Fermilab Accelerator Science & Technology (IOTA/FAST) Electron Injector

Revision 3
November 11, 2019
Author(s)

Elvin Harms, Jr.
John Anderson, Jr.
Dean R Edstrom, Jr.
Daniel R. Broemmelsiek

Revision History

Author	Description of Change	Revision No. & Date
Elvin Harms, Jr. John Anderson, Jr.	Initial release of the ASTA Chapter for the Fermi National Accelerator Laboratory Safety Assessment Document (SAD).	Revision 0 31 December 2014
Dean R Edstrom, Jr. Daniel R. Broemmelsiek	Update to reflect the name change from ASTA to IOTA/FAST and address the 300 MeV beamline.	Revision 1 28 August 2017
Daniel R. Broemmelsiek	Update to include the IOTA Ring.	Revision 2 April 23, 2018
John Anderson, Jr. Daniel R. Broemmelsiek	Updated to include protocols used for the FAST Control Room Operations. Incorporated 2018-09-11 USID “Change to FAST SAD Chapter to Align with Shielding Assessment”	Revision 3 11 November 2019

Table of Contents

IV - 3 IOTA/FAST Facility

IV - 3.1 IOTA/FAST Location and Scope

The following aerial photograph shows the location of the Integrable Optics Test Accelerator/Fermilab Accelerator Science & Technology (IOTA/FAST) Facility in relation to the Fermilab site. It includes the buildings New Muon Lab (NML), the Electrical Service Building (ESB), and the Cryo Module Test Facility (CMTF).

The scope of this chapter is limited to the accelerators located within the NML building, the tunnel extending north, and the enclosure below ESB. These are the IOTA/FAST Electron Injector, Proton Injector and IOTA synchrotron which are collectively referred to as the Accelerator Division R&D Accelerator (ADRDA) through the remainder of this document. The injectors provide electrons and protons to the IOTA synchrotron. The electron injector has evolved considerably since its conception, referred in historical documentation as the International Linear Collider Test Area (ILCTA) and the Advanced Superconducting Test Accelerator (ASTA). The proton injector source was originally the High Intensity Neutrino Source (HINS).

IV - 3.2 Inventory of Hazards

The following table lists the identified hazards found in the ADRDA enclosure and support buildings. All hazards marked with an asterisk (*) have been addressed in Chapters 1-10 of the Fermilab SAD and are not addressed in this section of the SAD.

Radiation Ionizing radiation Residual activation X-Ray producing devices Groundwater activation Surface water activation Particle interactions in soil Radioactive waste Lasers High Power RF (non-ionizing)	**Kinetic Energy** Power tools * Pumps and motors *
Toxic Materials Lead shielding * Beryllium components *	**Potential Energy** Crane operations * Compressed gases * Vacuum / pressure vessels * Vacuum Pumps *
Flammable & Combustible Materials Cables *	**Magnetic Fields** Fringe fields *
Electrical Energy Stored energy exposure * High voltage exposure * Low voltage, high current exposure *	**Gaseous Hazards** Confined spaces * Oxygen Deficiency Hazard (ODH) Sulfur Hexafluoride (SF_6)
Thermal Energy Cryogenics *	**Access / Egress** Life Safety Egress *

IV - 3.3 Introduction

This section covers development of the IOTA/FAST ADRDA, providing an overview for the entire planned facility. The ADRDA is being constructed in phases with the energy and intensity increasing as outlined in Table 1[1] below. The shielding assessment and this chapter will be updated as each phase of the facility construction is completed.

Table 1 Phase, energy and intensity. Completed phases are denoted with a dagger†

Phase	Energy	Macropulse Duration	Nominal Repetition rate	Max Micropulses	Intensity per Micropulse
Low Energy Electron†	55 MeV e^-	1 ms	1 Hz	3000	2×10^{10}
High Energy Electron†	300 MeV e^-	1 ms	1 Hz	3000	2×10^{10}
IOTA Ring	150 MeV $e^{-\dagger}$	< 1 ns	< 1 Hz	1	2×10^{10}
	2.5 MeV p^+	100 μs	< 0.1 Hz	1	1×10^{11}

IV - 3.3.1 *Purpose of the IOTA/FAST Facility ADRDA*

The IOTA/FAST Electron Injector provides a beam of accelerated electrons to beam lines located in the same shielded enclosure. Electrons are produced within a 1.5 cell normal-conducting radio-frequency (RF) electron gun (e-gun) when an ultra violet (UV) laser pulse produced in an adjacent room is transported and impinges on a cathode coated with a few micrograms of cesium-telluride (Cs_2Te). Nominally, the UV is delivered to the photocathode in a train of 3 MHz micropulses with a repetition rate of 1 Hz, but can be up to 5 Hz as determined by the IOTA/FAST clock system. The intensity of each bunch is determined by the intensity of the UV laser pulse, nominally 5 μJ/micropulse, and the quantum efficiency of the photocathode. The intensity, nominally 3 to 4 nC/micropulse, may easily be reduced from full transmission by the qualified operator.

With proper timing and nominal cavity gradient, the electrons produced by the photocathode are accelerated to a kinetic energy of 5 MeV by the e-gun. Subsequent acceleration to a maximum beam energy of 55 MeV is achieved through two 9-cell, 1.3-GHz, niobium, superconducting RF 'capture' cavities downstream of the e-gun. The beam is then directed through a low-energy beamline and, depending on the current mode of operation, directed either to a low-energy absorber through the spectrometer dipole magnet, or through a single cryomodule consisting of eight 9-cell, 1.3-GHz, niobium, superconducting RF cavities that provide acceleration on the order of 250 MeV. The high-energy beamline will transport the beam from the cryomodule to either the IOTA ring or to the High-Energy Absorber (HEA). Each of the beam absorbers are graphite-cored and water-cooled using a closed-loop Radioactive Water (RAW) system. The low-energy absorber is designed to safely absorb 2.5 kW of beam power and is located immediately before the cryomodule, below the beamline plane. The high-energy absorber is designed to absorb 75 kW of beam power (capable of accommodating a beam energy of up to 1.5 GeV from a string of six 8-cavity cryomodules) and is located at the end of the high-energy beamline. Both are adequate to absorb the particle intensities described in sections 3.3.2 and 3.5.3.2.

The IOTA/FAST electron injector is housed in a shielded enclosure that spans the western half of the NML building as found on the IOTA/FAST location map at the beginning of this section and extends 135 meters into an underground enclosure beyond the NML building (beneath ESB) terminating in the high-energy beam absorber. The IOTA/FAST ADRDA enclosure and main operational components are depicted in Figure 1.

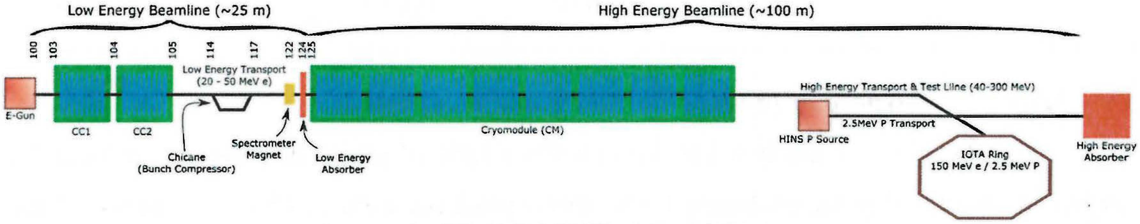

Figure 1 – IOTA/FAST Facility ADRDA

IV - 3.3.2 *Operating Modes*

Operation plans for the IOTA/FAST Facility ADRDA depends on programmatic decisions made by the Accelerator Division (AD), FAST Facility Department, and the greater collaboration community. Low and high energy electron experiments will be carried out according to approved Advanced Accelerator Research & Development and Laboratory-Directed Research & Development (AARD and LDRD respectively) proposals or discretionary studies.

The electron beamline can operate in low or high energy electron mode depending on operation of the spectrometer magnet, N:D122. All other beamline supplies and the cryomodule should be operated at prescribed levels if high-energy electrons will be needed as a part of the shift operations.

The Integrable Optics Test Accelerator (IOTA) ring is adjacent to the high-energy electron beamline immediately upstream of the high-energy beam absorber. The IOTA ring is a 40-meter circumference ring capable of storing electrons with a kinetic energy of 150 MeV or a proton beam of 2.5 MeV as provided by the former HINS gun and RFQ, which will eventually be moved to the IOTA/FAST ADRDA.

The specified FAST operating mode authorizes up to 1.96 x 10^{17} 55-MeV electrons per hour to the low-energy beam absorber, and 3.37 x 10^{18} 300-MeV electrons per hour to the high-energy beam absorber. The maximum IOTA circulating intensity is 2 x 10^{10} 150 MeV electrons. The maximum intensity injected into IOTA is 3.6 x 10^{13} 150 MeV electrons/hour. These limits are derived from detailed shielding assessments[2,3] performed to mitigate the radiological concerns as summarized in section IV - 3.4.1. The shielding assessment[2] for the 55 MeV electron injector, which is upstream of the 300 MeV region, provides the intensity limit for the IOTA/FAST ADRDA.

IV - 3.3.3 *Operations*

The AD FAST Facility Department is responsible for the operation of the IOTA/FAST ADRDA under a written Accelerator Division Administrative Procedure ADAP-02-0011 FAST Facility Control Room Procedure. This includes the pulse-by-pulse beam currents, intensity, losses, etc. Administrative procedures and documents, such as Beam Permits and Running Conditions, are used to define safe operational parameters, such as intensity limits, energy limits, and repetition rates.

The IOTA/FAST ADRDA operators are trained in accordance with the AD FAST Facility Department Procedure ADDP-FF-0003, FAST Control Room On-The-Job Training (OJT), and authorized by the FAST Facility Department Head. The ASE beam intensity limits are monitored and enforced by the Main Control Room Crew Chief.

IV - 3.4 Safety Assessment

This section analyzes the unique hazards associated with electron operation at the IOTA/FAST Facility. The radiological hazards include ionizing radiation, residual activation, x-ray producing devices, groundwater and surface water activation, particle interactions with air and soil, radioactive waste, lasers, and high-power RF. Gaseous hazards include oxygen deficiency hazards from the use of cryogenic liquids for superconducting components and SF_6 in RF components.

IV - 3.4.1 *Radiological Hazards*

The IOTA/FAST Facility ADRDA has radiological hazards in the form of prompt radiation from the accelerated beams, residual ionizing radiation from activated components, x-rays from high gradient accelerating cavities, and non-ionizing radiation from lasers and high-power RF systems. There are two predominant prompt radiological hazards. The first type of radiological hazard results from the interaction of the primary beams with the materials surrounding the beam pipes and beam line elements. The second type of radiological hazard results from the interactions of the primary electron beam with the IOTA/FAST electron injector absorbers and the subsequent interactions of the secondary beam with surrounding materials.

There are three categories of beam-induced radiation hazards:

- Prompt radiation levels inside and surrounding the enclosures that are present during operation. The radiation may include neutrons and other energetic particles.
- Residual radiation due to activation of beam line components. Residual radiation can give rise to radiation exposures to personnel during accesses to the beam enclosures for repair, maintenance and inspection activities.
- Environmental radioactivity associated with activation of air, groundwater, or soil from prompt radiation generated from beam loss during beamline operations.

Detailed shielding assessments[2,3] address these concerns with analyses of the facility, the utilization of signs, requirements for fences, and application of radiation safety interlocks to comply with the Fermilab Radiological Control Manual[4] (FRCM). The shielding assessments for the IOTA/FAST Facility encompass the IOTA/FAST Facility ADRDA and all affected service areas including the NML building, ESB, and fenced-in radiation areas. Prior assessments were prepared and approved for photoinjector operation[2], e-gun-only operation[5], and low-energy beamline operation of the IOTA/FAST Facility ADRDA Electron Injector.

The shielding assessments provide a detailed analysis of radiation shielding requirements. These include labyrinth and penetration considerations, and permanent and movable shielding. Also addressed therein are interlocked radiation detectors, residual dose rates, groundwater and surface water activation, particle interactions in soil, air activation, skyshine, muon cloud, and ozone production. Finally, the use of signs, fences, and active interlocks are prescribed to limit access to areas of potentially higher prompt radiation exposure.

IV - 3.4.1.1 Prompt Ionizing Radiation

Prompt ionizing radiation is the principal radiological hazard that arises when beam is transported through the applicable beam lines. To protect workers and the general public, the enclosures and beam pipes are surrounded either by sufficient shielding (i.e., soil, concrete, and/or iron), and/or networks of interlocked radiation detectors to limit any prompt radiation exposure to acceptable levels. The Fermilab Shielding Assessment Review Panel and Senior Radiation Safety Officer have reviewed and approved the relevant shielding assessments to address ionizing radiation concerns.

The approved shielding assessments for the IOTA/FAST Facility ADRDA have included analyses of production, extraction, and absorption areas. The shielding assessments require that:

- *All penetrations must be filled with shielding as specified.*
- *All movable shielding blocks must be installed as specified.*
- *The average beam intensity shall not exceed the limits prescribed in section 3.3.2.*
- *The radiation safety interlock system must be certified as working.*
- *Radiation detectors are installed as prescribed by the assigned Radiation Safety Officer (RSO) and interlocked to the radiation safety interlock system.*

IV - 3.4.1.2 Residual Activation

Electron absorber surfaces and the associated vacuum windows immediately upstream may be radioactive even when the electron beamline is not in operation. Access to beam absorber components are to be tightly controlled according to the level of residual radiation and contamination. The control measures may include training and training verification, centralized access authorization, key entry, and discretionary measures placed by the assigned RSO (e.g., ropes and signage to indicate radiation levels and/or contamination). Controls required for residual radiation are specified in the FRCM and are detailed in the Radiological Work Permit (RWP).

The general enclosure RWP is applicable to most inspection and maintenance activities. In the event that work is required in areas of higher-activation or on activated components with a potential individual exposure greater than 200 milli-rem (mrem) or potential job exposure greater than 1000 person-mrem, a job-specific RWP shall be prepared according to the laboratory radiation safety principle of ALARA (As-Low-As-Reasonably-Achievable). These tasks will be supervised at the discretion of the assigned RSO.

IV - 3.4.1.3 X-Ray Producing Devices

Radiofrequency accelerating structures, including those used in the IOTA/FAST Facility ADRDA, may generate electromagnetic fields of sufficient amplitude to generate 'dark-current' electrons of sufficient energy to produce x-rays. The current shielding assessments[2,3] provide detailed analyses of this hazard. For superconducting RF cavities, this analysis concludes that with

3 feet of shielding on the enclosure roof, the worst-case dose rates will result in less than 10 mrem/hour. This is well within the FRCM parameters for a fenced, interlocked, Radiation Area. The analyses further conclude that a minimum of 4.4 feet of concrete is necessary to limit dose rates to less than 1.0 mrem/hour on the outside walls of the enclosure in the low-energy section and 9 feet of concrete is similarly necessary in the high-energy section. The enclosure walls are constructed to satisfy these requirements.

The safety interlock system for the IOTA/FAST Facility ADRDA enclosure disables RF power to the cavities thereby mitigating the x-ray hazard whenever personnel access the enclosure.

IV - 3.4.1.4 Groundwater and Surface Water Activation

Radioactivity is induced by photo-nuclear interaction with the soils that surround the accelerator enclosure. Methods have been designed to provide conservative estimates of groundwater and surface water activation. The release estimate[3] for surface and groundwater after 20 years of operation at an integrated intensity of 3.40 x 10^{21} electrons per year will produce combined ^{3}H (tritium) and ^{22}Na (sodium-22) concentrations that are more than five orders of magnitude lower than applicable FRCM limits and so are negligible. Groundwater is sampled regularly as part of the ES&H Environmental Monitoring Program[6] and in accordance with the Fermilab Environment, Safety, and Health Manual (FESHM)[7] chapter, *Surface Water Protection*. Sump discharges and pond surface waters are also sampled regularly by members of the ES&H Section.

IV - 3.4.1.5 Particle Interactions in Soil

Studies of residual radioactivity have been performed as a part of the shielding assessment[3]. The possible sources of soil contamination were estimated to be undetectable outside of the enclosure concrete shielding. The soil surrounding the IOTA/FAST Facility areas will be sampled during decommissioning to document activation levels as required by the chapter 8070 *Decontamination and Decommissioning Documentation* of FESHM.

IV - 3.4.1.6 Radioactive Waste

Radioactive waste hazards and waste disposal at the IOTA/FAST Facility will be managed within the program established for the Fermilab accelerator complex and as prescribed in the 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 IOTA/FAST Facility beamlines, beam loss or intentional interception of the beam in some diagnostic devices may result in activation of these components or other beam line elements. Activated items will be reused when feasible. Activated items that cannot be reused will be disposed of as radioactive waste according to the FRCM requirements.

IV - 3.4.1.7 Lasers

Class 3B and Class 4, near-infrared, UV, and visible lasers will be used in the IOTA/FAST Facility for purposes such as electron production, beam diagnostics, beam instrumentation, and dedicated studies[8]. Production and delivery of these lasers both outside and inside the beamline enclosure are required to be completely contained to transport pipes or designated enclosures for the Class 3B and Class 4 lasers, thus creating a Laser Controlled Area (LCA) in accordance with FESHM 4260. Establishing the LCA limits surrounding areas to remaining below the Maximum Permissible Exposure (MPE) as set by the Laser Safety Officer (LSO). Because of continuity, the particle beamline of the ADRDA must be considered a part of the LCA unless demonstrated otherwise.

These lasers and the operation thereof are subject to the stipulations of the FESHM 4260: *Lasers* chapter. The LSO is responsible for assuring all laser safety precautions are implemented and followed and it is the responsibility of all laser operators to follow established Standard Operating Procedures.

IV - 3.4.1.8 Non-Ionizing Radiation

Hazardous levels of radio frequency electromagnetic energy are generated by the RF power sources (Klystrons) for the IOTA/FAST Facility ADRDA Electron Injector. This energy is not normally radiated, and is nominally confined within waveguide, coaxial transmission lines, and the accelerating structures. Specific "Lock-out/Tag-out" (LOTO) and configuration control procedures are in place to establish safe conditions for personnel working on or around these systems. Antennae have been installed in the controls racks for each RF system to monitor leakage and automatically shut off the appropriate RF system. Periodic surveys for stray RF fields are also performed by Fermilab ES&H Section.

IV - 3.4.2 *Gaseous Hazards*

Several IOTA/FAST Facility accelerating structures are superconducting and therefore cooled with liquid nitrogen and helium during nominal operation. Also, a section of the RF power distribution system serving the electron gun requires SF_6 to prevent electrical breakdown. Use of these gases presents the possibility of an ODH emergency as covered in the following subsection.

IV - 3.4.2.1 Oxygen Deficiency Hazards

IV - 3.4.2.1.1 Cryogens

IOTA/FAST Facility superconducting accelerating structures are cooled with superfluid liquid helium to a nominal operating temperature of approximately 2 Kelvin. This is accomplished by operating at subatmospheric pressure, nominally 23 Torr. Precooling of the cryomodules is accomplished with liquid nitrogen. The potential for a cryogenic rupture and consideration of the enclosure volume results in the area being designated as an Oxygen Deficiency Hazard Class 1[9] area when the cryogenic system is flowing cryogenic gases and fluids into the enclosure.

IV - 3.4.2.1.2 Sulfur Hexafluoride

Sulfur Hexafluoride is an inert, non-toxic gas that is optimum for increasing the dielectric capacity of high-power RF distribution components. The coaxial RF power window feeding the Photoinjector Gun of the IOTA/FAST Facility ADRDA Electron Injector requires a static fill of SF_6 for reliable operation at the nominal RF power level. The total volume of SF_6 sealed in the waveguide-window system is 0.38 cubic feet (10.73 liters).

SF_6 is recognized as a greenhouse gas and electrical discharge into SF_6 can produce toxic substances. These hazards are controlled by capturing the gas with a designated SF_6-recapture skid to minimize atmospheric releases. This section of the RF line is filled with SF_6 from a compressed gas cylinder located outside the enclosure and is replenished as necessary. Before and after weights of the compressed gas cylinder shall be recorded upon every manual replenishment. Any amounts released are minimized using the recapture skid, documented, and included in the annual reporting of this gas to DOE.

The section of the ADRDA enclosure local to this SF_6 space comprises a floor area of approximately 342 square feet and a ceiling height of 10.5 feet, for a volume of 3591 cubic feet. 0.38 cubic feet of SF_6 represents less than 0.011% of that volume and thus does not present an ODH hazard.

IV - 3.5 Credited Controls

IV - 3.5.1 *Passive Controls*

Passive controls are fixed accelerator elements that are part of the physical design of the facility that require no action to function properly and require direct interaction to remove. These include the concrete blocks, penetration shielding, and permanent shielding that surround the portion of the ADRDA beamline within NML.

Additionally, a posted and locked radiological fence has been erected outside to prevent access immediately to the west and north of the NML building. While this is not interlocked, it requires a Rad Fence key to access, which in turn requires those accessing the area to receive RSO approval to check-out the key from the Main Control Room.

IV - 3.5.1.1 Permanent Shielding

The current IOTA/FAST Facility ADRDA shielding assessments[2,3] indicate that all locations provide adequate shielding for normal operations and are within FRCM requirements for operations up to 1.96 x 10^{17} 55-MeV electrons/hr to the low-energy absorber, 3.37 x 10^{18} 300-MeV electrons/hr to the high-energy absorber, or 3.6×10^{13} 150-MeV electrons/hr injected into IOTA. Permanent shielding consists of gravel, concrete, and soil immediately external to NML and ESB, as specified in the shielding assessments.

IV - 3.5.1.2 Access Points, Penetrations, and Movable Shielding

The IOTA/FAST Facility ADRDA enclosure within NML is constructed from movable concrete shielding blocks. Accesses may be made from the gallery floor at the southeast end or the northeast end through labyrinths constructed of shielding blocks, or through a stairwell from the catwalk at ground level along the west wall of the building. The stairwell access point is entirely fenced off and is considered part of the beam enclosure. All three of these enclosure access points have beam interlocked gates. There is also access to the enclosure from ESB. Entrances to the catwalk on both south and north walls above the enclosure and the enclosure roof itself are surrounded by 8' fences and all gates are interlocked to the Radiation Safety Interlock System (RSIS).

There are seven penetrations in the east shielding wall, four in the west shielding wall, and two in the enclosure roof for utilities and RF to enter the enclosure. The current shielding assessments[2,3] detail the mitigations necessary for the enclosure and each penetration to comply with the requirements of the FRCM from both normal operations and accident conditions.

The assigned RSO controls locks for the shielding that is able to be moved (i.e., the roof blocks) and ensures they are in place and secured before permitting beam.

IV - 3.5.1.3 Radiation Fencing and Posting

A posted and locked radiological fence has been erected outside to designate potential radiological areas during machine operations according to the shielding assessment immediately to the west and north of the NML building. They are maintained in accordance with Chapter 2 of FRCM.

IV - 3.5.2 *Active Controls*

Active engineered controls are systems designed to reduce the risks from accelerator operations to acceptable levels. These automatic systems limit operations, shut down operations, or provide warning alarms when operating parameters are exceeded. The active controls in place for the IOTA/FAST Facility include beam loss controls and a radiation safety interlock system.

IV - 3.5.2.1 Beam Loss Controls and Monitors

Beam loss monitors (BLMs) and calibrated beam current toroids are beamline components used to determine when too much beam is lost. The BLM system is monitored by the Machine Protection System (MPS) and above independent thresholds may stop beam operation within a single macropulse repetition period by withholding the timing gate required to generate the UV Drive Laser Pulse. There are 33 BLMs distributed along the length of the IOTA/FAST Electron Injector beamline to safeguard the machine.

There are 4 calibrated beam current toroids, T102, T124, T440, and T612, and a Direct-Current Current Transformer (DCCT) located in the IOTA synchrotron monitored by the Beam Budget Monitor (BBM) on an hourly basis. These are used to account for overall electron intensity and beamline efficiency. The BBM uses the combination of T102 and T124 to determine how much beam is delivered to the low-energy absorber. The BBM uses the combination of T440 and T612 to determine how much beam is delivered to the high-energy absorber. The IOTA DCCT is used to determine how much beam is circulating in the IOTA synchrotron.

IV - 3.5.2.2 Radiation Safety Interlock System

The IOTA/FAST Facility employs a RSIS. The characteristics of the system are described in Section I of the Fermilab SAD which conforms to requirements of the FRCM. The IOTA/FAST Facility RSIS prevents personnel access to the enclosure with beam enabled by inhibiting the beam when disabled.

The RSIS inhibits beam by controlling redundant critical devices, N:LGXBS1 and N:LGXBS2, which are pneumatic laser-light beam stops located in the laser transport pipe before the pipe exits the Laser lab adjacent to the IOTA/FAST Electron Injector enclosure. When the UV Drive Laser is blocked in this manner, it does not impinge on the photocathode of the Electron Injector's gun. In the event of a critical device failure, the system has a failure mode function that will disable the AC contactor for laser amplifier power supplies making it impossible for any laser light to be produced.

Additionally, radiation detectors are interlocked to the IOTA/FAST Facility RSIS to ensure compliance with FRCM requirements. Placement of radiation detectors (chipmunks) were determined as a part of the shielding assessments[2,3] based on a series of potential accident conditions. Such detectors can disable beam within one second of exceeding a predetermined trip level. The radiation detectors limit the radiation dose from beam loss accidents to less than the limit appropriate to each part of the IOTA/FAST Facility. The detectors are placed with appropriate trip levels so that a beam loss producing a radiation flux that exceeds the allowable dose limit to that area will trip critical devices that prevent further beam operation.

Trained and qualified personnel from the AD Operations Department are required to search and secure the enclosures before permits from the RSIS can be reestablished following any personnel access to the area except under controlled access conditions. The RSIS including requirements for hardware and system testing, inventory of interlock keys, search and secure procedures, controlled access procedures, personnel training requirements, and procedures for maintenance of interlock systems are maintained in conformance with the requirements stated in the FRCM.

IV - 3.5.3 *Administrative Controls*

All IOTA/FAST Facility 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 maintained in accordance with Laboratory standards for such documents. These procedures are the administrative controls that encompass the human interactions that define safe accelerator operations.

IV - 3.5.3.1 Beam Permits and Run Conditions

In accordance with AD Administrative Procedure on *Beam Permits, Running Conditions, and Start-up* (ADAP-11-0001), beam will not be accelerated in the IOTA/FAST ADRDA without an approved Beam Permit and Running Condition. The Beam Permit specifies beam power limits as determined and approved by the AD Division Head in consultation with the ES&H Radiation Physics Operations Department Head, assigned RSO, AD Operations Department Head, and

AD/FAST Facility Department Head. The Running Conditions list the operating modes and safety envelope for the IOTA/FAST ADRDA Injectors and IOTA synchrotron. Running Conditions are signed by the AD/FAST Facility Department Head, AD Operations Department Head, assigned RSO, and AD Head.

IV - 3.5.3.2 Summary of Beam Operating and Safety Envelope Parameters

The IOTA/FAST Electron Injector has been assessed from the standpoint of beam operating and safety envelope parameters. The enclosure was assessed[2,3] for intensities not to exceed 5.45×10^{13} electrons/sec (1.96×10^{17} electrons/hour) at energies up to 55 MeV to the low-energy absorber, 3.37×10^{18} electrons/hour at energies up to 300 MeV to the high-energy absorber, or 3.6×10^{13} electrons/hour at energies up to 150 MeV injected into IOTA. Accelerator operational approvals shall be obtained by following the AD Procedure ADAP-11-0001, administered by the ES&H Section and AD Head. Beam Permit and Running Condition documents shall identify the beam power and operating parameters allowed within the current Accelerator Safety Envelope. The Beam Permit specifies beam power limits as determined and approved by the AD Head in consultation with the ES&H Section Radiation Physics Operations Department Head, assigned RSO, AD Operations Department Head, and AD/FAST Facility Department Head. The Running Condition for the IOTA/FAST Electron Injector describes the operating configuration as reviewed by the assigned RSO, AD/FAST Facility Department Head, AD Operations Department Head, and as approved by the AD Head.

IV - 3.6 Summary and Conclusion

Specific hazards associated with the operation of the IOTA/FAST ADRDA are identified and assessed in this chapter of the Fermilab SAD. The designs, controls, and procedures to mitigate hazards specific to operation of the ADRDA are identified and described. The IOTA/FAST Facility is subject to the safety requirements, controls and procedures outlined in Section I of the Fermilab SAD.

The preceding discussion of the hazards presented by IOTA/FAST Facility operations and the credited controls established to mitigate those hazards demonstrate that the area can be operated in a manner that will produce minimal hazards to the health and safety of Fermilab workers, researchers, members of the public, and the environment.

IV - 3.7 Glossary, Acronyms

AARD	Advanced Accelerator R&D
AD	Accelerator Division
ADAP	Accelerator Division Administrative Procedure
ADDP	Accelerator Division Department Procedure
ALARA	As-Low-As-Reasonably-Achievable
ASTA	Advanced Superconducting Test Accelerator
ADRDA	Accelerator Division R&D Accelerator
BLM	Beam Loss Monitor
CMTF	Cryomodule Test Facility
Cs_2Te	Cesium telluride
Ci	Curie
cm	centimeter
DCCT	Direct-Current Current Transformer
DOE	Department of Energy
E-gun	Electron Gun
ESB	Electrical Service Building
ES&H	Environment, Safety and Health
FAST	Fermilab Accelerator Science and Technology
Fermilab	Fermi National Accelerator Laboratory
FESHM	Fermilab Environment, Safety, and Health Manual
FRCM	Fermilab Radiological Control Manual
RWP	Radiological Work Permit
GeV	Giga-electron volt
^3H	Tritium
HEA	High-Energy Absorber
hr	hour
IOTA	Integrable Optics Test Accelerator
LCA	Laser Controlled Area
LSO	Laser Safety Officer
MPS	Machine Protection System
m	meter
MeV	Mega-electron volt

mrad	milli-radian
mrem	milli-rem
mrem/hr	milli-rem per hour
^{22}Na	Sodium-22
NML	Building which houses the IOTA/FAST Injector
ODH	Oxygen Deficiency Hazard
pCi/ml	pico-Curie per milliliter
RF	Radiofrequency
RSIS	Radiation Safety Interlock System
RSO	Radiation Safety Officer
RWP	Radiological Work Permit
SAD	Safety Assessment Document
SF_6	Sulfur Hexafluoride
SRF	Superconducting Radiofrequency
STD	Standard
UV	Ultra Violet

IV - 3.8 References

[1] **Proposal for an Accelerator R&D User Facility at Fermilab's Advanced Superconducting Test Area (ASTA)**, M. Church, H. Edwards, E. Harms, S. Henderson, S. Holmes, A. Lumpkin, R. Kephart, V. Lebedev, J. Leibfritz, S. Nagaitsev, P. Piot, C. Prokop, V. Shiltsev, Y.E. Sun, A. Valishev, October 2013.

[2] **Shielding Assessment for the Advanced Superconducting Test Accelerator (ASTA) injector**, M. Church, I. Rakhno, E. Harms, December 12, 2014.

[3] **Shielding Assessment for IOTA/FAST Electron Injector at 300 MeV**, D. Broemmelseik, I. Rakhno, August 2017. Addendum to Shielding Assessment for IOTA/FAST Electron Injector at 300 MeV to add the IOTA Ring with Electrons, D. Broemmelsiek, I. Rakhno, March 2018.

[4] **Fermilab Radiological Control Manual.** - The web link is: http://esh.fnal.gov/xms/FRCM

[5] **Shielding Assessment for Electron Gun Commissioning at the New Muon Lab**, M. Church, April 3, 2012.

[6] **Fermilab Ground Water Protection Management Plan (GWPMP)**, May 2008, ESH&Q DocDb # 1689.

[7] **Fermilab Environment Safety & Health Manual**. - The web link is: http://esh.fnal.gov/xms/FESHM.

[8] **NML Laser Lab ESH&Q Documents**, ESH-Doc-2404.

[9] **NML-ILCTA Test Cave ODH Analysis**, Joseph Hurd, Teamcenter EN02120, 3/28/2016.