered by the Illinois Environmental Protection Agency (IEPA), govern releases of airborne radionuclides. The regulations limit the effective dose equivalent delivered to a member of the public to 10 mrem/year [1]. Fermilab has established a secondary goal of keeping the maximum effective dose equivalent at the site boundary due to air emissions under 0.1 mrem/yr.

The principal radionuclides of concern to air activation are carbon-11 (which has a 20-minute half-life), nitrogen-13 (which has about a 10-minute half-life), oxygen-15 (which has about a 2-minute half-life), tritium (which has 4,500-day half-life), and argon-41 (with a 110-minute half-life, which is produced by thermal neutron capture on argon-40). Normally the ventilation systems in the enclosure would have a slow air transit time in minutes through protected areas before air is released to an outdoor area, which helps eliminate the short-lived particle emitters through decay during the transit time.

Air activation for MTA is considered in the shielding assessment [2]. For an assumed intensity of 1.3E18 protons per year, and a natural air exchange rate of 200 cfm, which is an overestimate, the anticipated release to the atmosphere is 0.99 Ci/year. Based on releases expected from the existing accelerators and the current and near future experiments, Fermilab will remain in compliance with EPA requirements [3]. Results of risk assessment have been demonstrated that baseline risk has reduced from a value of I to a residual risk of IV when preventive and mitigative measures are considered.

### III-2.2.1.7 Closed Loop Air Cooling

N/A

### III-2.2.1.8 Soil Interactions

The hazards due to worker, co-located worker, or public interaction due to interactions with soil have been evaluated by a qualitative assessment. The baseline qualitative risk was determined to be a risk level of IV (minimal concern). The consequences from potential exposure to this hazard is considered to be of negligible consequence, and since this material is inaccessible to workers, co-located workers, and public due to where it may be found within the facility, the risk is of a minimal concern. For facility and MOI, the baseline risk is IV and the mitigated risk is IV. For co-located workers, the baseline risk is I and the mitigated risk is IV.

### III-2.2.1.9 Radioactive Waste

Radioactive waste produced in the course of MTA operations will be managed within the established Radiological Protection Program (RPP) and as prescribed in the Fermilab Radiological Control Manual (FRCM). This includes incidental radioactive materials produced during the irradiation of target materials, as well as beamline components that that have been hit by the beam.

Radioactive waste is a standard radiological hazard that is managed within the established Radiological Protection Program (RPP) and as prescribed in the Fermilab Radiological Control Manual (FRCM). Waste minimization is an objective of the equipment design and operational procedures. Although production of radioactive material is not an operational function of the MTA, beam loss and, in the case of some beam diagnostics devices, intentional interception of the beam will result in activation of beam line elements. Reuse of activated items will be carried out when feasible. Activated items that cannot be reused will be disposed of as radioactive waste in accordance with the FRCM requirements. Results of risk assessment have been demonstrated that baseline risk has reduced from a value of I to a residual risk of IV when preventive and mitigative measures are considered.

### III-2.2.1.10 Contamination

Although not typically encountered throughout the MTA enclosure, a well-defined and roped off posted contamination area is present around the front porch where the experimental set ups are located. Personnel are required by the RWP to appropriate PPE (double show cover and gloves when in controlled access) when accessing this area, and an RCT must be continually present. The hazards due to worker, co-located worker, or public interaction due to contamination have been evaluated by a qualitative assessment. The baseline qualitative risk was determined to be a risk level of IV (minimal concern). The consequences from potential exposure to this hazard is considered to be of negligible consequence. Since this material is inaccessible to workers, co-located workers, and public due to where it may be found within the facility, no preventive or mitigative measures are required. The risk is of a minimal concern and not subject to additional evaluation.

### III-2.2.1.11 Beryllium-7

As mentioned above, the posted contamination area is present around the front porch of the experimental area. Beryllium-7 is a predominant radioisotope present in this area. The hazards due to worker, co-located worker, or public interaction with Beryllium-7 and other contamination have been evaluated by a qualitative assessment. The baseline qualitative risk was determined to be a risk level of IV (minimal concern). The consequences from potential exposure to this material is considered to be of negligible consequence. Since this material is inaccessible to workers, co-located workers, and public due to where it may be found within the facility, and with the very short half-lives, no preventive or mitigative measures are required. The risk is of a minimal concern and not subject to additional evaluation.

### III-2.2.1.12 Radioactive Sources

The hazards due to worker, co-located worker, or public interaction due to radioactive source use have been evaluated by a qualitative assessment. For facility and co-located workers, the baseline risk is I and the mitigated risk is IV. For MOI, the baseline risk is III and the mitigated risk is IV. The consequences from potential exposure to this hazard is considered to be of negligible consequence. Since this material is inaccessible to workers, co-located workers, and public due to where it may found within the facility, no preventive or mitigative measures are required. The risk is of a minimal concern and not subject to additional evaluation.

### III-2.2.1.13 Nuclear Material

N/A

### III-2.2.1.14 Radiation Generating Devices (RGDs)

N/A

#### III-2.2.1.15 Non-Ionizing Radiation Hazards

It is anticipated that lasers may need to be brought into the MTA enclosure, for experimental purposes. This hazard has been evaluated within the common risk matrix table included in SAD Section I Chapter 04 *Safety Analysis*. Work in MTA involving this hazard implements the controls specified in the common risk matrix table. No unique controls are in use. Baseline risk for this hazard was R I and, after control measures were evaluated, the residual risk level was R IV.

### III-2.2.2 Toxic Materials

The MTA presents toxic material hazards identified in Table 1. his hazard has been evaluated within the common risk matrix table included in SAD Section I Chapter 04 *Safety Analysis*. Work in MTA involving this hazard implements the controls specified in the common risk matrix table. No unique controls are in use.

#### III-2.2.2.1 Lead

The primary lead hazard is in the form of lead solder from older electronics that are still in use. Lead radiation shielding is used in MTA counting house, typically in the form of encased lead blankets. This hazard has been evaluated within the common risk matrix table included in SAD Section I Chapter 04 *Safety Analysis*. Work in MTA involving this hazard implements the controls specified in the common risk matrix table. No unique controls are in use. Baseline risk for this hazard was R II and, after control measures were evaluated, the residual risk level was R IV.

#### III-2.2.2.2 Beryllium

While not expected, this SAD considers that Beryllium may need to be brought into the MTA enclosure for experimental purposes. This hazard has been evaluated within the common risk matrix table included in SAD Section I Chapter 04 *Safety Analysis*. Work in MTA involving this hazard implements the controls specified in the common risk matrix table. No unique controls are in use. Baseline risk for this hazard was R II and, after control measures were evaluated, the residual risk level was R IV.

#### III-2.2.2.3 Fluorinert & Its Byproducts

N/A

#### III-2.2.2.4 Liquid Scintillator Oil

It is anticipated that liquid scintillator oil may need to be brought into the MTA enclosure for experimental purposes. This hazard has been evaluated within the common risk matrix table included in SAD Section I Chapter 04 *Safety Analysis*. Work in MTA involving this hazard implements the controls specified in the common risk matrix table. No unique controls are in use. Baseline risk for this hazard was R III and, after control measures were evaluated, the residual risk level was R IV.

Liquid scintillator oil may contain pseudocumene. The pseudocumene is an eyes, skin and respiratory irritant, central nervous system depressant, and is toxic to marine life. A job-specific hazard analysis and procedure will prescribe Personal Protective Equipment (PPE) to prevent worker contact with the liquid scintillator. Emergency spill equipment, an eye wash and PPE will be stationed nearby in the event of a release. A secondary containment membrane will be used that has the capacity to contain 100% of the liquid scintillator oil and prevent a release to the environment. For facility and co-located workers, the baseline risk is III and the mitigated risk is IV. For MOI, the baseline risk is IV and the mitigated risk is IV.

#### III-2.2.2.5 Ammonia

N/A

#### III-2.2.2.6 Nanoparticle Exposures

N/A

### III-2.2.3 Flammables and Combustible Materials

Common industrial lubricants, solvents, and paints are used by technicians to maintain equipment and are stored in flammable materials lockers. This hazard has been evaluated within the common risk matrix table included in SAD Section I Chapter 04 *Safety Analysis*. Work in MTA involving this hazard implements the controls specified in the common risk matrix table. No unique controls are in use. Baseline risk for this hazard was R I and, after control measures were evaluated, the residual risk level was R IV.

### III-2.2.4 Electrical Energy

Electrical hazards are present in the form of low and high voltage power supplies that power magnets, ion pumps, and diagnostic equipment. This hazard has been evaluated within the common risk matrix table included in SAD Section I Chapter 04 *Safety Analysis*. Work in MTA involving this hazard implements the controls specified in the common risk matrix table. No unique controls are in use.

#### III-2.2.4.1 Stored Energy Exposure

The MTA electrical hazards from the alternating current (AC) power distribution systems and the power supplies mentioned in the previous section have been evaluated within the common risk matrix table included in SAD Section I Chapter 04 *Safety Analysis*. Work in MTA involving this hazard implements the controls specified in the common risk matrix table. No unique controls are in use. Baseline risk for this hazard was R I and, after control measures were evaluated, the residual risk level was R IV.

#### III-2.2.4.2 High Voltage Exposure.

See previous sections III-2.2.4 and III-2.2.4.1. This hazard has been evaluated within the common risk matrix table included in SAD Section I Chapter 04 *Safety Analysis*. Work in MTA involving this hazard implements the controls specified in the common risk matrix table. No unique controls are in use. Baseline risk for this hazard was R I and, after control measures were evaluated, the residual risk level was R IV.

#### III-2.2.4.3 Low Voltage, High Current Exposure

See previous sections III-2.2.4 and III-2.2.4.1. This hazard has been evaluated within the common risk matrix table included in SAD Section I Chapter 04 *Safety Analysis*. Work in MTA involving this hazard implements the controls specified in the common risk matrix table. No unique controls are in use. Baseline risk for this hazard was R I and, after control measures were evaluated, the residual risk level was R IV.

### III-2.2.5 Thermal Energy

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

#### III-2.2.5.1 Bakeout

Historically, MTA does not do magnet or beam pipe bakeouts. However, if there is a need to do bakeouts, this hazard has been evaluated within the common risk matrix table included in SAD Section I Chapter 04 *Safety Analysis*. Work in MTA involving this hazard implements the controls specified in the common risk matrix table. No unique controls are in use. Baseline risk for this hazard was R I and, after control measures were evaluated, the residual risk level was R IV.

#### III-2.2.5.2 Hot Work

Qualified welders could occasionally need to work in the enclosure to repair waterlines and other metalwork. Hot work in MTA areas has been evaluated within the common risk matrix table included in SAD Section I Chapter 04 Safety Analysis. Work in MTA involving this hazard implements the controls specified in the common risk matrix table. No unique controls are in use. Baseline risk for this hazard was R I and, after control measures were evaluated, the residual risk level was R IV.

#### III-2.2.5.3 Cryogenics

It is anticipated that experiments may require cryogenic liquids. The amount of cryogens brought in the MTA enclosure will not exceed a liquid volume of 34L (verified through the TSW and ORC processes). Due to this amount of cryogenic liquid, the oxygen concentration in the enclosure can never be lower than 19.5%. As a result, the ODH remains negligible (category IV) at all times. This analysis is documented in an Engineering Note.

This hazard is addressed in the oxygen deficiency hazard section and has been evaluated within the common risk matrix table included in SAD Section I Chapter 04 *Safety Analysis*. Work in MTA involving this hazard implements the controls specified in the common risk matrix table. No unique controls are in use. Baseline risk for this hazard was R IV and, after control measures were evaluated, the residual risk level was R IV.

### III-2.2.6 Kinetic Energy

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

#### III-2.2.6.1 Power Tools

Power tools are commonly used when working on MTA equipment in the enclosure, counting house, and linac gallery. Power tool use has This hazard has been evaluated within the common risk matrix table included in SAD Section I Chapter 04 *Safety Analysis*. Work in MTA involving this hazard implements the controls specified in the common risk matrix table. No unique controls are in use. Baseline risk for this hazard was R I and, after control measures were evaluated, the residual risk level was R IV.

#### III-2.2.6.2 Pumps and Motors

Standard industrial pumps and motors are utilized in the MTA area for water cooling and vacuum systems. This hazard has been evaluated within the common risk matrix table included in SAD Section I Chapter 04 *Safety Analysis*. Work in MTA involving this hazard implements the controls specified in the common risk matrix table. No unique controls are in use. Baseline risk for this hazard was R I and, after control measures were evaluated, the residual risk level was R III.

#### III-2.2.6.3 Motion Tables

MTA experiments use a mechanical motion table to position target materials at selected locations or for optimal beam irradiation. This hazard has been evaluated within the common risk matrix table included in SAD Section I Chapter 04 *Safety Analysis*. Work in MTA involving this hazard implements the controls specified in the common risk matrix table. No unique controls are in use. Baseline risk for this hazard was R I and, after control measures were evaluated, the residual risk level was R III.

#### III-2.2.6.4 Mobile Shielding

This hazard is addressed in the shielding sections below and have been evaluated within the common risk matrix table included in SAD Section I Chapter 04 *Safety Analysis*. Work in MTA involving this hazard implements the controls specified in the common risk matrix table. No unique controls are in use. Baseline risk for this hazard was R I and, after control measures were evaluated, the residual risk level was R III.

### III-2.2.7 Potential Energy

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

#### III-2.2.7.1 Crane Operations

N/A

#### III-2.2.7.2 Compressed Gasses

It is anticipated that compressed gasses may need to be brought into the MTA enclosure for experimental purposes. $ArCO_2$ is used in beam line diagnostic components. These gas cylinders are securely stored in the MTA gas shed. This hazard has been evaluated within the common risk matrix table included in SAD Section I Chapter 04 *Safety Analysis*. Work in MTA involving this hazard implements the controls specified in the common risk matrix table. No unique controls are in use. Baseline risk for this hazard was R I and, after control measures were evaluated, the residual risk level was R IV.

#### III-2.2.7.3 Vacuum/Pressure Vessels/Piping

Vacuum vessels are present in Linac in the form of beam pipes or other beamline components. This hazard has been evaluated within the common risk matrix table included in SAD Section I Chapter 04 *Safety Analysis*. Work in MTA involving this hazard implements the controls specified in the common risk matrix table. No unique controls are in use. Baseline risk for this hazard was R I and, after control measures were evaluated, the residual risk level was R III.

#### III-2.2.7.4 Vacuum Pumps

Vacuum pumps are used throughout the MTA beam line to maintain vacuum in the beamline and other components. This hazard has been evaluated within the common risk matrix table included in SAD Section I Chapter 04 *Safety Analysis*. Work in MTA involving this hazard implements the controls specified in the common risk matrix table. No unique controls are in use. Baseline risk for this hazard was R I and, after control measures were evaluated, the residual risk level was R III.

#### III-2.2.7.5 Material Handling

Trained personnel operate a forklift or hand carts to move materials throughout the MTA area. This hazard has been evaluated within the common risk matrix table included in SAD Section I Chapter 04 *Safety Analysis*. Work in MTA involving this hazard implements the controls specified in the common risk matrix table. No unique controls are in use. Baseline risk for this hazard was R I and, after control measures were evaluated, the residual risk level was R IV.

### III-2.2.8 Magnetic Fields

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

#### III-2.2.8.1 Fringe Fields

The fringe field hazard mainly comes from electromagnets, permanent magnets, and permanent magnets that are in ion pumps. Fields are nominally only hazardous to people who have medical device implants. This hazard has been evaluated within the common risk matrix table included in SAD Section I Chapter 04 *Safety Analysis*. Work in MTA involving this hazard implements the controls specified in the common risk matrix table. No unique controls are in use. Baseline risk for this hazard was R I and, after control measures were evaluated, the residual risk level was R III.

### III-2.2.9 Other Hazards

#### III-2.2.9.1 Confined Spaces

This hazard has been evaluated within the common risk matrix table included in SAD Section I Chapter 04 *Safety Analysis*. Work in MTA involving this hazard implements the controls specified in the common risk matrix table. No unique controls are in use. Baseline risk for this hazard was R I and, after control measures were evaluated, the residual risk level was R III.

### III-2.2.9.2 Noise

Operational beamline systems or experimental set-ups, have the potential to create a noise hazard. This hazard has been evaluated within the common risk matrix table included in SAD Section I Chapter 04 *Safety Analysis*. Work in MTA involving this hazard implements the controls specified in the common risk matrix table. No unique controls are in use. Baseline risk for this hazard was R III and, after control measures were evaluated, the residual risk level was R IV.

### III-2.2.9.3 Silica

Silica dust may be created when drilling into concrete floors or walls This hazard has been evaluated within the common risk matrix table included in SAD Section I Chapter 04 *Safety Analysis*. Work in MTA involving this hazard implements the controls specified in the common risk matrix table. No unique controls are in use. Baseline risk for this hazard was R I and, after control measures were evaluated, the residual risk level was R IV.

### III-2.2.9.4 Ergonomics

Both office and technical work in MTA areas may involve sitting or standing for long periods of time, repetitive motion, cramped conditions, and other ergonomic concerns. This hazard has been evaluated within the common risk matrix table included in SAD Section I Chapter 04 *Safety Analysis*. Work in MTA involving this hazard implements the controls specified in the common risk matrix table. No unique controls are in use. Baseline risk for this hazard was R I and, after control measures were evaluated, the residual risk level was R IV.

### III-2.2.9.5 Asbestos

Access penetrations connecting the Linac gallery to the MTA enclosure may be asbestos lined due to common fire prevention practices during the period when the building was constructed. Due to the age of the building, asbestos may be present in other areas as well. This hazard has been evaluated within the common risk matrix table included in SAD Section I Chapter 04 *Safety Analysis*. Work in MTA involving this hazard implements the controls specified in the common risk matrix table. No unique controls are in use. Baseline risk for this hazard was R I and, after control measures were evaluated, the residual risk level was R IV.

### III-2.2.9.6 Working at Heights

Technicians utilize ladders, step stools, and mobile work platforms to conduct maintenance in the MTA areas. Utilizing fall protection equipment, trained personnel may work on top of equipment where there is a chance of falling. This hazard has been evaluated within the common risk matrix table included in SAD Section I Chapter 04 *Safety Analysis*. Work in MTA involving this hazard implements the controls specified in the common risk matrix table. No unique controls are in use. Baseline risk for this hazard was R I and, after control measures were evaluated, the residual risk level was R III.

### III-2.2.10 Access & Egress

#### III-2.2.10.1 Life Safety Egress

The MTA enclosure has access and egress points at both the upper level and the lower pit level. This hazard has been evaluated within the common risk matrix table included in SAD Section I Chapter 04 *Safety Analysis*. Work in MTA involving this hazard implements the controls specified in the common risk matrix table. No unique controls are in use. Baseline risk for this hazard was R I and, after control measures were evaluated, the residual risk level was R IV.

### III-2.2.11 Environmental

#### III-2.2.11.1 Hazard to Air

N/A

#### III-2.2.11.2 Hazard to Water

N/A

#### III-2.2.11.3 Hazard to Soil

N/A

## III-2.3. Maximum Credible Incident (MCI) Scenario(s) for the Accelerator Specific Hazard(s)

### III-2.3.1 Definition of the Maximum Credible Incident

This section of the MTA SAD evaluates the maximum credible incident (MCI) scenario that could happen in the MTA. Consideration and analysis of this MCI is focused on an onsite facility worker, onsite co-located worker, and a maximally exposed off-site individual (MOI).

#### III-2.3.1.1 Radiological Hazard

The MTA can provide protons or H- ions from the Linac to the irradiation test area (ITA) or to the final absorber for beam tuning. A maximum credible incident would be one that produces the greatest beam loss for the longest period of time. The MTA MCI is dependent on the intensity of the Linac resulting from the MCI for Linac. After careful evaluation, it has been determined that the Linac MCI, with respect to beam intensity, has the following beam parameters. At 400 MeV, Linac can achieve a maximum beam pulse length of 60 microseconds and beam current of 130 mA at 15 Hz. The maximum current is limited by the RFQ transmission, and the beam pulse width is limited by the SCL coupling cavities. See the Linac SAD chapter on maximum credible incident scenario(s) for the accelerator-specific hazard(s) for more information. A change to the Linac MCI will be evaluated for its effect on MTA through the USI process.

As a result, the maximum beam intensity output that can be achieved from the Linac is 2.58E18 protons/hour, with 4.78E13 protons/pulse at 15 Hz. Since the two pulsed C magnets that extract beam horizontally into the MTA line can operate at the full 15 Hz cycle, the MCI for MTA will also need to take into account this maximum beam output of 2.58E18 protons/hr. A maximum credible incident would be one that produces the greatest beam loss for the longest period of time. The MTA MCI occurs when 2.58E18 protons/hour is lost and continuously incident on a beamline component that is both the closest to the thinnest section of permanent shielding and the farthest away from interlocked radiation detectors in the MTA beamline for one hour. This MCI in MTA can be a result of the misdirection of the beam so that it impacts the beam pipe and surrounding structures inside the accelerator enclosure, which can occur from a single failure of one or more devices or power supplies, or erroneous operation of them. Also, the C magnet's power supply is assumed to be left on and pulsing at 15 Hz for a full hour.

Prompt radiation causes hazardous radiation fields directly and indirectly through material effects. Assuming no shielding is present, this incident would result in a dose that far exceeds acceptable levels for radiation exposure to workers or members of the public. The MCI analysis finds that a peak dose rate of 9505 mrem/hr would occur at the surface of the MTA berm in this accident condition. Without any preventative or mitigative measures, the prompt radiation dose level associated with this accident is not acceptable.

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

- Worker Basis: Mitigated consequence of any credible postulated accident scenario at maximum operating intensity that could potentially result in 5 rem in one hour in any area accessible by facility workers and co-located workers.
- General Site Basis: Mitigated consequence of any credible postulated accident scenario at maximum operating intensity that could potentially result in 500 mrem in one hour in areas to which the public is assumed to be excluded.
- Public Area Basis: Mitigated consequence of any credible postulated accident scenario at maximum operating intensity that could potentially result in 100 mrem in one hour at Fermilab’s site boundary AND/OR in any areas onsite in which the public is authorized.

These Credited Controls are discussed in Section III-2.4.

The MCI for MTA utilizes the General Site Basis, therefore requiring the passive Credited Control of Obvious and Operating Barriers to ensure only authorized access. The 8GeV segment is located beyond the Obvious and Operating Barriers. The accumulated dose outside of the shielding on the MTA berm is mitigated, by use of Credited Controls, to less than 500 mrem in an MCI. The closest possible location of a member of the public to the MTA enclosure is the Wilson Hall parking lot. This location is more than five feet away from the location of the Credited Control radiation monitors, which would result in dose of less than 100 mrem applying a conservative dose reduction of 1/r.

## III-2.4. Summary of Credited Controls

This section describes the Credited Controls that are required to reduce the risk associated with the MCI to a negligible consequence level.

### III-2.4.1 Credited Engineering Controls

The purpose of this section is to provide the information necessary to understand the engineered controls, which can be active or passive, and administrative controls that are used to prevent or mitigate the consequences of the MCI. This analysis then verifies that the risk associated with the MTA MCI is reduced to a negligible level.

#### III-2.4.1.1 Passive Credited Controls

Passive controls are elements that are part of the physical design of the facility that require no action to function properly. These are fixed elements of the beamline that take direct human intervention to remove. The MTA enclosure is designed and constructed as a permanent concrete and earth-covered radiation shield that uses a combination of permanent shielding, movable shielding, and penetration shielding, to protect personnel from radiological exposure due to an MCI.

##### *III-2.4.1.1.1 Permanent Shielding Including Labyrinths*

The permanent shielding encompasses the structural elements surrounding the beamline components and experimental hall. The concrete structure is contiguous with the Linac and includes an upstream equipment access hatch, an equipment access pit on the south side of the experimental hall, a personnel access labyrinth with two exits, utility penetrations, and earthen berms and overburden.

There are two categories of beam-material interactions that are considered for the MTA shielding requirements for the MCI. The first is beam hitting a magnet in an enclosure, and the second is beam hitting the beam pipe in the enclosure. The MCI, is 2.58E18 protons/hour hitting a magnet. This scenario requires 17.2 effective feet of dirt (e.f.d) to limit the radiation dose rate to less than 500 mrem-per-hour for a person outside of the beamline areas. If there is 17.2 e.f.d. of shielding that surrounds the MTA line, then a person outside of the beamline areas and right next to the shielding will receive at most a dose of 500 mrem within one hour from the assumed one hour of maximum beam power operations. See

Table 3 for the amounts of shielding along the Linac and MTA berms. Three locations where there is more than 17.2 e.f.d., the hatch, pipe to absorber and absorber, 17.2 e.f.d. is the credited control. There are a number of areas along the MTA beamline with less than 17.2 e.f.d. which will require active controls as described below in addition to the existing shielding. In the locations with less than 17.2 e.f.d., 0.5 e.f.d. less than the values in

Table 3 will be taken as the credited control along with the interlocked detector. The trip setting for the interlocked detector will be set to account for this lessor amount of shielding taken as a credited control.

*Table 2. Scaled Shielding Requirements from the MTA shielding assessment*

| Effective Dose, D, per hour | A. Beam on Magnet in Enclosure | Primary Scaled (efd) | Secondary Scaled (efd) |
|---|---|---|---|
| | **Category** | | |
| | | | |
| **D < 1 mrem** | 1A | **26.4** | **26.4** |
| **1 ≤ D < 5 mrem** | 2A | **24.0** | **24.0** |
| **1 ≤ D ≤ 10 mrem** | 1SE-A | **23.0** | **23.0** |
| **1 ≤ D ≤ 10 mrem** | 2SE-A | **23.0** | **23.0** |
| **5 ≤ D < 100 mrem** | 3A | **19.6** | **19.6** |
| **100 ≤ D < 500 mrem** | 4A | **17.2** | **17.2** |
| **500 ≤ D < 1000 mrem** | 5A | **16.2** | **16.2** |

*Table 3. MTA Longitudinal Shielding Thicknesses*

| Beam Type | Longitudinal Range | Location | Fixed Shielding (efd) | Movable Shielding (efd) | Current Shielding (efd) |
|---|---|---|---|---|---|
| | **(z)** | | | | |
| | | | | | |
| **P** | 0-41 | Main Linac enclosure | 14.9 | | 14.9 |
| **P** | 41-55 | Linac high ceiling | 13.3 | | 13.3 |
| **P** | 55-103 | Linac ramp | 15.7 | | 15.7 |
| **P** | 103-106 | Beam stop alcove | | 18.1 | 18.1 |
| **P** | 106-115 | Hatch | | 21.7 | 21.7 |
| **P** | 115-147 | MTA upstream stub | 10.4 | | 10.4 |
| **P** | 147-187 | MTA main hall | 10.6 | | 10.6 |
| **P** | 187-193 | Pipe to absorber | 19.0 | | 19.0 |
| **P** | 193-203 | Absorber in berm | 21.7 | | 21.7 |

*Table 4. MTA Transverse Shielding Thicknesses*

| Beam Type | Transverse Station (ft) | Location | Fixed Shielding (efd) | Movable Shielding (efd) | Current Shielding (efd) |
|---|---|---|---|---|---|
| | | | | | |
| **P** | 15 | C-Magnet | 13.0 | | 13.0 |
| **P** | 45 | 13-ft Ceiling | 11.9 | | 11.9 |
| **P** | 57 | 10-ft Ceiling | 14.2 | | 14.2 |
| **P** | 104 | Beam Stop Alcove | | 18.1 | 18.1 |
| **P** | 110 | Hatch Waveguide | | 21.7 | 21.7 |
| **P** | 110 | Hatch Waveguide | | 21.7 | 21.7 |
| **P** | 112 | Hatch Waveguide | | 21.7 | 21.7 |
| **P** | 115 | Hatch Waveguide | | 21.7 | 21.7 |
| **P** | 135 | MTA Stub | 10.4 | | 10.4 |
| **P** | 157 | MTA Exp Hall | 10.2 | | 10.2 |
| **P** | 167 | MTA Rollup Door | | 15.0 | 15.0 |

### *III-2.4.1.1.2 Penetration and Movable Shielding*

The MTA does have a few areas where movable shielding is located. This includes vents and penetrations that are no longer used. The MTA has several penetrations routing between the enclosure and the counting house upstairs and have been addressed in the shielding assessment [2]. These penetrations leading to the counting house have been completely filled with polyethylene and sand. The hatch and ceiling vent leading to the MTA berm has been completely filled with sand and concrete. All moveable shielding has been verified by the Fermilab Radiation Protection Operations Department (RPO) and is a credited control. The RPO department utilizes a configuration management control system to ensure that all movable shielding is present and is an administrative credited control. All movable shielding at the MTA is covered and locked to also ensure that it remains in place. An interlocked radiation detector is placed in front of the penetrations in the counting house to protect personnel from the accident condition and again ensure that all dose rates remain below the posting limit for the area. This interlocked radiation detector is also a credited control.

### *III-2.4.1.1.3 Obvious and Operating Barriers*

To permit entry to only authorized individuals into the area where the General Site Basis applies (see Figure 4) surrounding the MTA segment of the Fermilab Main Accelerator, Obvious and Operating Barriers shall be established to the following locations to permit only authorized access:

- Wilson Hall West
- Wilson Hall East
- Site 55

### III-2.4.2 Active Engineered Credited Controls

Active engineered controls are systems designed to reduce the risks from the MCI to an acceptable level. The active controls in place for the MTA operations are discussed below.

#### III-2.4.2.1 Radiation Safety Interlock System

The MTA enclosure employs a Radiation Safety Interlock System (RSIS). The characteristics of the system are described in Section I of the Fermilab SAD. There are interlocked doors at each of the two entrance labyrinth access points into the MTA enclosure. The interlock system inhibits transport of beam into the MTA enclosure except when the MTA enclosure is properly secured and locked.

The RSIS inhibits beam by controlling redundant critical devices. In this case, the E: UH101 power supply that feeds a four-magnet dipole bend string that directs beam to the MTA enclosure, and the UBS109 beam stop located at the entrance of the equipment hatch shielding that separates the Linac and MTA enclosures. In the event of a critical device failure, the system has a failure mode function that will reach back and inhibit beam to the Linac, thus eliminating the possibility of beam reaching the MTA.

The RSIS including requirements for hardware and system testing, inventory of interlock keys and procedures for maintenance of interlock systems. The RSIS hardware enforces the Search and Secure and Controlled Access processes. The RSIS is designed, installed, and configuration managed in conformance with the requirements stated in the FRCM. The “search and secure” process consists of a through exploration of the enclosure to ensure that the MTA RSIS area is not occupied. This process is completed by resetting the interlock boxes and a prescribed order in preparation for beam delivery. Trained and qualified personnel from the AD Operations Department are required to search and secure the enclosure before permits from the RSIS may be reestablished following any personnel access to the enclosure, except under strictly specified controlled access conditions.

As mentioned above, with the MTA MCI having an intensity of 2.58E18 protons/hr, the amount of permanent shielding needed to keep an individual exposure below 500 mrem in an hour is 17.2 e.f.d. This is the shielding between the interior surface of the enclosure walls and the nearest areas accessible by any individual. However, for the MCI, there are a number of areas along the MTA beamline that do not have the required shielding of 17.2 e.f.d. As a result, Interlocked radiation detectors are employed at those areas so that the same level of protection is provided and a dose to an individual standing in these areas will not receive a dose greater than 500 mrem in one hour. These radiation detectors are interlocked to the critical device controller (CDC), and if any one of them is absent from the CDC loop in the RSIS, beam cannot be transported to the MTA enclosure.

Interlocked radiation detectors are placed on the berm along the primary beamline and the experimental hall in those areas that are the most likely to be occupied at locations capable of detecting all accident conditions and are Credited Controls. The interlocked radiation detectors protect personnel by disabling the beam should prompt radiation from operations exceed specific dose rate limits. The credited control trip limits for these interlocked radiation detectors are set to levels that prevent any individual from receiving a dose rate beyond what is defined in Section III-2.3.1.1, even with an unforeseen reduction of the permanent shielding between the interior of the enclosure walls and the surface of the berm by 0.5

e.f.d. at the time of the maximum credible incident. The analysis to determine the credited control trip limits is provided as a reference in the "Analysis of the Maximum Credible Incident for MeV Test Area Beamline and Hall" document [6]. This analysis evaluates the consequence of the maximum credible beam intensity being lost at multiple points along the MTA berm and in the Counting House. The specific detector type, their locations and their credited control trip limit values are presented in Table 5 below. Operationally, the trip levels are set lower than this value to satisfy occupancy requirements per 10 CFR Part 835 through the direction of the Radiation Physics Operation Department (RPO).

Interlocked radiation detectors are capable of disabling beam within a maximum of 3 seconds to the MTA, allowing only 45 pulses into the MTA beamline in the event of an accident condition including initial detection of the event. This therefore limits the total number of protons delivered in an accident condition to $2.15 \times 10^{15}$. Interlocked radiation detectors on the berm have at least a 10' radius detection and therefore can be spaced ~20' apart on top of the berm. These interlocked radiation detectors will also protect transverse shielding loss points. Based on the MCI analysis the following interlocked radiation detectors are the Credited Controls. [6]

*Table 5. Interlocked radiation detectors at MTA*

| Type of Radiation Detector | Interlocked Radiation Detector Location | Credited Control Limit |
|---|---|---|
| Chipmunk | Linac High Ceiling | < 177 mrem/hr |
| Chipmunk | Linac Ramp – top of berm Upstream | < 165 mrem/hr |
| Chipmunk | Linac Ramp – top of berm Downstream | < 500 mrem/hr |
| Chipmunk | Beam Stop Alcove – top of berm upstream of hatch | < 500 mrem/hr |
| Chipmunk | MTA Upstream Stub- above UVB11 (SQA) | < 500 mrem/hr |
| Chipmunk | MTA Hall – Ceiling Vent | < 500 mrem/hr |
| Chipmunk | MTA Hall Mid-Hall | < 500 mrem/hr |
| Chipmunk | MTA Hall "Front Porch" | < 500 mrem/hr |
| Chipmunk | Pipe to Absorber | < 500 mrem/hr |
| Chipmunk | MTA Counting House | < 5 Rem/hr |

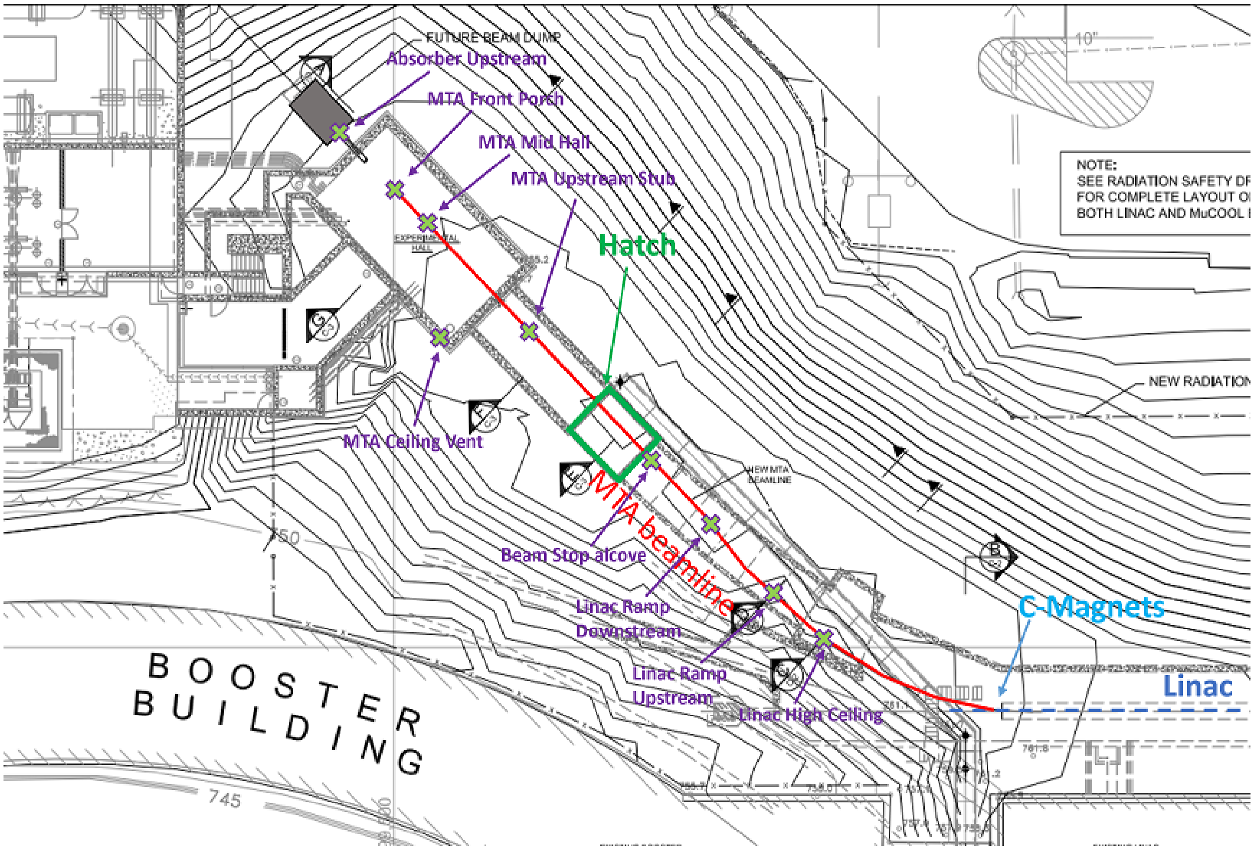

*Figure 5. Locations of interlocked detectors on the MTA berm*

### III-2.4.2.2 ODH Safety System

Oxygen Deficiency Hazards (ODH) due to cryogenic systems within accelerator enclosures have been identified as accelerator-specific hazards, and as such, any preventative or mitigative controls used to prevent an ODH MCI are identified as Credited Controls and documented in the ASE. As part of the ITA experimental program, it is possible for cryogenic liquids to be present in the MTA enclosure. As a result an analysis of this potential hazard has been performed.

The amount of cryogens an ITA experiment may bring into the MTA has been reviewed in engineering note EN08855 and will not exceed a liquid volume threshold of 34 liters. With this amount of cryogenic liquid, the oxygen concentration in the enclosure will never be lower than 19.5% and thus the ODH hazard remains negligible (category IV) at all times with no Credited Controls. As a result, an ODH Safety System is not needed at MTA.

### III-2.4.3 Administrative Credited Controls

All MTA administrative Credited Controls are discussed below.

#### III-2.4.3.1 Operation Authorization Document

Beam will not be transported to the MTA enclosure without an approved Beam Permit and Running Condition. The Beam Permit specifies beam power limits as determined and approved by the AD Associate Laboratory Director, in consultation with the ES&H Radiation Physics Operations Department Head, ES&H Accelerator Safety Department Head, assigned RSO, AD Operations Department Head, and AD External Beam Delivery Department Head. The Running Condition for the MTA describes the operating configuration as reviewed by the assigned RSO, AD Operations Department Head, and AD External Beam Delivery Department Head and as approved by the AD Associate Laboratory Director.

#### III-2.4.3.2 Staffing

MCR must be appropriately staffed to ensure that a valid search and secure is performed for all enclosures, that all interlocked radiation detector trip limits are below the ASE limit and all beam losses stay under one hour in duration.

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 duty.
- At least one member of the AD Operations Department shall be present in the Main Control Room (MCR).

A single person could satisfy both of these conditions.

#### III-2.4.3.3 Accelerator Operating Parameters

To ensure operations within bounding conditions used in the MCI analysis, the following intensity shall not be exceeded: 2.58e18 protons/hr at 400 MeV.

## III-2.5. Summary of Defense-in-Depth Controls

MTA has additional controls in place that reduce the risk associated with the maximum credible incident, but that are not required to mitigate it. These controls are considered defense-in-depth, and they are defined in the following sections.

### III-2.5.1 Defense-in-Depth Engineering Controls

#### III-2.5.1.1 Passive Defense-in-Depth Engineering Controls

##### *III-2.5.1.1.1 Permanent Shielding*

Existing shielding in excess of the credited amount shown in Tables 3-4 is defense in depth and is at least 0.5 e.f.d. in all locations.

### III-2.5.1.2 Active Defense-in-Depth Engineering Controls

#### *III-2.5.1.2.1 Machine Protection Controls*

MTA is protected by beam loss monitors.

### III-2.5.1.3 Defense-in-Depth Administrative Controls

#### *III-2.5.1.3.1 Fencing and Posting*

Fences are used and posted to designate potential radiation areas during machine operations. The MTA shielding assessment concluded that the radiation levels that can be expected along the MTA beamline require fences with a radiation area posting. The entire Linac berm along with the MTA beamline was fenced and posted consistent with its identification as a radiation area in accordance with the FRCM.

#### *III-2.5.1.3.2 Training*

All personnel engaged in the commissioning, operation, and emergency management of the Linac shall have at a minimum, Fermilab's Radiological Worker Training. Furthermore, personnel approved for access into the MTA interlocked enclosure shall have Fermilab's Controlled Access training current as well.

Training in Fermilab's General or system-specific Lock Out/Tag Out procedures shall be required to perform troubleshooting and maintenance as applicable.

#### *III-2.5.1.3.3 Procedures*

As applicable, either Fermilab's general Lock Out/Tag Out or written Departmental Lock Out/Tag Out procedures shall be used. As per Fermilab's FESHM Chapter 2100, written departmental safety procedures shall be reviewed and re-approved every 12 months, at a minimum, or when the configuration of the equipment has been altered. Re-training for these procedures shall also be carried out every 12 months to remain current.

## III-2.6. Decommissioning

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

## III-2.7. Summary and Conclusion

Specific hazards associated with commissioning and operation of the MTA beam line enclosure and experimental areas are identified and assessed in this Chapter of the Fermilab Safety Assessment Document. The designs, controls, and procedures to mitigate the MTA beam line specific hazards are identified and described. In addition to these specific safety considerations, the MTA beam line is subject to the global and more generic safety requirements, controls and procedures outlined in Section 1 of this Fermilab SAD.

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

## III-2.8. References

[1] Fermilab Radiological Control Manual

[2] 2020 "Shielding Assessment Document for the MeV Test Area at the Fermilab Linac Endstation

[3] Title 40, Code of Federal Regulations, Part 61, Subpart H, "National emissions standard for hazardous air pollutants (NESHAP) for the emission of radionuclides other than radon from Department of Energy Facilities", 1989.

[4] MARS Code System Users Guide

[5] Environmental Protection Notes

[6] C. Johnstone, A Mazzacane and S. McGimpsey "Analysis of the Maximum Credible Incident for MeV Test Area Beamline and Hall", 2023

## III-2.9. Appendix – Risk Matrices

Risk Assessment methodology was developed based on the methodology described in DOE-HDBK-1163-2020 and is presented in Tables 6.1 through 6.28. Hazards and their potential events are evaluated for likelihood and potential consequence assuming no controls in place, which results in a baseline risk. A baseline risk (i.e., an unmitigated risk) value of III and IV does not require further controls based on the Handbook. Events with a baseline risk value of I or II do require prevention and/or mitigation measures to be established in order to reduce the risk value to an acceptable level of III or IV. Generally, preventive controls are applied prior to a loss event, reflecting a likelihood reduction, and mitigative controls are applied after a loss event, reflecting a consequence reduction. For each control put in place, likelihood or consequence can have a single “bin drop,” resulting in a new residual risk (i.e., a mitigated risk). This risk assessment process is repeated for each hazard for Facility Workers (FW), Co-Located Workers (CLW), and Maximally Exposed Offsite Individual (MOI). At the conclusion of the risk assessments, controls that are in place for the identified accelerator-specific hazards are identified as Credited Controls and further summarized in Section III-2.3 of this Chapter as well as SAD Chapter VII-A.1 *Accelerator Safety Envelope – Fermilab Main Accelerator*.