400 MeV Test Area

Revision 1
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Revision History

Author	Description of Change	Revision No. & Date
Herman B. White	Initial release of the MuCool Test Area (MTA) Chapter for the Fermi National Accelerator Safety Assessment Document (SAD)	Revision 0 January 20, 2011
T. Kobilarcik E. Niner	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.	Revision 1 August 25, 2020

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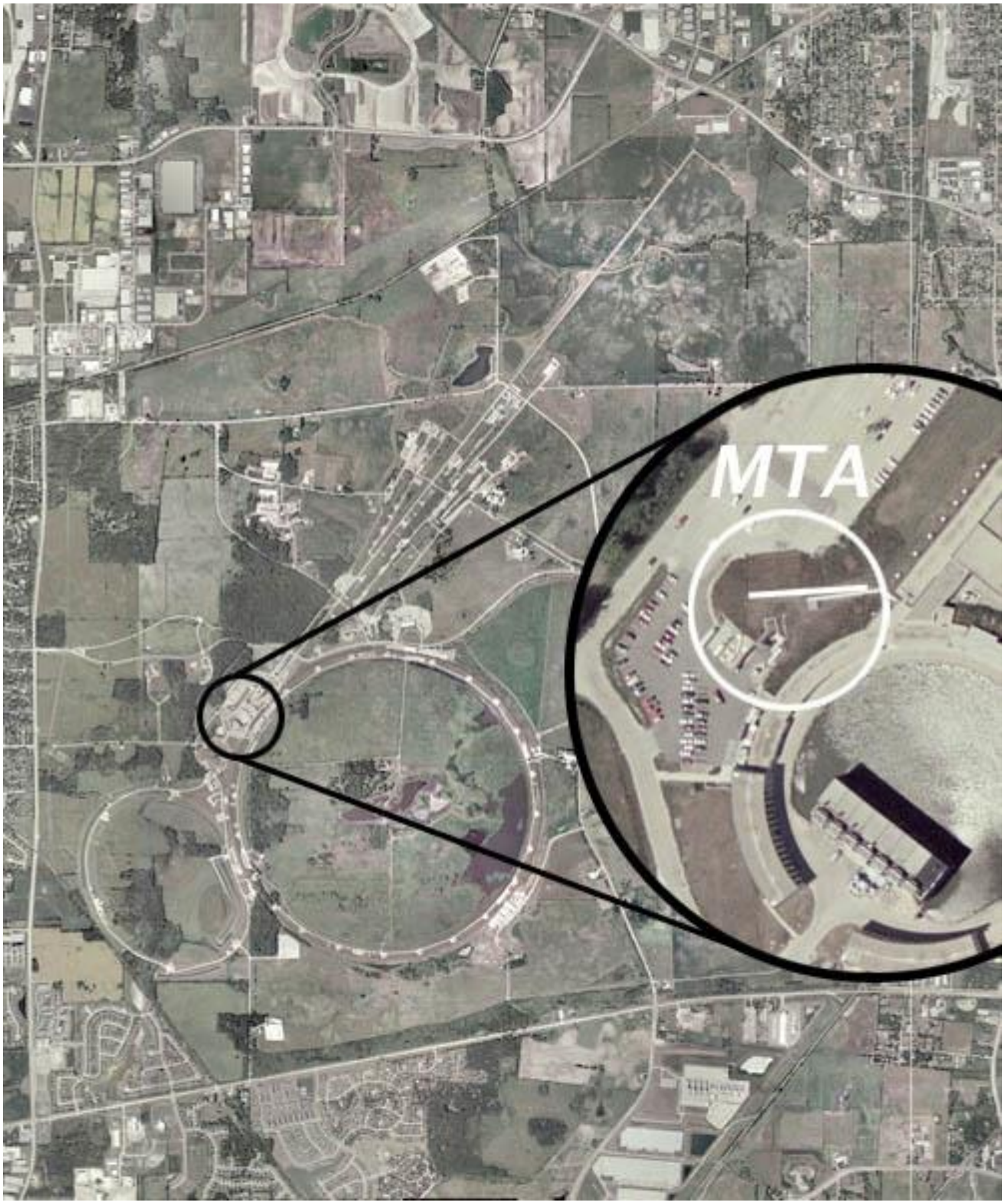
II - 2.1 400 MeV Test Area Location on Fermilab Site



II - 2.2 Inventory of Hazards

The following table lists the identified hazards found in the 400 MeV Test Area (MTA) enclosure and support buildings. All hazards with an * have been discussed in Chapters 1-10 of the Fermilab Safety Assessment Document and are not covered further in this section.

Radiation Particle beams and prompt radiation Surface water activation Ground water activation Air activation Soil activation Residual component activation Radioactive waste Radioactive sources	**Kinetic Energy** Power tools * Pumps and motors * Motion tables*
Toxic Materials Lead shielding * Other gasses*	**Potential Energy** Crane operations * Compressed gases * Vacuum / pressure vessels * Vacuum pumps *
Flammable & Combustible Materials Cables * Flammable gasses * Combustible and flammable liquids *	**Magnetic Fields** Fringe fields *
Electrical Energy Stored energy exposure * High voltage exposure * Low voltage, high current exposure *	**Asphyxiant** ODH hazards*
Thermal Energy Cryogens*	**Access / Egress** Life Safety Egress *

II - 2.3 Introduction

This Section II, Chapter 2 of the Fermi National Accelerator Laboratory (Fermilab) Safety Assessment Document (SAD) covers the MTA enclosure located southwest of the 400 MeV end of the Linac.

II - 2.3.1 Purpose of the MeV Test Area

The purpose of the 400 MeV Test Beam is to provide 400 MeV H- or protons to the MTA. The 400 MeV Test Beam 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.

II - 2.3.2 Description of the MeV Test Area

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 (see figure 1).

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 (see figure 1). 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. As shown in figure 1, 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)[6] 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.

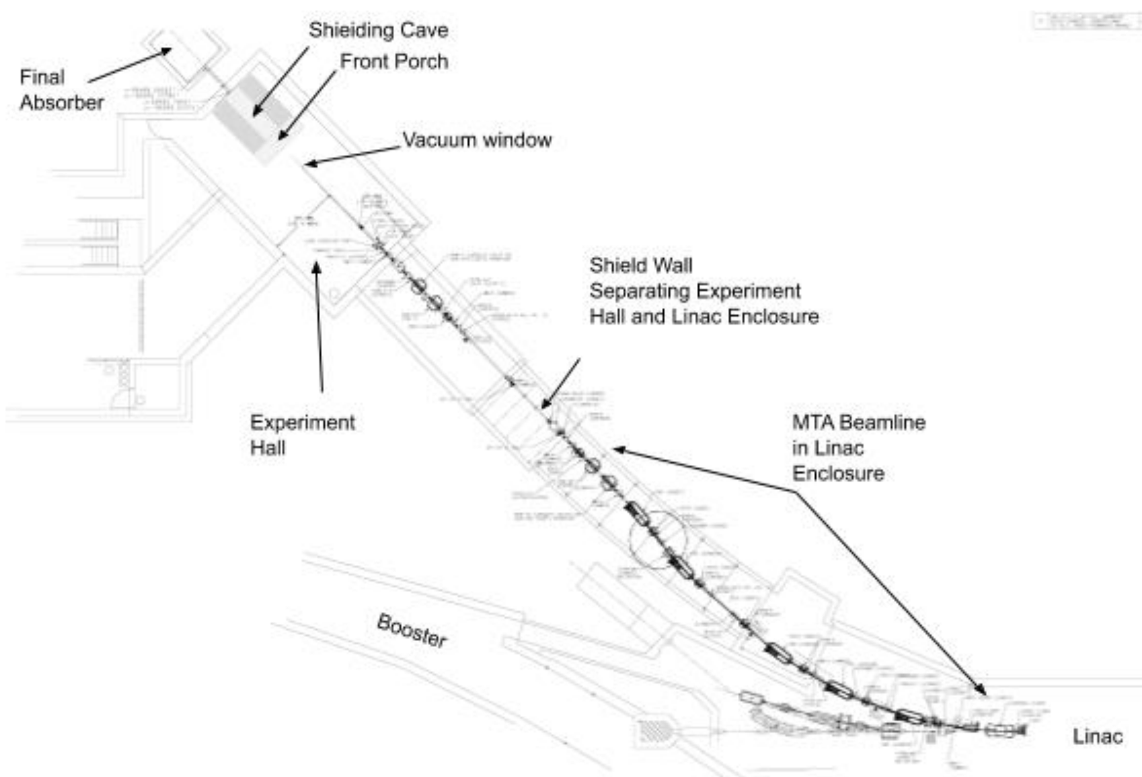


Figure 1. MTA Beamline layout

II - 2.3.3 Operating Modes

The "Shielding Assessment Document for the MeV Test Area at the Fermilab Linac Endstation"[5] (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.

II - 2.4 Safety Assessment

The accelerator specific hazards of the MTA are analyzed in this section.

II - 2.4.1 Radiological Hazards

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[5] 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. The results of the assessment are summarized in Sections 2.4.1.1 through 2.4.1.5 below.

II - 2.4.1.1 Ionizing Radiation

When beam is transported through the MTA Beamline, 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).

In summary, 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.

II - 2.4.1.2 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. The controls will follow the administrative controls and safety guidelines found in the radiological work permit (RWP), including a “cool off” time period before access. 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.

II - 2.4.1.3 Ground Water and Surface Water 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[7]. 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[5], the simulation program MARS[2] 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.

II - 2.4.1.4 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 [3, 4]. 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[5]. For an assumed intensity of 1.3E18 protons per year, and an air exchange rate of 200 cfm, 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].

II - 2.5 Credited Controls

II - 2.5.1 Passive 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.

II - 2.5.1.1 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.

II - 2.5.1.2 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.

II - 2.5.1.3 Penetration Shielding

Penetrations have been addressed in the shielding assessment[5]. All unused penetrations are filled with sand and poly, as specified by the shielding assessment[5]. 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].

II - 2.5.1.4 Radiation 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 and the outdoor pit area adjacent to the experimental hall is posted as a Controlled Area in accordance with the FRCM[1].

II - 2.5.2 Active Controls

Active engineered controls are systems designed to reduce the risks from accelerator operations to an acceptable level. These are automatic systems that limit operations, shutdown operations, or provide warning alarms when operating parameters are exceeded. The active controls in place for MTA operations are discussed below.

II - 2.5.2.1 Radiation Safety Interlock System

The MTA enclosure employs a Radiation Safety Interlock System (RSIS). The characteristics of the system are described in Chapter I, Section 4.3.2.1 of the Fermilab SAD.

There are interlocked gates 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:UHB03 power supply that feeds a four-magnet dipole bend string immediately downstream of the Linac extraction point and the E:UBS01 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.

II - 2.5.3 Administrative 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.

II - 2.5.3.1 Beam Permits and Running Conditions

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 Head 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 Head.

II - 2.5.3.2 Summary of beam operating and safety envelope parameters

The MTA shielding assessment [5] 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.

II - 2.6 Experimental Approval and Operations

The experimental collaboration of each proposed experiment will submit a Technical Scope of Work (TSW), which describes the experiment in detail including any safety issues. The TSW will enumerate material design and composition of any material, including samples and any sample holders, placed in the beam path as well as plans for use on-site, storage, retrieval from MTA, and shipping and use at home institutions. Division management reviews, approves, and distributes the TSW to the appropriate ES&H review committee(s) for the operational readiness review in accordance with FESHM Chapter 2005 *Operational Readiness Clearance*[6]. Prior to operations, the appropriate ES&H review committee(s) reviews the installation for environmental, safety and health issues. Once the committee is satisfied with the installation, the division office grants approval for operations.

II - 2.6.1.1 Beamline Operations

Commissioning, normal operations, and emergency management of the MTA are all conducted under the auspices of the AD Headquarters, the assigned RSO, PPD Headquarters and the AD Operations Department.

II - 2.7 Summary & 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.

II - 2.8 References

1. **Fermilab Radiological Control Manual.** The web link is: http://eshq.fnal.gov/manuals/frcm/ .
2. **The MARS Code System User's Guide**, N.V. Mokhov, Fermilab-FN-628 (1995); N.V. Mokhov, O.E. Krivosheev, "MARS Code Status", Proc. Monte Carlo 2000 Conf., p. 943, Lisbon, October 23-26, 2000; Fermilab-Conf-00/181 (2000).
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. **Illinois Environmental Protection Agency Registrations of Smaller Sources registration memo**, August 21, 2012.
5. **Shielding Assessment Document for the MeV Test Area at the Fermilab Linac Endstation**, August 24, 2020, 2020. The web link is: https://fermipoint.fnal.gov/org/eshq/sa/SitePages/Home.aspx
6. **Fermilab ES&H Manual, Chapter 2005 "Operational Readiness Clearance"**. The web link is: http://eshq.fnal.gov/manuals/feshm/ .
7. **Environmental Protection Notes**. The web link is: https://eshq.fnal.gov/atwork/ep/environmental-technical-notes/