FERMILAB ACCELERATOR SCIENCE & TECHNOLOGY (IOTA/FAST) ELECTRON INJECTOR

SECTION V CHAPTER 01 OF THE FERMILAB SAD

Revision 4 August 7, 2023

This Chapter of the Fermilab Safety Assessment Document (SAD) contains a summary of the results of the Safety Analysis for the FAST accelerators that are pertinent to understanding the risks to the workers, the public, and the environment due to its operation.

SAD Chapter Review

This Section V, Chapter 1 of the Fermi National Accelerator Laboratory (Fermilab) Safety Assessment Document (SAD), FAST, was prepared and reviewed by the staff of the Accelerator Directorate, Accelerator Research Division, FAST Facility 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.

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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
Daniel R. Broemmelsiek	4	August 7, 2023	• Update to align with updated SAD layout • Incorporation of Risk Matrix tables and hazard discussion
John Anderson Jr. Daniel R. Broemmelsiek	3	November 11, 2019	Update 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”
Daniel R. Broemmelsiek	2	April 23, 2018	Update to include the IOTA Ring
Dean R. Edstrom Jr. Daniel R. Broemmelsiek	1	August 28, 2017	Update to reflect the name change from ASTA to IOTA/FAST and address the 300 MeV beamline
Elvin Harms, Jr. John Anderson, Jr.	0	December 31, 2014	Initial release of the ASTA Chapter for the Fermi National Accelerator Laboratory Safety Assessment Document (SAD)

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Acronyms and Abbreviations

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

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

HA	Hazard Analysis
HAR	Hazard Analysis Report
HCA	High Contamination Area
HCTT	Hazard Control Technology Team
HEP	High Energy Physics
HFD	Hold for Decay
HLCF	High Level Calibration Facility
HPR	Highly Protected Risk
Hr	Hour
HRA	High Radiation Area
HSSD	High Sensitivity Air Sampling Detection
HVAC	Heating, Ventilation, and Air Conditioning
HWSF	Hazardous Waste Storage Facility
Hz	Hertz
IB	Industrial Building
IBC	International Building Code
ICW	Industrial Cooling Water
IEPA	Illinois Environmental Protection Agency
IEEE	Institute of Electrical and Electronics Engineers
INFN	Istituto Nazionale di Fisica Nucleare
IMPACT	Integrated Management Planning and Control Tool
IPCB	Illinois Pollution Control Board
IQA	Integrated Quality Assurance
ISD	Infrastructure Services Division
ISM	Integrated Safety Management
ITNA	Individual Training Needs Assessment
KeV	kilo-electron volt
kg	kilo-grams
kW	kilo-watt
LBNF	Long Baseline Neutrino Facility
LCW	Low Conductivity Water
LHC	Harge Hadron Collider
LLCF	Low Level Calibration Facility
LLWCP	Low Level Waste Certification Program
LLWHF	Low Level Waste Handling Facility
LOTO	Lockout/Tagout
LPM	Laser Profile Monitor

LSND	Liquid Scintillator Neutrino Detector
LSO	Laser Safety Officer
m	meter
mA	milli-amp
MABAS	Mutual Aid Box Alarm System
MARS	Monte Carlo Shielding Computer Code
MC	Meson Center
MC&A	Materials Control and Accountability
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

V-1. Fermilab Accelerator Science & Technology (IOTA/FAST) Electron Injector

V-1.1. Introduction

This Section V, Chapter 1 of the Fermi National Accelerator Laboratory (Fermilab) Safety Assessment Document (SAD) covers the FAST accelerators.

This section covers development of the IOTA/FAST accelerators, providing an overview for the entire planned facility. The FAST facility is being constructed in phases with the energy and intensity increasing as outlined in Table 1 below [4]. 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}

V-1.1.1 Purpose/Function

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.

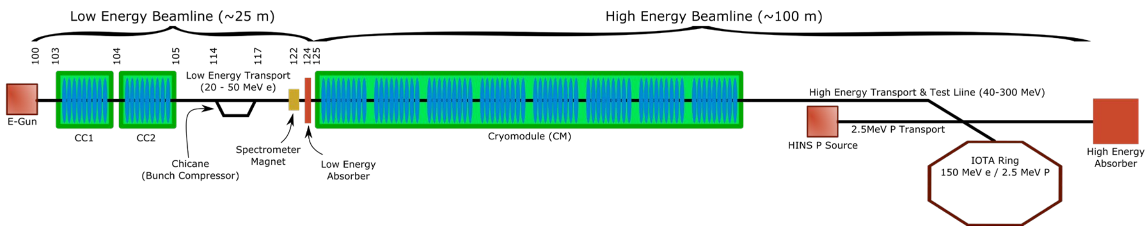

Figure 1. IOTA/FAST Facility ADRDA.

V-1.1.2 Current Status

The FAST accelerators are currently: **Operational**

V-1.1.3 Description

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.

V-1.1.4 Location

The FAST accelerators are located on the Fermilab site in Batavia, IL.

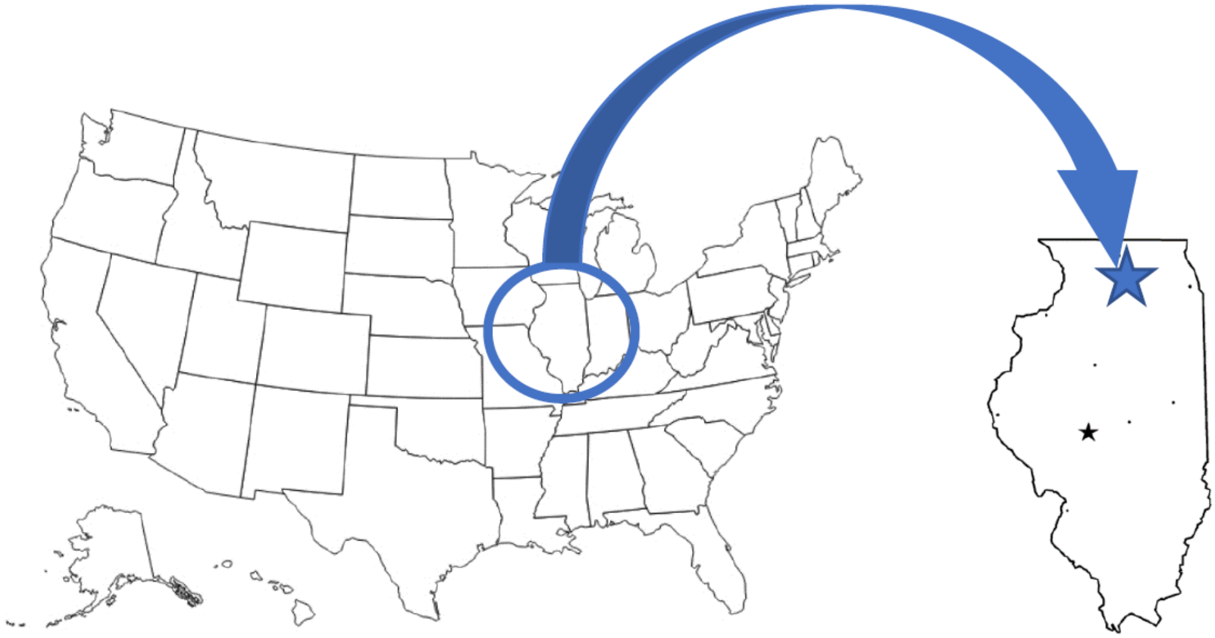

Figure 2. Regional view showing the location of the Fermilab site in Batavia, IL.

The FAST accelerators are located on the Fermilab site.

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).

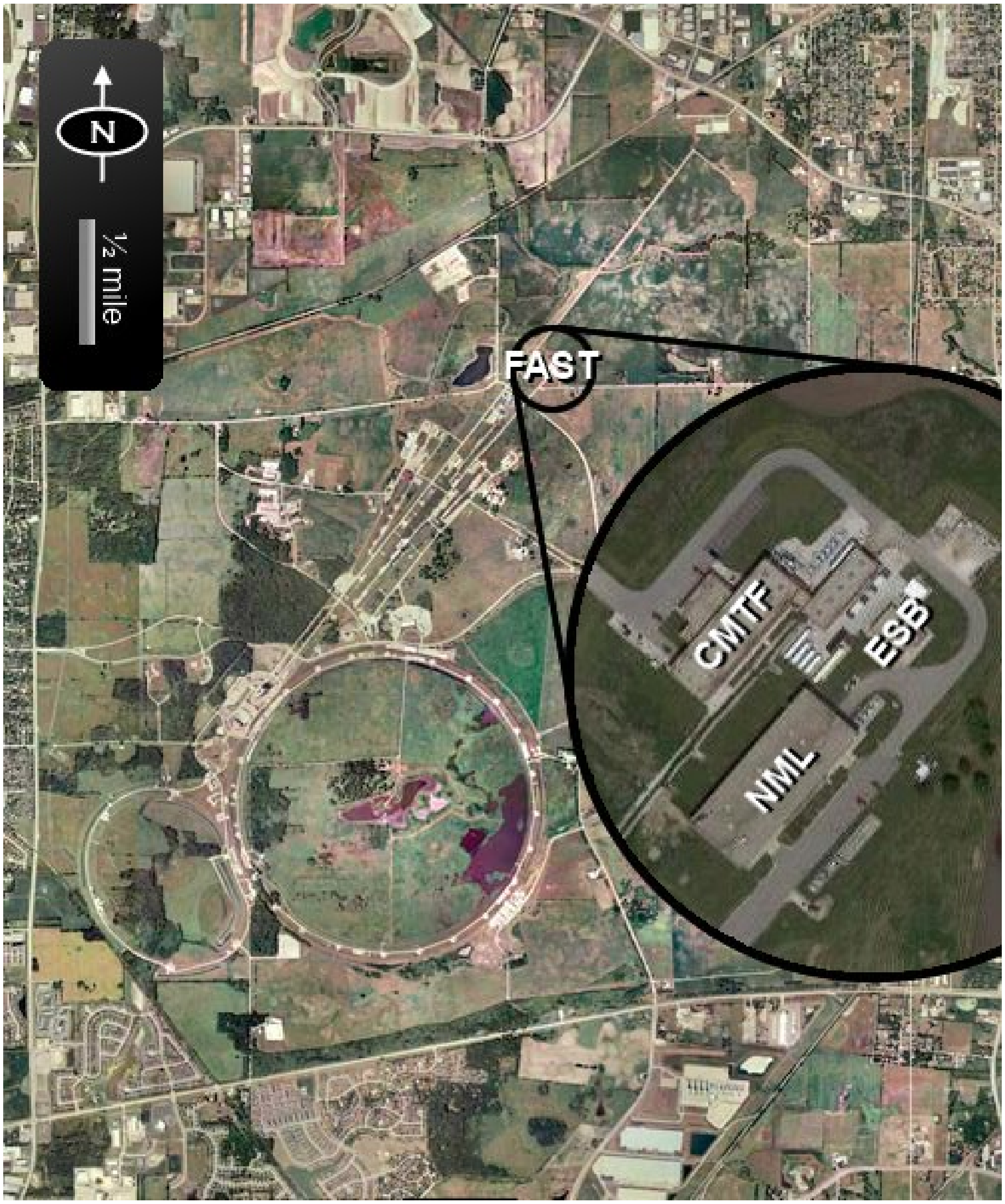

Figure 3. Aerial view of the Fermilab site, indicating the location of the FAST accelerators.

V-1.1.5 Management Organization

The Accelerator Research Division/FAST Operations Department is responsible for the operation and maintenance of all accelerators and instrumentation with support from the Accelerator Complex Technology Division support departments. FAST Operations is responsible for the FAST Control Room (FCR), a remote control room located in the NML building. FAST Operations is responsible for the FCR and FAST facility beams operations. The Beams Division Operations Department monitors the state of the

FAST facility from the MCR. Building infrastructure is maintained by the Infrastructure Services Directorate.

V-1.1.6 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 V-1.2.1. 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.

V-1.1.7 Inventory of Hazards

The following table lists all the identified hazards found in the FAST accelerator enclosure and support buildings. Section V-1.10 *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 V-1.2 *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 FAST accelerator. Accelerator specific controls are identified as **purple/bold** throughout this Chapter.

All other hazards present in the FAST accelerator complex 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 considered to be Standard Industrial Hazards (SIH), and their analysis will be summarized in this SAD Chapter.

Table 1. Hazard Inventory for the FAST accelerators.

	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
☒	Bakeouts	☐	Motion Tables
☐	Hot Work	☐	Mobile Shielding
☒	Cryogenics (ODH and burns)		**Magnetic Fields**
	Potential Energy	☒	Fringe Fields
☒	Crane Operations		**Other Hazards**
☒	Compressed Gasses	☒	Confined Spaces
☒	Vacuum/Pressure Vessels/Piping	☐	Noise
☒	Vacuum Pumps	☐	Silica
☐	Material Handling	☒	Ergonomics
	Access & Egress	☐	Asbestos
☒	Life Safety Egress	☒	Working at Heights

V-1.2. Safety Assessment

Additional hazard not listed above Sulfur Hexaflouride (SF_6).

All hazards for the FAST accelerators are summarized in this section, with additional details of the analyses for accelerator specific hazards.

V-1.2.1 Radiological Hazards

The FAST accelerators present radiological hazards in the form of Prompt Ionizing Radiation, Residual Activation, Groundwater Activation, Radioactive Water Systems, Air Activation, Soil Interactions, Radioactive Waste, Radioactive Sources, Radiation Generating Devices, and Non-Ionizing Radiation Hazards. A detailed shielding assessment**Error! Reference source not found.** 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].

The IOTA/FAST Facility 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 [1] (FRCM). The shielding assessments for the IOTA/FAST Facility encompass the IOTA/FAST Facility 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 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, sky shine, 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.

Baseline risk due to radiological hazards was a risk level L I prior to crediting the control measures in place. Following the risk assessment, an acceptable risk level R IV was achieved

V-1.2.1.1 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 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.*

V-1.2.1.2 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 is 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. If 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.

V-1.2.1.3 Groundwater 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 3.40×10^{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.

V-1.2.1.4 Surface Water Activation

This hazard in not applicable within FAST.

V-1.2.1.5 Radioactive Water (RAW) Systems

This hazard in not applicable within FAST.

V-1.2.1.6 Air Activation

This hazard in not applicable within FAST.

V-1.2.1.7 Closed Loop Air Cooling

This hazard in not applicable within FAST.

V-1.2.1.8 Soil Interactions

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.

V-1.2.1.9 Radioactive Waste

Radioactive waste produced in the course of FAST accelerator 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 FAST accelerators, 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.

V-1.2.1.10 Contamination

This hazard in not applicable within FAST

V-1.2.1.11 Beryllium-7

This hazard in not applicable within FAST

V-1.2.1.12 Radioactive Sources

Standard check-sources contained in monitoring equipment are present. These sources are controlled as part on the lab-wide radiological controls program.

V-1.2.1.13 Nuclear Material

This hazard in not applicable within FAST

V-1.2.1.14 Radiation Generating Devices (RGDs)

This hazard in not applicable within FAST

V-1.2.1.15 Non-Ionizing Radiation Hazards

Hazardous levels of radio frequency electromagnetic energy are generated by the RF power sources (Klystrons) for the IOTA/FAST Facility 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.

Radiofrequency accelerating structures, including those used in the IOTA/FAST Facility, 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 enclosure disables RF power to the cavities thereby mitigating the x-ray hazard whenever personnel access the enclosure.

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.

V-1.2.2 Toxic Materials

V-1.2.2.1 Lead

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

V-1.2.2.2 Beryllium

Beryllium particle windows are installed at each beam absorber in the FAST facility. The windows are engineered to be completely contained in the vacuum system. Procedures and instrumentation are in place to assure appropriate pressure differential across particle windows.

V-1.2.2.3 Fluorinert & Its Byproducts

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

V-1.2.2.4 Liquid Scintillator Oil

Not applicable

V-1.2.2.5 Ammonia

Not applicable

V-1.2.2.6 Nanoparticle Exposures

Not applicable

V-1.2.2.7 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 Electron Injector requires a static fill of SF6 for reliable operation at the nominal RF power level. The total volume of SF6 sealed in the waveguide-window system is 0.38 cubic feet (10.73 liters).

SF6 is recognized as a greenhouse gas and electrical discharge into SF6 can produce toxic substances. These hazards are controlled by capturing the gas with a designated SF6-recapture skid to minimize atmospheric releases. This section of the RF line is filled with SF6 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 enclosure local to this SF6 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 SF6 represents less than 0.011% of that volume and thus does not present an ODH hazard.

V-1.2.3 Flammables and Combustibles

V-1.2.3.1 Combustible Materials

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

V-1.2.3.2 Flammable Materials

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

V-1.2.4 Electrical Energy

V-1.2.4.1 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 FAST involving this hazard implements the controls specified in the common Risk Matrix table. No unique controls are in use.

V-1.2.4.2 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 FAST involving this hazard implements the controls specified in the common Risk Matrix table. No unique controls are in use.

V-1.2.4.3 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 FAST involving this hazard implements the controls specified in the common Risk Matrix table. No unique controls are in use.

V-1.2.5 Thermal Energy

V-1.2.5.1 Bakeouts

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

V-1.2.5.2 Hot Work

Not applicable

V-1.2.5.3 Cryogenics

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 sub atmospheric 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[i] area when the cryogenic system is flowing cryogenic gases and fluids into the enclosure.

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

V-1.2.6 Kinetic Energy

V-1.2.6.1 Power Tools

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

V-1.2.6.2 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 FAST involving this hazard implements the controls specified in the common Risk Matrix table. No unique controls are in use.

V-1.2.6.3 Motion Tables

Not applicable

V-1.2.6.4 Mobile Shielding

Not applicable

V-1.2.7 Potential Energy

V-1.2.7.1 Crane Operations

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

V-1.2.7.2 Compressed Gasses

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

V-1.2.7.3 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 FAST involving this hazard implements the controls specified in the common Risk Matrix table. No unique controls are in use.

V-1.2.7.4 Vacuum Pumps

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

V-1.2.7.5 Material Handling

Not applicable

V-1.2.8 Magnetic Fields

V-1.2.8.1 Fringe Fields

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

V-1.2.9 Other Hazards

V-1.2.9.1 Confined Spaces

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

V-1.2.9.2 Noise

Not applicable

V-1.2.9.3 Silica

Not applicable

V-1.2.9.4 Ergonomics

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

V-1.2.9.5 Asbestos

Not applicable

V-1.2.9.6 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 FAST involving this hazard implements the controls specified in the common Risk Matrix table. No unique controls are in use.

V-1.2.10 Access & Egress

V-1.2.10.1 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 FAST involving this hazard implements the controls specified in the common Risk Matrix table. No unique controls are in use.

V-1.2.11 Environmental

V-1.2.11.1 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 FAST involving this hazard implements the controls specified in the common Risk Matrix table. No unique controls are in use.

V-1.2.11.2 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 FAST involving this hazard implements the controls specified in the common Risk Matrix table. No unique controls are in use.

V-1.2.11.3 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 FAST involving this hazard implements the controls specified in the common Risk Matrix table. No unique controls are in use.

V-1.3. Summary of Hazards to Members of the Public

Under normal operating conditions, the FAST accelerator is not hazardous to members of the public. Defense in depth exists in the form of active and passive controls sufficient to contain hazards even during unforeseen events.

V-1.4. Summary of Credited 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 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.

V-1.4.1 Passive Credited 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.

V-1.4.1.1 Shielding

V-1.4.1.1.1 Permanent Shielding Including Labyrinths

The current IOTA/FAST Facility shielding assessments [2][3] indicate that all locations provide adequate shielding for normal operations and are within FRCM requirements for operations up to 1.96×10^{17} 55-MeV electrons/hr to the low-energy absorber, 3.37×10^{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.

The IOTA/FAST Facility 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).

V-1.4.1.1.2 Movable Shielding

The assigned RSO controls locks for the movable shielding (i.e., the roof blocks) and ensures they are in place and secured before permitting beam.

V-1.4.1.1.3 Penetration Shielding

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.

V-1.4.1.2 Fencing

V-1.4.1.2.1 Radiation Area Fencing

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.

V-1.4.1.2.2 Controlled Area Fencing

All controlled areas are within the NML and ESB buildings.

V-1.4.2 Active Engineered Credited 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.

V-1.4.2.1 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.

V-1.4.2.2 ODH Safety System

Based on the ODH Analysis [9], the ODH Safety System is established with the specified components required to maintain the ODH Classification: area/fixed oxygen monitors, ODH fans.

V-1.4.3 Administrative Credited 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.

V-1.4.3.1 Operation Authorization Document

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.

V-1.4.3.2 Staffing

Commissioning, normal operations, and emergency management of the FAST accelerators are all conducted under the auspices of the AD Headquarters, the ES&H Department, and the FAST Operations Department in accordance with the Fermilab SAD.

V-1.4.3.3 Accelerator Operating Parameters

The IOTA/FAST Electron Injector has been assessed from the standpoint of beam operating and safety envelope parameters. The enclosure was assessed2,3 for intensities not to exceed 5.45x1013 electrons/sec (1.96 x 1017 electrons/hour) at energies up to 55 MeV to the low-energy absorber, 3.37 x 1018 electrons/hour at energies up to 300 MeV to the high-energy absorber, or 3.6 x 1013 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.

V-1.5. Defense-in-Depth 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.

V-1.6. Machine Protection Controls

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.

V-1.7. Decommissioning

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

V-1.8. Summary and Conclusion

Specific hazards associated with the operation of the IOTA/FAST are identified and assessed in this chapter of the Fermilab SAD. The designs, controls, and procedures to mitigate hazards specific to operation of the FAST accelerators are identified and described. The IOTA/FAST Facility is subject to the safety requirements, controls and procedures outlined in Chapter 04 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.

V-1.9. References

[1] Fermilab Radiological Control Manual

[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] **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.
[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.

V-1.10. 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 V-1.4 of this Chapter as well as SAD Chapter VII-A.2 *Accelerator Safety Envelope – FAST Accelerator*.