VERTICAL TEST STAND (VTS) ACCELERATOR

SECTION VI CHAPTER 04 OF THE FERMILAB SAD

Revision 0 August 8, 2023

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

SAD Chapter Review

This Section VI, Chapter 04 of the Fermi National Accelerator Laboratory (Fermilab) Safety Assessment Document (SAD), *Vertical Test Stand (VTS) Accelerator*, was prepared and reviewed by the staff of the Applied Physics & Superconducting Technology Directorate (APS-TD), SRF Technology & Materials Science Division, SRF Material & Research Department in conjunction with the Environment, Safety & Health Division (ESH) Accelerator Safety Department.

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

☐ ____________________________________
Line Organization Owner

☐ ____________________________________
Accelerator Safety Department Head

☐ ____________________________________
SAD Review Subcommittee Chair

Revision History

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

Author	Rev. No.	Date	Description of Change
Fumio Furuta	0	August 8, 2023	• Initial release of the VTS Chapter

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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
^3H	Tritium
HA	Hazard Analysis
HAR	Hazard Analysis Report
HCA	High Contamination Area
HCTT	Hazard Control Technology Team
HEP	High Energy Physics
HFD	Hold for Decay

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

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

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

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

VI-4. Vertical Test Stand (VTS) Accelerator

VI-4.1. Introduction

This Section VI, Chapter 04 of the Fermi National Accelerator Laboratory (Fermilab) Safety Assessment Document (SAD) covers the VERTICAL TEST STAND (VTS) ACCELERATOR.

VI-4.1.1 Purpose/Function

The purpose of the VTS Accelerator is to characterize superconducting radiofrequency (SRF) cavities in liquid helium at temperatures between 1.3 K and 4.4 K. The VTS Accelerator has no beam sources or is not designed for any beam operations. Baseline characterization of SRF cavity in the VTS accelerator involves measuring intrinsic quality factor Q_0 as a function of accelerating field *Eacc* using low- and high-power RF. Advanced diagnostic equipment such as, second sound quench detection system, temperature mapping system for single cell cavities, magnetic field measurement system, and externally controlled magnetic field environment, are available for detail studies of SRF cavity.

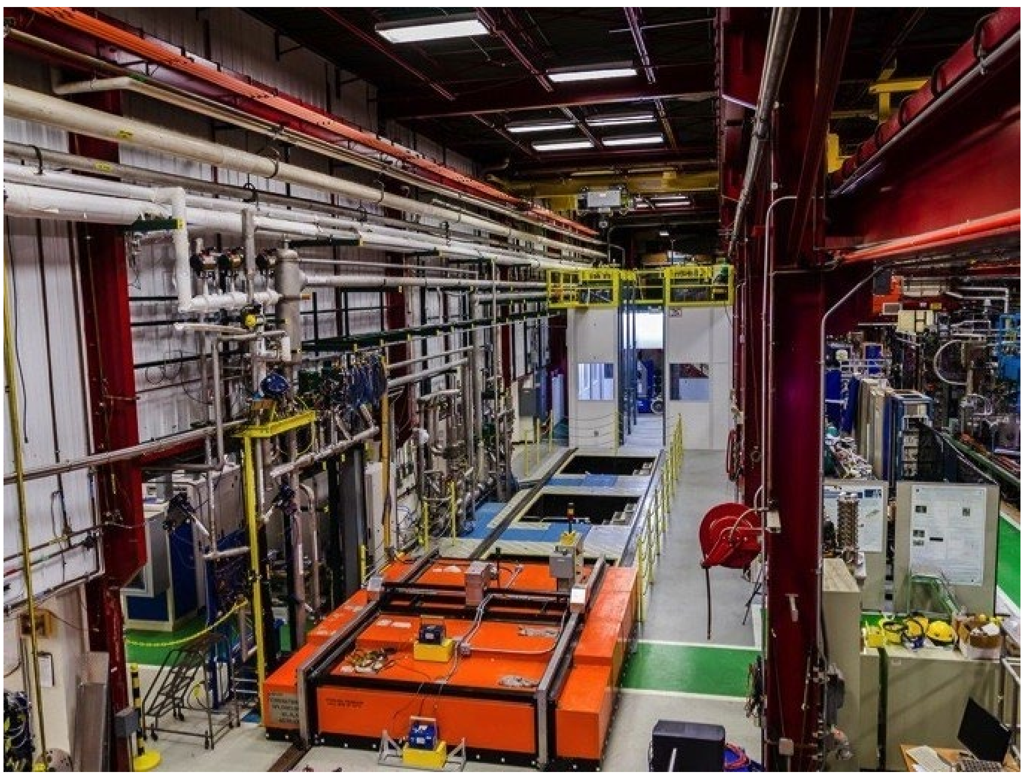

Figure 1: The VTS Accelerator where SRF cavities are tested at cryogenic temperatures

VI-4.1.2 Current Status

The VTS ACCELERATOR is currently: Operational.

VI-4.1.3 Description

The VTS Accelerator has three test stands, each of which features a large cryogenic vessel called a “dewar” and can host and test multiple SRF cavities simultaneously depends on a cavity geometry. RF system of the VTS accelerator has low- and high-power RF amplifiers and a that are capable over a frequency range of 10 MHz through 20 GHz, and the cryogenic system can cool liquid helium baths as low as 1.3 K.

The VTS Accelerator contributes to various projects (especially qualification of cavities for cryomodules) and R&D (e.g., testing new treatments, performing studies of how superconductors behave under different relevant conditions for accelerators and quantum systems, testing of new instrumentation at cryogenic temperatures).

Safety of personnel is always the highest priority of the VTS accelerator. Mobile shielding and VTS radiation safety interlock system is available. Mobile shielding covers a dewar that hosts and tests SRF cavities and can reduce radiation levels at outside of the shielding to background levels if radiological hazards happen under the shielding during cavity testing. VTS radiation safety interlock system includes Mobile shielding position monitor switches and radiation detectors on and under mobile shielding. To turn on high power RF amplifiers those interlocks need to be established. If any one of their signals drops or trips, high power amplifiers will be shut off, no more RF power will go into cavities.

VI-4.1.4 Location

The VTS ACCELERATOR is located on the Fermilab site in Batavia, IL.

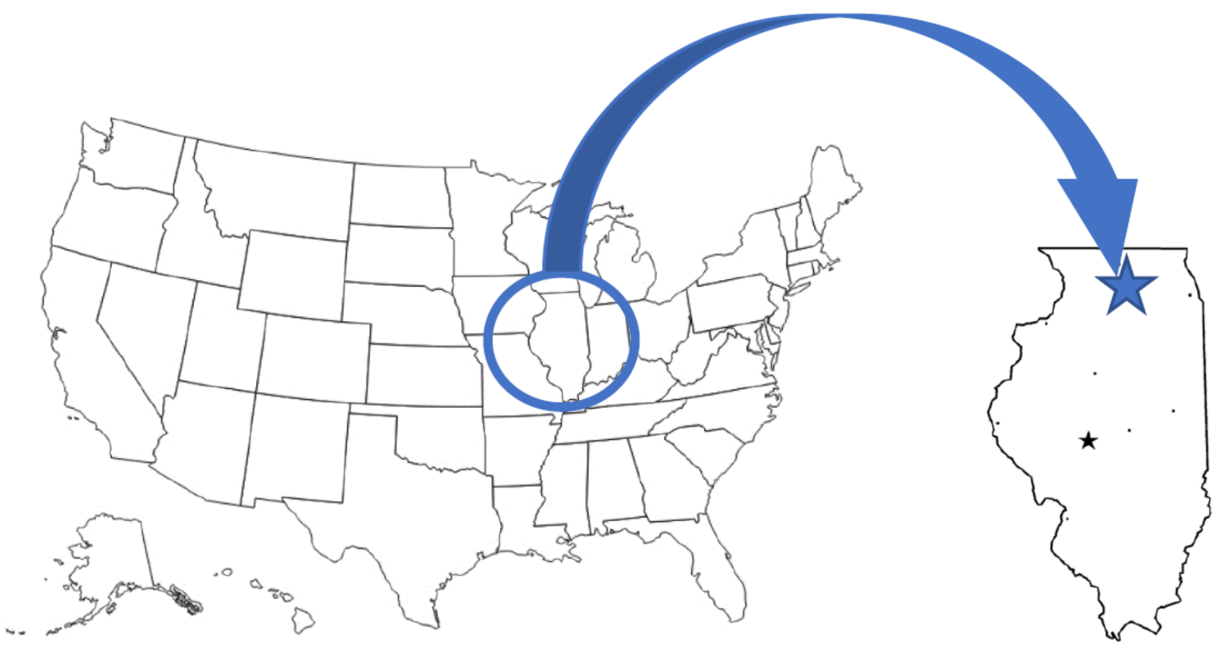

Figure 1. Regional view showing the location of the Fermilab site in Batavia, IL.

The VTS ACCELERATOR is located in the Industrial Building #1 (IB1) of APS-TD Industrial Building Complex on the Fermilab site.

Figure 2. Aerial view of the Fermilab site, indicating the location of the VERTICAL TEST STAND (VTS) ACCELERATOR.

VI-4.1.5 Management Organization

The APS-TD SRF Materials & Research Department is responsible for the management of the VTS Accelerator. Projects and PIs (owners of SRF cavities) are responsible to submit cavity processing and testing request forms to the department. The department discusses and finalizes cavity testing priorities weekly based on those request forms submitted by cavity owners. The cavity measurement group under the department is responsible to arrange, prepare, and perform cavity cryogenic testing based on priorities given by the department. The operation support group under APS-TD Cryogenic Engineering Department is responsible for the operation of cryogenic facility in IB1 that provides cryogens to the VTS accelerator.

VI-4.1.6 Operating Modes

Operating modes of the VTS accelerator are "low power operation" and "high power operation". The VTS accelerator is not designed to accelerate any beams or has no beam sources. NO "beam operation" mode at the VTS accelerator.

A low power operation mode uses a 1W RF amplifier and performs coaxial transmission RF cable calibrations, frequency searches, power decay measurements, and other cavity characterizations can be performed at or below 1W RF power conditions.

A high-power operation mode uses one of high-power RF amplifiers at the VTS accelerator and performs measurements of intrinsic quality factor Q0 from low accelerating field to high field and other characterizations that require high power RF. each high-power RF amplifiers has specific frequency band and maximum available RF output power (e.g., 500W 620-650MHz Solid State Amplifier (SSA), 500W 1270-1310MHz SSA, 200W 0.7-4GHz SSA).

VI-4.1.7 Inventory of Hazards

The following table lists all of the identified hazards found in the VTS Accelerator enclosure and support buildings. Section VI-4.10 *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 VI-4.2 *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 VTS Accelerator. Accelerator specific controls are identified as **purple/bold** throughout this Chapter.

All other hazards present in the VTS Accelerator 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 Section I Chapter 04 Safety Analysis.

Table 1. Hazard Inventory for VTS Accelerator.

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

VI-4.2. Safety Assessment

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

VI-4.2.1 Radiological Hazards

The VTS Accelerator presents radiological hazards in the form of Prompt Ionizing Radiation, Residual Activation, Radioactive Waste, Radiation Generating Devices (RGDs), and Non-Ionizing Radiation Hazards. A detailed shielding assessment[2] and post-assessment documents [3-5] address 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].

VI-4.2.1.1 Prompt Ionizing Radiation

SRF cavities in VTS accelerator have no beam sources but may generate electron field emissions of sufficient energy to produce x-rays.

To prevent and mitigate Prompt Ionizing Radiation Hazards and protect personnel such as, Facility Worker (W), Co-located Worker (Co-W), and Maximally-exposed Offsite Individual (MOI), below Preventative (P)/Mitigative (M) actions are available.

P: Cavity cleaning and particle-free assembly are performed to eliminate contaminants and particles that may generate electron field emissions and x-rays. (for W, Co-W, MOI)

P: Mobile shielding and position monitor switches are available as a part of Radiation Safety Interlock system. To turn on high-power RF, mobile shielding needs to be in position of covering the dewar that host cavity testing. (for W, Co-W, MOI)

M: Access to the space is only granted to trained personnel. Untrained personnel are escorted at all times. (for W, Co-W, MOI)

M: Radiation detectors on mobile shielding are available as a part of Radiation Safety Interlock System; if any one of them trips, high-power RF will be turned off, no more x-rays will be produced. (for W, CO-W, MOI)

M: Mobile shielding available to reduce radiation levels at outside of VTS accelerator to background levels. (for W, Co-W, MOI)

M: Radiation detectors under mobile shielding and operation procedure are available to provide test operators real-time and allowable radiation levels under the shielding. if the levels beyond allowable ones, operators will turn off RF and stop cavity testing. (for W)

VI-4.2.1.2 Residual Activation

x-rays produced by electron field emissions in SRF cavities may activate components of VTS accelerator.

To prevent and mitigate Residual Activation Hazardsand protect personnel such as, Facility Worker (W), Co-located Worker (Co-W), and Maximally-exposed Offsite Individual (MOI), below Preventative (P)/Mitigative (M) actions are available.

P: Cavity cleaning and particle-free assembly are performed to eliminate contaminants and particles that may generate electron field emissions and may cause activation. (for W, Co-W, MOI)

P: Mobile shielding is available to reduce radiation levels at outside of VTS accelerator to background levels and to avoid activation of components at outside of the shielding. (for W, Co-W, MOI)

M: Access to the space is only granted to trained personnel. Untrained personnel are escorted at all times. (for W, Co-W, MOI)

M: Radiation detectors on mobile shielding are available as a part of radiation safety interlock system; if any one of them trips, high-power RF will be turned off, no more x-rays or no more activation of the components under the shielding will happen. (for W, Co-W, MOI)

M: Radiation detectors under mobile shielding and operation procedure are available to provide test operators real-time radiation levels and potential radiation levels that may activate components of VTS accelerator under the shielding. (for W)

M: Radiation surveys and material release plan are applied on all tested cavities and components that stay under the shielding during cavity testing. (for W, Co-W, MOI)

VI-4.2.1.3 Groundwater Activation

This hazard is not applicable to this area.

VI-4.2.1.4 Surface Water Activation

This hazard is not applicable to this area.

VI-4.2.1.5 Radioactive Water (RAW) Systems

This hazard is not applicable to this area.

VI-4.2.1.6 Air Activation

This hazard is not applicable to this area.

VI-4.2.1.7 Closed Loop Air Cooling

This hazard is not applicable to this area.

VI-4.2.1.8 Soil Interactions

This hazard is not applicable to this area.

VI-4.2.1.9 Radioactive Waste

Radioactive waste produced in the course of VTS 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 VTS Accelerator, x-rays produced by electron field emissions in SRF cavities may activate components and/or disposable items (e.g., metal gasket and fasteners) in the VTS accelerator. To prevent and mitigate Radiological waste Hazards and protect personnel such as, Facility Worker (W), Co-located Worker (Co-W), and Maximally-exposed Offsite Individual (MOI), below Preventative (P)/Mitigative (M) actions are available. 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.

P: Cavity cleaning and particle-free assembly are performed to eliminate contaminants and particles that may generate electron field emissions and may cause activation. (for W, Co-W, MOI)

P: Mobile shielding is available to reduce radiation levels at outside of VTS accelerator to background levels and to avoid activation of components at outside of the shielding. (for W, Co-W, MOI)

M: Access to the space is only granted to trained personnel. Untrained personnel are escorted at all times. (for W, Co-W, MOI)

M: Radiation detectors on mobile shielding are available as a part of radiation safety interlock system; if any one of them trips, high-power RF will be turned off, no more x-rays or no more activation of the components under the shielding will happen. (for W, Co-W, MOI)

M: Radiation detectors under mobile shielding and operation procedure are available to provide test operators real-time radiation levels and potential radiation levels that may activate components of VTS accelerator under the shielding. (for W)

M: Radiation surveys and material release plan are applied on all tested cavities and components that stay under the shielding during cavity testing. (for W, Co-W, MOI)

VI-4.2.1.10 Contamination

This hazard is not applicable to this area.

VI-4.2.1.11 Beryllium-7

This hazard is not applicable to this area.

VI-4.2.1.12 Radioactive Sources

This hazard is not applicable to this area.

VI-4.2.1.13 Nuclear Material

This hazard is not applicable to this area.

VI-4.2.1.14 Radiation Generating Devices (RGDs)

SRF cavities in VTS accelerator may be operated with RGD conditions (potential energy gain per cavity is at or below 10MeV) but may have the same radiological hazards with accelerator conditions (potential energy gain per cavity is more than 10MeV) summarized in this section (SAD Chapter VI section 4.2.1.

To prevent and mitigate RGDs Hazard and protect personnel such as, Facility Worker (W), Co-located Worker (Co-W), and Maximally-exposed Offsite Individual (MOI), below Preventative (P)/Mitigative (M) actions are available.

P: Cavity cleaning and particle-free assembly are performed to eliminate contaminants and particles that may generate electron field emissions and x-rays. (for W, Co-W, MOI)

P: Mobile shielding and position monitor switches are available as a part of radiation safety interlock system. To turn on high-power RF, mobile shielding needs to be in position of covering the dewar that host cavity testing. (for W, Co-W, MOI)

M: Access to the space is only granted to trained personnel. Untrained personnel are escorted at all times. (for W, Co-W, MOI)

M: Mobile shielding is available to reduce radiation levels at outside of VTS accelerator to background levels. (for W, Co-W, MOI)

M: Radiation detectors under mobile shielding and operation procedure are available to provide test operators real-time and allowable radiation levels under the shielding. if the levels beyond allowable ones, operators will turn off RF and stop cavity testing. (for W)

M: Radiation surveys and material release plan are applied on all tested cavities and components that stay under the shielding during cavity testing. (for W, Co-W, MOI)

VI-4.2.1.15 Non-Ionizing Radiation Hazards

Connections of coaxial transmission lines and SRF cavities in VTS accelerator may have leakage of hazardous level of RF power generated by RF sources (Solid State Amplifiers).

To prevent and mitigate Non-Ionizing Radiation Hazards and protect personnel such as, Facility Worker (W), Co-located Worker (Co-W), and Maximally-exposed Offsite Individual (MOI), below Preventative (P)/Mitigative (M) actions are available.

P: All RF connectors are eye inspected before making connections to identify if any visible damages are on them. (W, Co-W, MOI)

P: RF quality control measurements are performed at room temperature after making connections to confirm connections are properly made and see if any indications of RF leakage are there. (W, Co-W, MOI)

M: Access to the space is only granted to trained personnel. Untrained personnel are escorted at all times. (W, Co-W, MOI)

M: Mobile shielding is available to reduce radiation levels at outside of VTS accelerator to background levels. (W, Co-W, MOI)

M: Radiation detectors on mobile shielding are available as a part of radiation safety interlock system; if any one of them trips, high-power RF will be turned off, no more RF leakage will happen. (W, Co-W, MOI)

M: Radiation detectors under mobile shielding and operation procedure are available to provide test operators real-time and allowable radiation levels under the shielding. if the levels beyond allowable ones, operators will turn off RF and stop cavity testing. (W)

VI-4.2.2 Toxic Materials

This hazard is not applicable to this area.

VI-4.2.2.1 Lead

This hazard is not applicable to this area.

VI-4.2.2.2 Beryllium

This hazard is not applicable to this area.

VI-4.2.2.3 Fluorinert & Its Byproducts

This hazard is not applicable to this area.

VI-4.2.2.4 Liquid Scintillator Oil

This hazard is not applicable to this area.

VI-4.2.2.5 Pseudocumene

This hazard is not applicable to this area.

VI-4.2.2.6 Ammonia

This hazard is not applicable to this area.

VI-4.2.2.7 Nanoparticle Exposures

This hazard is not applicable to this area.

VI-4.2.3 Flammables and Combustibles

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

VI-4.2.3.1 Combustible Materials

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

VI-4.2.3.2 Flammable Materials

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

VI-4.2.4 Electrical Energy

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

VI-4.2.4.1 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 VTS accelerator involving this hazard implements the controls specified in the common Risk Matrix table. No unique controls are in use.

VI-4.2.4.2 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 VTS accelerator involving this hazard implements the controls specified in the common Risk Matrix table. No unique controls are in use.

VI-4.2.4.3 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 VTS accelerator involving this hazard implements the controls specified in the common Risk Matrix table. No unique controls are in use.

VI-4.2.5 Thermal Energy

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

VI-4.2.5.1 Bakeouts

This hazard is not applicable to this area.

VI-4.2.5.2 Hot Work

This hazard is not applicable to this area.

VI-4.2.5.3 Cryogenics

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

VI-4.2.6 Kinetic Energy

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

VI-4.2.6.1 Power Tools

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

VI-4.2.6.2 Pumps and Motors

This hazard is not applicable to this area.

VI-4.2.6.3 Motion Tables

This hazard is not applicable to this area.

VI-4.2.6.4 Mobile Shielding

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

VI-4.2.7 Potential Energy

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

VI-4.2.7.1 Crane Operations

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

VI-4.2.7.2 Compressed Gasses

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

VI-4.2.7.3 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 VTS accelerator involving this hazard implements the controls specified in the common Risk Matrix table. No unique controls are in use.

VI-4.2.7.4 Vacuum Pumps

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

VI-4.2.7.5 Material Handling

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

VI-4.2.8 Magnetic Fields

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

VI-4.2.8.1 Fringe Fields

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

VI-4.2.9 Other Hazards

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

VI-4.2.9.1 Confined Spaces

This hazard is not applicable to this area.

VI-4.2.9.2 Noise

This hazard is not applicable to this area.

VI-4.2.9.3 Silica

This hazard is not applicable to this area.

VI-4.2.9.4 Ergonomics

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

VI-4.2.9.5 Asbestos

This hazard is not applicable to this area.

VI-4.2.9.6 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 VTS accelerator involving this hazard implements the controls specified in the common Risk Matrix table. No unique controls are in use.

VI-4.2.10 Access & Egress

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

VI-4.2.10.1 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 VTS accelerator involving this hazard implements the controls specified in the common Risk Matrix table. No unique controls are in use.

VI-4.2.11 Environmental

This hazard is not applicable to this area.

VI-4.2.11.1 Hazard to Air

This hazard is not applicable to this area.

VI-4.2.11.2 Hazard to Water

This hazard is not applicable to this area.

VI-4.2.11.3 Hazard to Soil

This hazard is not applicable to this area.

VI-4.3. Summary of Hazards to Members of the Public

Specific hazards associated with the operation of the VTS accelerator are identified and assessed in this chapter of the Fermilab SAD. The designs, controls, and procedures to mitigate hazards specific to operation of the VTS accelerator are identified and described. The VTS accelerator 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 VTS accelerator 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 Members of the Public.

VI-4.4. Summary of Credited Controls

VI-4.4.1 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 mobile shielding, penetration shielding, permanent concrete that surround the portion of the VTS accelerator.

VI-4.4.1.1 Shielding

The VTS accelerator is designed and constructed under a ground floor level of IB1, top portion of test stands including the exit of penetrations are contiguous with IB1 ground floor surface. The area in IB1 immediately surrounding the VTS accelerator including the exit of penetrations is considered a minimally-occupied Controlled Area. Per table 2-6 in the Fermilab Radiological Control Manual, the effective dose rate limit is 5 mrem per one hour for minimally-occupied Controlled Areas under normal operating conditions. To comply that, mobile shielding and penetration shielding are implemented as Shielding of the VTS accelerator.

VI-4.4.1.1.1 Permanent Shielding Including Labyrinths

This is not applicable to this area.

VI-4.4.1.1.2 Movable Shielding

The VTS accelerator has Mobile shielding on a guide rail that can travel between top surfaces of test stands to cover. The current shielding assessments [2-5] indicate Mobile shielding maintains “minimally-occupied Controlled Area” conditions in the immediate vicinity of the shielding while cavity testing.

VI-4.4.1.1.3 Penetration Shielding

There are four penetrations at the VTS accelerator for utilities, cryogens, and RF to enter the space. The current shielding assessments [2-5] indicate Penetration shielding of the VTS accelerator maintains “minimally-occupied Controlled Area” conditions in the immediate vicinity of the exit of penetrations shielding while cavity testing.

VI-4.4.1.2 Fencing

This is not applicable to the VTS accelerator.

VI-4.4.1.2.1 Radiation Area Fencing

This is not applicable to the VTS accelerator.

VI-4.4.1.2.2 Controlled Area Fencing

This is not applicable to the VTS accelerator.

VI-4.4.2 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 VTS accelerator include radiation safety interlock system.

VI-4.4.2.1 Radiation Safety Interlock System

Safety of personnel is always the highest priority of the VTS accelerator. to protect personnel from radiological hazards at the space, Radiation safety interlock system is available and that includes Mobile shielding position monitor switches and radiation detectors on and under mobile shielding. To turn on high power RF amplifiers those interlocks need to be established. If any one of their signals drops or trips, RF power amplifiers will be shut off, no more RF power will go into cavities. Trip setting point of each radiation detector located in a test stand for a low power operation mode is 1.0 mrem per one hour. Trip setting point of radiation detector on mobile shielding for high power operation mode are 2.5mrem per one hour (one at north side of mobile shielding, one at south) and 1.0 mrem per one hour (one at center of mobile shielding).

VI-4.4.2.2 ODH Safety System

not applicable

VI-4.4.3 Administrative Credited Controls

All VTS accelerator 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.

VI-4.4.3.1 Operation Authorization Document

"VCTF RF/Cavity Test Operations Authorized Operators List" is maintained by the APS-TD SRF Materials & Research Department as an Operation Authorization Document of the VTS accelerator. The document indicates the requirements to be an authorized RF operator of the VTS accelerator. Once personnel completed and satisfied the requirements and also signed the latest Radiological Work Permit (RWP) of Vertical Test Stands (VTS) 1, 2, and 3, his/her name, ID number, and date training completed will be added on the list. Final authorization will be given by the SRF Measurements & Research Department Head or his/her designee.

VI-4.4.3.2 Staffing

Technicians in the cavity measurement group is responsible to follow given instructions and prepare cavities for cooldown and testing, to perform survey after cavity testing, and to remove cavities and equipment from a test stand.

Cryo operators in the operation support group is responsible to follow given instructions and bring cavities in a dewar to cryo temperatures. Minimum one responsible cryo operator is at cryo operation control room in IB1 during cavity testing at the VTS accelerator.

RF operators in the cavity measurement group are responsible to follow given instructions, establish VTS interlocks in safe condition, perform cavity testing, and switch operating modes between low- and high-power accordingly in the VTS accelerator. Minimum one responsible RF operator is at VTS operation control room in IB1 during high power RF operations. No on-site staffing requirement for low power RF operation.

VI-4.4.3.3 Accelerator Operating Parameters

Projects and PIs (owners of SRF cavities) are responsible to provide instructions and operating parameters of their cavities installed into the VTS accelerator. Instructions may include, but is not limited to cooldown parameters, characterization plans, and diagnostic equipment need to be attached on cavities. Operating parameter may include but is not limited to allowable radiation levels under Mobile shielding, administrative accelerating field limit, and cavity behaviors that may indicate cavity performance limitations (e.g., severe multipacting and/or quenching barrier, low intrinsic cavity quality factor *Q0*, degradation of *Q0* after quenching, thermal heating on cavity surface, etc.). Operating parameters provided by cavity owners will guide RF operators where to stop cavity testing.

VI-4.5. Defense-in-Depth Controls

This is not applicable to the VTS accelerator.

VI-4.6. Machine Protection Controls

This is not applicable to the VTS accelerator.

VI-4.7. Decommissioning

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

VI-4.8. Summary and Conclusion

Specific hazards associated with the operation of the VTS accelerator are identified and assessed in this chapter of the Fermilab SAD. The designs, controls, and procedures to mitigate hazards specific to operation of the VTS accelerator are identified and described. The VTS accelerator 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 VTS accelerator 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.

VI-4.9. References

[1] Fermilab Radiological Control Manual
[2] C. Ginsburg et al. “Modified radiation shielding of the vertical cavity test facility for VTS2/3 operations” Fermilab-TM-2483-APC-TD, April 2011 https://tiweb.fnal.gov/website/controller/1364
[3] Yu. Pischalnikov and R. Ruthe, “Fourth Addendum to the Hazard Analysis (Formerly the Safety Assessment Document) for the Vertical Cavity Test Facility”, October 2013
[4] M. Vincent, “Revised Penetration Worksheet for Proposed IB1 VTS Trench”, July 2017
[5] M. Vincent , Revised Exit Effective dose rate for proposed VTS RF Waveguide penetration at IB1, July 2017

VI-4.10. 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 VI-4.4 of this Chapter as well as SAD Chapter VII-A.05 *Accelerator Safety Envelope – the VTS accelerator*.