400 MEV TEST AREA

SECTION III CHAPTER 02 OF THE FERMILAB SAD

Revision 2 August 7, 2023

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.

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 (ESH) 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

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 ESH DocDB #1066 along with all other current revisions of all Chapters of the Fermilab SAD.

Author	Rev. No.	Date	Description of Change
Herman B. White	0	January 20, 2011	Initial release of the MuCool Test Area Chapter for the Fermi National Accelerator Safety Assessment Document (SAD)
T. Kobilarcik 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.
S. McGimpsey	2	August 7, 2023	Updated for use with the new template and editorial changes.

Table of Contents

SAD Chapter Review 2
Revision History 4
Table of Contents 6
Acronyms and Abbreviations 10
III-2. 400 MeV Test Area 16
III-2.1. Introduction 16
III-2.1.1 Purpose/Function 16
III-2.1.2 Current Status 16
III-2.1.3 Description 16
III-2.1.4 Location 17
III-2.1.5 Management Organization 18
III-2.1.6 Operating Modes 18
III-2.1.7 Inventory of Hazards 19
III-2.2. Safety Assessment 20
III-2.2.1 Radiological Hazards 20
III-2.2.1.1 Prompt Ionizing Radiation 21
III-2.2.1.2 Residual Activation 21
III-2.2.1.3 Groundwater Activation 22
III-2.2.1.4 Surface Water Activation 22
III-2.2.1.5 Radioactive Water (RAW) Systems 22
III-2.2.1.6 Air Activation 22
III-2.2.1.7 Closed Loop Air Cooling 23
III-2.2.1.8 Soil Interactions 23
III-2.2.1.9 Radioactive Waste 23
III-2.2.1.10 Contamination 24
III-2.2.1.11 Beryllium-7 24
III-2.2.1.12 Radioactive Sources 24
III-2.2.1.13 Nuclear Material 24
III-2.2.1.14 Radiation Generating Devices (RGDs) 24
III-2.2.1.15 Non-Ionizing Radiation Hazards 24
III-2.2.2 Toxic Materials 24

III-2.2.2.1 Lead 25
III-2.2.2.2 Beryllium 25
III-2.2.2.3 Fluorinert & Its Byproducts 25
III-2.2.2.4 Liquid Scintillator Oil 25
III-2.2.2.5 Pseudocumene 25
III-2.2.2.6 Ammonia 25
III-2.2.2.7 Nanoparticle Exposures 25
III-2.2.3 Flammables and Combustibles 25
III-2.2.3.1 Combustible Materials 25
III-2.2.3.2 Flammable Materials 26
III-2.2.4 Electrical Energy 26
III-2.2.4.1 Stored Energy Exposure 26
III-2.2.4.2 High Voltage Exposure 26
III-2.2.4.3 Low Voltage, High Current Exposure 26
III-2.2.5 Thermal Energy 26
III-2.2.5.1 Bakeout 26
III-2.2.5.2 Hot Work 26
III-2.2.5.3 Cryogenics 27
III-2.2.6 Kinetic Energy 27
III-2.2.6.1 Power Tools 27
III-2.2.6.2 Pumps and Motors 27
III-2.2.6.3 Motion Tables 27
III-2.2.6.4 Mobile Shielding 27
III-2.2.7 Potential Energy 27
III-2.2.7.1 Crane Operations 27
III-2.2.7.2 Compressed Gasses 28
III-2.2.7.3 Vacuum/Pressure Vessels/Piping 28
III-2.2.7.4 Vacuum Pumps 28
III-2.2.7.5 Material Handling 28
III-2.2.8 Magnetic Fields 28
III-2.2.8.1 Fringe Fields 28
III-2.2.9 Other Hazards 28

III-2.2.9.1 Confined Spaces ... 28
III-2.2.9.2 Noise ... 28
III-2.2.9.3 Silica ... 29
III-2.2.9.4 Ergonomics ... 29
III-2.2.9.5 Asbestos ... 29
III-2.2.9.6 Working at Heights ... 29
III-2.2.10 Access & Egress ... 29
III-2.2.10.1 Life Safety Egress ... 29
III-2.2.11 Environmental ... 29
III-2.2.11.1 Hazard to Air ... 29
III-2.2.11.2 Hazard to Water ... 29
III-2.2.11.3 Hazard to Soil ... 30
III-2.3. Summary of Hazards to Members of the Public ... 30
III-2.4. Summary of Credited Controls ... 30
III-2.4.1 Passive Credited Controls ... 30
III-2.4.1.1 Shielding ... 30
III-2.4.1.1.1 Permanent Shielding Including Labyrinths ... 30
III-2.4.1.1.2 Movable Shielding ... 30
III-2.4.1.1.3 Penetration Shielding ... 31
III-2.4.1.2 Fencing ... 31
III-2.4.2 Active Engineered Credited Controls ... 31
III-2.4.2.1 Radiation Safety Interlock System ... 31
III-2.4.2.2 ODH Safety System ... 31
III-2.4.3 Administrative Credited Controls ... 32
III-2.4.3.1 Operation Authorization Document ... 32
III-2.4.3.2 Staffing ... 32
III-2.4.3.3 Accelerator Operating Parameters ... 32
III-2.5. Defense-in-Depth Controls ... 32
III-2.6. Machine Protection Controls ... 32
III-2.7. Decommissioning ... 32
III-2.8. Summary and Conclusion ... 33
III-2.9. References ... 33

III-2.10. Appendix – Risk Matrices 33

Acronyms and Abbreviations

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

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

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

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

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

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

III-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 400 MeV Test Area is to provide 400 MeV H- or protons to the MTA. The 400 MeV Test Area 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 is located southwest of the Linac accelerator and consists of a beamline that extends from the end of the Linac through a shield wall into a 50 m region separating the Linac tunnel and the experimental hall. This SAD chapter will only address the hazards in the MTA enclosure.

The MTA Beamline is extracted from the Linac accelerator using two C-type magnets. When energized, these dipoles kick the Linac beam into the extraction channel. Once the beam is extracted, it is directed through a shield wall into the downstream section of beamline and through the experimental hall.

In the experiment hall, beam emerges at the end of the beam line through a titanium 5 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 which serves as another position for target material. Uninteracted beam 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.

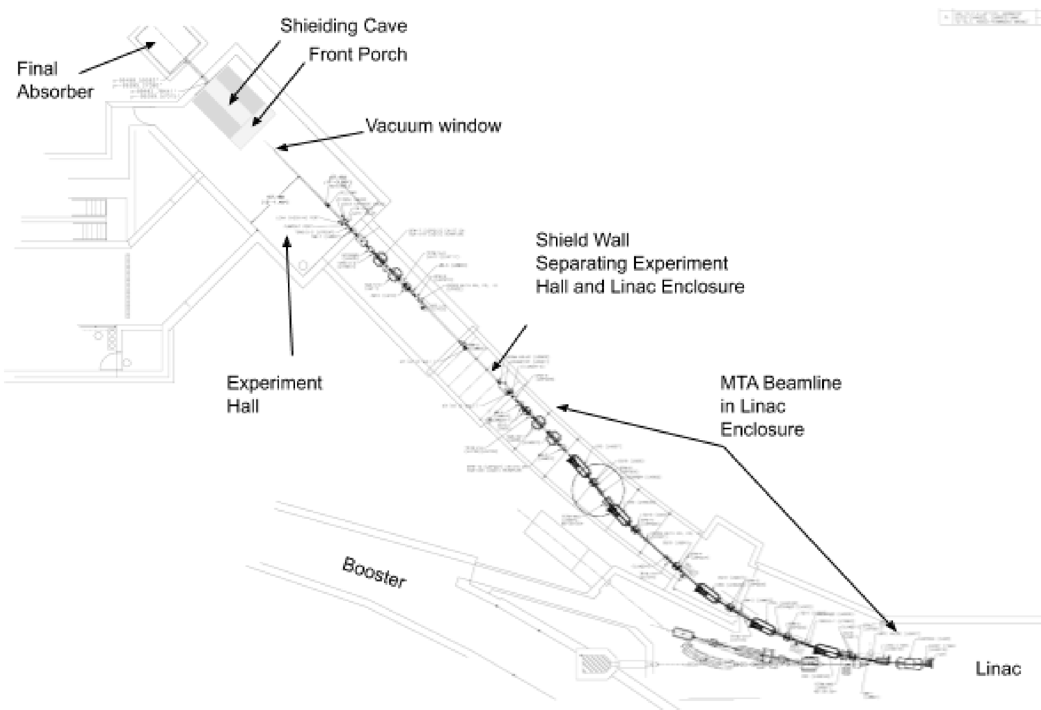

Figure 1. MTA Experimental Hall

III-2.1.4 Location

The MTA segment of the Fermilab Main Accelerator is located on the Fermilab site in Batavia, IL.

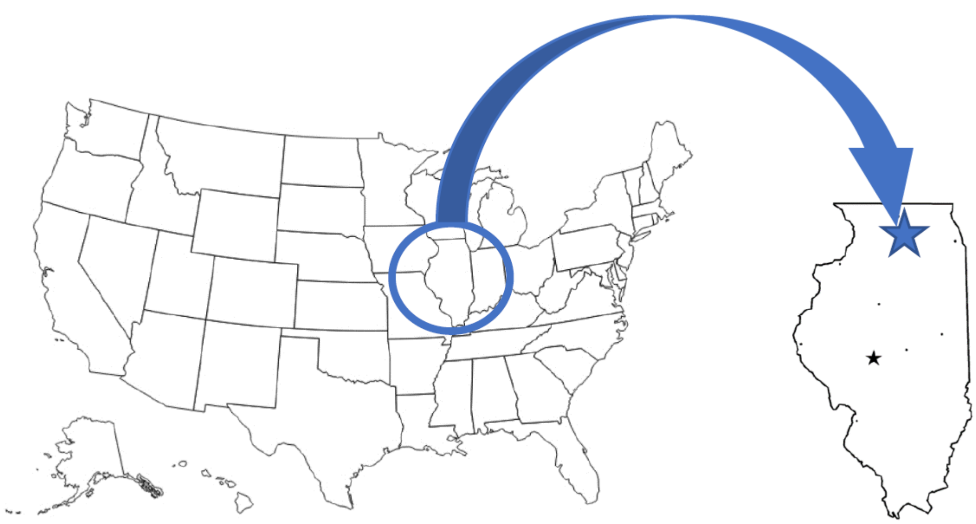

Figure 2. Regional view showing the location of the Fermilab site in Batavia, IL.

The MTA is located in the central campus on the Fermilab site.

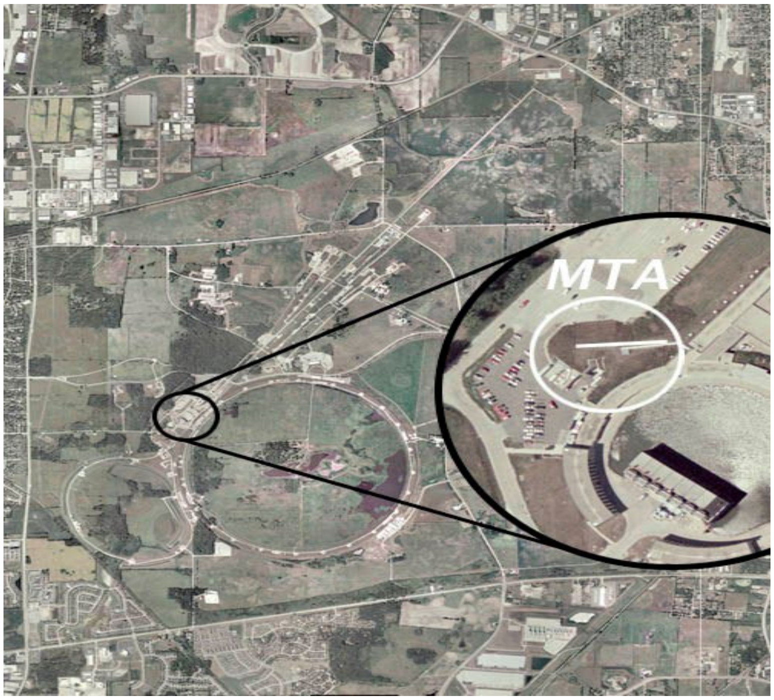

Figure 3. Aerial view of the Fermilab site, indicating the location of the MTA.

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 (H- or protons) 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.

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-2.10 *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 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, Oxygen Deficiency Hazards due to cryogenic systems within accelerator enclosures, and fluorinert byproducts due to use of fluorinert that is subject to particle beam 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 Standard Industrial Hazards (SIH), 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
☐	Bakeout	☒	Motion Tables
☐	Hot Work	☒	Mobile Shielding
☒	**Cryogenics**		**Magnetic Fields**
	Potential Energy	☒	Fringe Fields
☐	Crane Operations		**Other Hazards**
☒	Compressed Gasses	☐	Confined Spaces
☒	Vacuum/Pressure Vessels/Piping/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).

With the use of signs, fences, gates, locks, interlocked radiation detectors, and the radiation safety interlock system, there is sufficient shielding to protect individuals from beam-on radiation hazards in and around the MTA Beamline and facility. 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-2.2.1.2 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. 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 Numbers 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. 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-2.2.1.4 Surface Water Activation

See ground water 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 4500 day half-life), and argon-41 (with a 269 year 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 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-2.2.1.9 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).

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

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, and 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-2.2.1.11 Beryllium-7

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, and since this material is inaccessible to workers, co-located workers and public due to where it may found within the facility, coupled 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. 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 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

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-2.2.2 Toxic Materials

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-2.2.2.1 Lead

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

III-2.2.2.2 Beryllium

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

III-2.2.2.3 Fluorinert & Its Byproducts

N/A.

III-2.2.2.4 Liquid Scintillator Oil

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-2.2.2.5 Pseudocumene

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-2.2.2.6 Ammonia

N/A.

III-2.2.2.7 Nanoparticle Exposures

N/A.

III-2.2.3 Flammables and Combustibles

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-2.2.3.1 Combustible Materials

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

III-2.2.3.2 Flammable Materials

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 Electrical 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-2.2.4.1 Stored Energy Exposure

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

III-2.2.4.2 High Voltage Exposure

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

III-2.2.4.3 Low Voltage, High Current Exposure

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

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

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-2.2.5.2 Hot Work

N/A.

III-2.2.5.3 Cryogenics

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 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

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-2.2.6.2 Pumps and Motors

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

III-2.2.6.3 Motion Tables

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

III-2.2.6.4 Mobile Shielding

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 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

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-2.2.7.3 Vacuum/Pressure Vessels/Piping

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

III-2.2.7.4 Vacuum Pumps

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

III-2.2.7.5 Material Handling

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

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

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-2.2.9 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.

III-2.2.9.2 Noise

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

III-2.2.9.3 Silica

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

III-2.2.9.4 Ergonomics

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

III-2.2.9.5 Asbestos

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-2.2.9.6 Working at Heights

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

III-2.2.10 Access & Egress

III-2.2.10.1 Life Safety Egress

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

III-2.2.11 Environmental

III-2.2.11.1 Hazard to Air

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

III-2.2.11.2 Hazard to Water

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

III-2.2.11.3 Hazard to Soil

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

III-2.3. Summary of Hazards to Members of the Public

All hazards to the public have been evaluated within the common Risk Matrix table included in SAD Section I Chapter 04, *Safety Analysis*. Work in MTA involving these hazards implements the controls specified in the common Risk Matrix table. No unique controls are in use.

III-2.4. Summary of Credited Controls

III-2.4.1 Passive Credited Controls

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

III-2.4.1.1 Shielding

The MTA beam line shielding analyses indicate the mitigations necessary to comply with the FRCM requirements. Interlocked radiation detectors are installed on the top of the berm as prescribed by the shielding assessments to mitigate this concern.

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.

The permanent shielding for the enclosure is documented in the shielding assessment [5] and consists of sufficient earth overburden such that unacceptable levels of prompt radiation cannot occur under the assessed beam conditions.

III-2.4.1.1.2 Movable Shielding

The MTA has two areas where movable shielding is located. These areas are the equipment access hatch and the experimental hall pit equipment access area. The shielding for each of these areas is defined in the shielding assessment [5] and is locked in place and controlled by the assigned RSO.

III-2.4.1.1.3 Penetration Shielding

Penetrations have been addressed in the shielding assessment [2]. All unused penetrations are filled with sand and poly, as specified by the shielding assessment [2]. Unfilled penetrations, used for cable runs, etc., are analyzed in the shielding assessment; prompt dose is within the limits allowed by posting. The prompt dose rates at the exits of all penetrations are within the limits established in the FRCM [1].

III-2.4.1.2 Fencing

Fences are used and posted to designate potential radiation areas during machine operations. For the MTA, the entire Linac berm, the area downstream of the absorber, and beamline areas are fenced and posted as a Radiation Area. Controlled Area Fencing The outdoor pit area adjacent to the experimental hall is posted as a Controlled Area in accordance with the FRCM [1].

III-2.4.2 Active Engineered Credited Controls

Active engineered controls are systems designed to reduce the risks from accelerator operations to an acceptable level. These are automatic systems that limit operations, shutdown operations, or provide warning alarms when operating parameters are exceeded.

III-2.4.2.1 Radiation Safety Interlock System

The MTA enclosure employs a Radiation Safety Interlock System (RSIS).

There are interlocked doors at each of the two entrance labyrinth access points into the MTA enclosure. The interlock system inhibits transport of beam beyond the Linac extraction point 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 immediately downstream of the Linac extraction point and the UBS109 beamstop 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.

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. The RSIS, including requirements for hardware and system testing, inventory of interlock keys, search and secure procedures for the beamline enclosure, controlled access procedures, personnel training requirements, and procedures for maintenance of interlock systems, are in conformance with the requirements stated in the FRCM.

III-2.4.2.2 ODH Safety System

An ODH Safety System is not needed at MTA. MTA would be an engineered ODH 0 area, in any ITA experiments would bring cryogens into the MTA enclosure.

III-2.4.3 Administrative Credited Controls

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

III-2.4.3.1 Operation Authorization Document

In accordance with AD Administrative Procedure on Beam Permits, Running Conditions, and Startup (ADAP-11-0001), 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, assigned RSO, AD Operations Department Head, and AD External Beams 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 Beams Department Head and as approved by the AD Associate Laboratory Director.

III-2.4.3.2 Staffing

MCR must be appropriately staffed according to the Accelerator Safety Envelope.

III-2.4.3.3 Accelerator Operating Parameters

The MTA shielding assessment [2] has assessed the safe beam operating parameters and have been used to develop the safety envelope parameters in Appendix A, Accelerator Safety Envelope. The shielding assessment determined that MTA can be safety operated at a kinetic energy of 400 MeV at a maximum of 2.7E15 protons per hour and 1.3E18 protons per year.

III-2.5. Defense-in-Depth Controls

No identified defense-in-depth controls.

III-2.6. Machine Protection Controls

Beam Loss Monitors routinely determine when beam is being lost at unacceptable regions and/or rates. Beam Position Monitors and multiwires determine the trajectories of the beam so that the Main Control Room may control losses. The Beam Budget Monitor continually monitors the integrated beam delivered to the MTA on an hourly basis.

III-2.7. Decommissioning

DOE Field Element Manager approval shall be obtained prior to the start pf ant decommissioning activities for 400 MeV Teste Area.

III-2.8. 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 Safety Assessment Document.

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-2.9. 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

III-2.10. Appendix – Risk Matrices

Risk Assessment methodology was developed based on the methodology described in DOE-HDBK-1163-2020. Hazards and their potential events are evaluated for likelihood and potential consequence assuming no controls in place, which results in a baseline risk. A baseline risk (i.e., an unmitigated risk) value of III and IV does not require further controls based on the Handbook. Events with a baseline risk value of I or II do require prevention and/or mitigation measures to be established in order to reduce the risk value to an acceptable level of III or IV. Generally, preventive controls are applied prior to a loss event, reflecting a likelihood reduction, and mitigative controls are applied after a loss event, reflecting a consequence reduction. For each control put in place, likelihood or consequence can have a single “bin drop”, resulting in a new residual risk (i.e., a mitigated risk). This risk assessment process is repeated for each hazard for Facility Workers (FW), Co-Located Workers (CLW), and Maximally Exposed Offsite Individual (MOI). At the conclusion of the risk assessments, controls that are in place for the identified accelerator specific hazards are identified as Credited Controls and further summarized in Section III-2.4 of this Chapter as well as SAD Chapter VII-A.1 *Accelerator Safety Envelope – Fermilab Main Accelerator*.