CRYOMODULE TEST STAND 1 (CMTS1)

SECTION VI CHAPTER 02 OF THE FERMILAB SAD

Revision 0 August 10, 2023

This Chapter of the Fermilab Safety Assessment Document (SAD) contains a summary of the results of the Safety Analysis for Cryomodule Test Stand 1 (CMTS1) within the Cryomodule Test Facility (CMTF) 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 02 of the Fermi National Accelerator Laboratory (Fermilab) Safety Assessment Document (SAD), *CMTS1* was prepared and reviewed by the staff of the Accelerator Directorate, Accelerator Complex Technology Division, Mechanical Support Department in conjunction with the LCLS-II-HE Project Team and 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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☐ ____
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
C. Baffes, A. Cravatta, B. Hartsell	0	August 10, 2023	• Initial release of the CMTS1 Chapter of the Fermilab 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
CMTF	Cryomodule Test Facility
CMTS1	Cryomodule Test Stand 1
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
PIP2IT	PIP-II Integrated Test Stand
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

IV-2. CMTS1

IV-2.1. Introduction

This Section VI, Chapter 02 of the Fermi National Accelerator Laboratory (Fermilab) Safety Assessment Document (SAD) covers the CMTS1 test stand within the CMTF Facility

IV-2.1.1 Purpose/Function

CryoModule Test Stand 1 (CMTS1) is a cryomodule test stand, currently configured for functional testing of 1.3GHz cryomodules for LCLS-II-HE Project at SLAC. In its current configuration, CMTS1 can accommodate one 8-cavity cryomodule. Cryomodule tests are conducted **without beam**, and the facility does not include any provisions to inject beam into the cryomodules under test. Cryomodules are cooled to their cryogenic operational temperature and cavities are operated with RF to demonstrate accelerating gradient and other acceptance criteria. During RF operations, radiation may be generated by incidentally accelerated dark current electrons. As such, CMTS1 is classified as a "Radiation Generating Device" Accelerator as described below.

IV-2.1.2 Current Status

The CMTS1 test stand within the CMTF Facility is currently: **Operational**

IV-2.1.3 Description

The CMTS1 test stand includes:

- A single 1.3GHz, β=1, 8-cavity cryomodule (unit under test)
- Eight 1.3GHz Radio Frequency Amplifiers (one per cavity)
- A Cryogenic Distribution System to interface the cryomodule to the facility's Helium cryoplant
- Support systems such as vacuum systems, magnet power systems, instrumentation readbacks and controls meeting the cryomodule's interfaces and allowing operation and validation of cryomodule function and performance.
- An enclosure Safety System, creating an interlocked exclusion area around the cryomodule under test. The enclosure includes shielding and interlocked radiation detectors to limit radiation outside the enclosure.

In order for a cryomodule to be brought into CMTS1, modular concrete shielding blocks that constitute the roof of the enclosure are removed. The cryomodule may then be craned into position on the test stand and interfaced. Shielding blocks are then replaced prior to test. The process is reversed to remove a cryomodule.

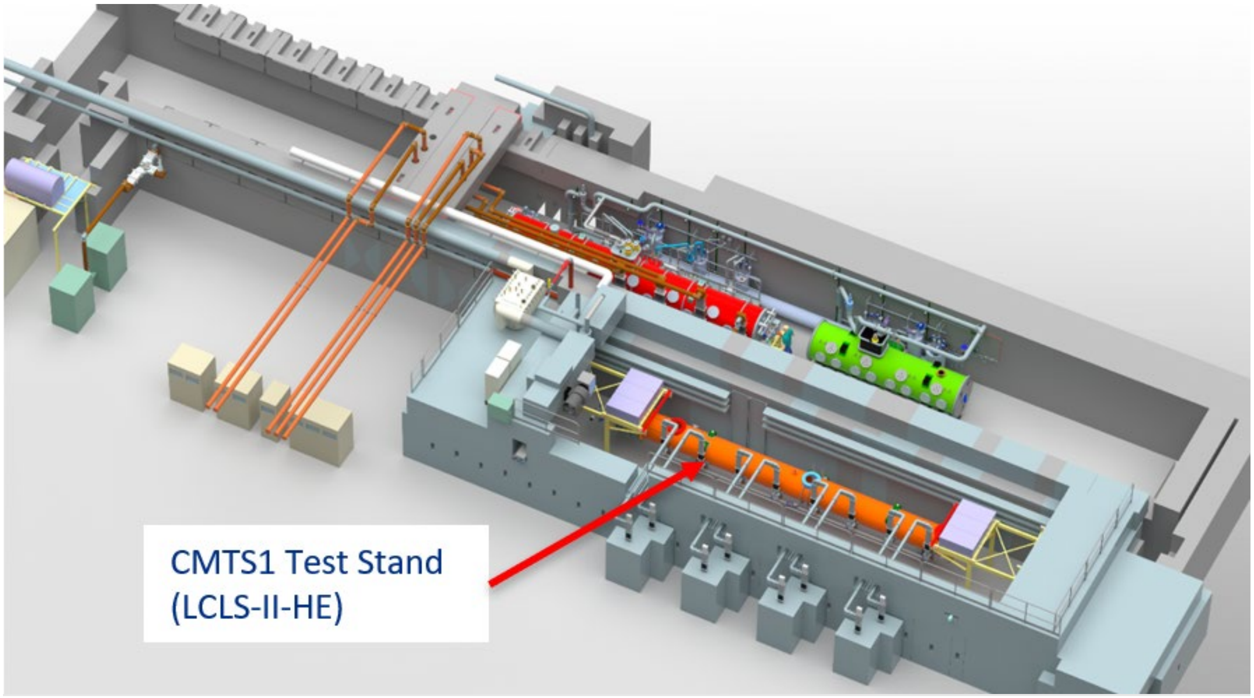

Figure 1. CMTS1 Test Stand

IV-2.1.4 Location

The CMTS1 test stand within the CMTF facility is located on the Fermilab site in Batavia, IL.

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

CMTS1 is located in the CMTF Building on the Fermilab site.

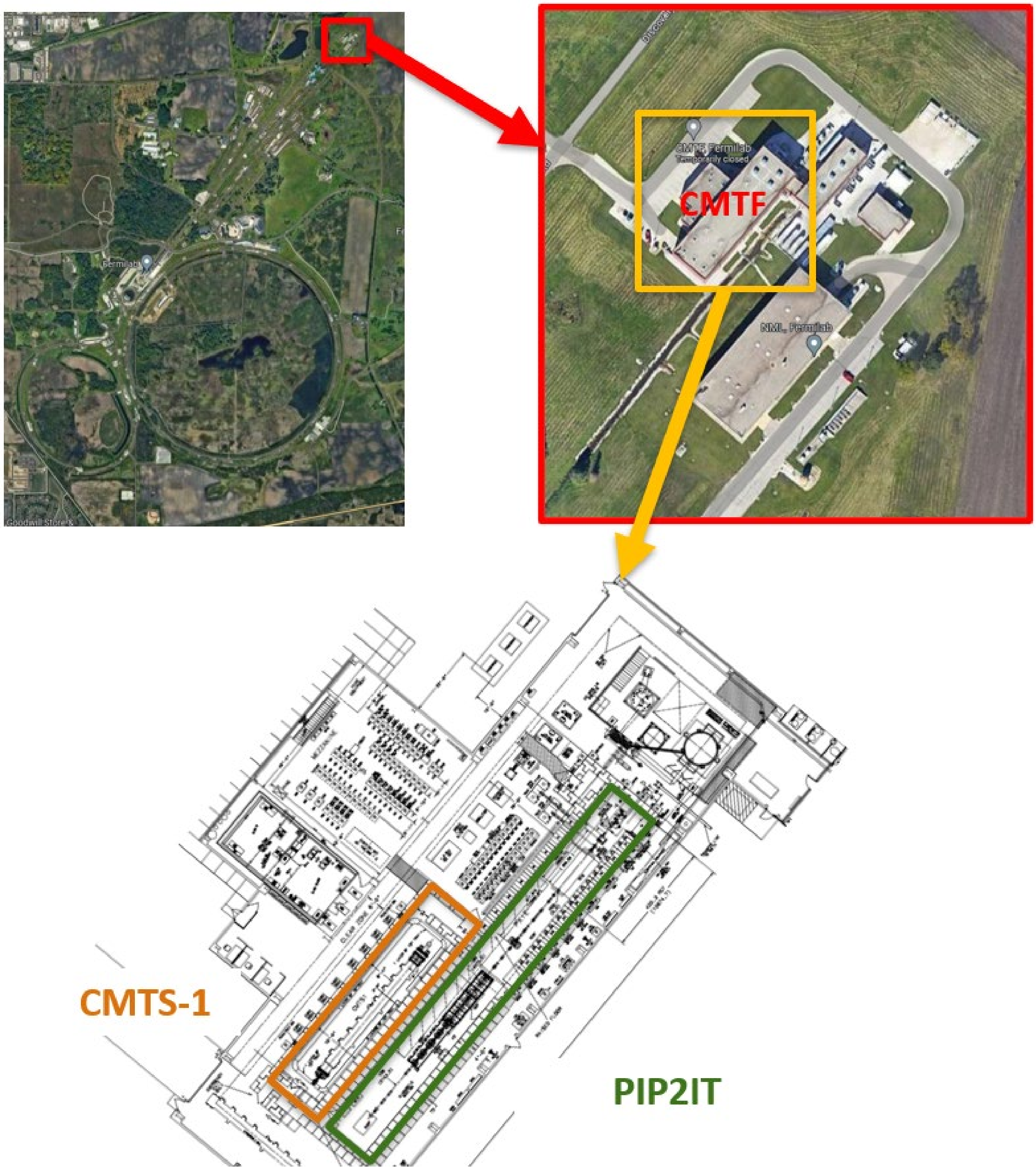

Figure 3. Aerial view of the Fermilab site, indicating the location of CMTS1.

IV-2.1.5 Management Organization

The CMTF Facility is managed by Fermilab's Accelerator Directorate, Accelerator Complex Technology Division. This includes shared infrastructure such as the cryoplant, control room, cleanroom facilities and tech areas.

The CMTS1 Test Stand is managed by the Fermilab LCLS-II-HE Project team, with matrixed support from Accelerator Directorate and APS-TD staff for CMTS1 systems (e.g. RF system, Cryogenics System, Safety System, etc).

IV-2.1.6 Operating Modes

The operational and non-operational modes of CMTS1 may be described as follows:

- Operational Modes
  - Single-Cavity Testing
    - In this mode, only one cavity is in operation.
  - Multi-Cavity Testing
    - In this mode, more than one cavity is in operation simultaneously. This mode carries the potential for coherent acceleration of electrons, within the limits as described in [2].
  - Unit Testing
    - In this mode, all cavities of a given cryomodule are operated together to demonstrate peak parameters (such as total dynamic heat load) for the cryomodule.
    - This mode carries the potential for coherent acceleration of electrons.
- Non-Operational Modes
  - Other – Secured Area Access
    - In this mode, interlocks are dropped and RF is locked out.

IV-2.1.7 Inventory of Hazards

The following table lists all the identified hazards found in the CMTS1 enclosure and support areas. Section IV-2.10 *Appendix – Risk Matrices* describes the baseline risk (i.e., unmitigated risk), any preventative controls and/or mitigative controls in place to reduce the risk, and residual risk (i.e., mitigated risk) for facility worker, co-located worker and Maximally Exposed Offsite Individual (MOI) (i.e., members of the public). A summary of these controls is described within Section IV-2.2 *Safety Assessment.*

Prompt ionizing, Oxygen Deficiency Hazards due to cryogenic systems within accelerator enclosures, and fluorinert byproducts due to the 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 CMTS1. Accelerator specific controls are identified as **purple/bold** throughout this Chapter.

All other hazards present in PIP2IT 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 CMTS1.

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

*All hazards marked with an asterisk (*) have been addressed elsewhere in Chapters 1-10 of the Fermilab SAD and are not addressed in this section of the SAD.

IV-2.2. Safety Assessment

All hazards for CMTS1 are summarized in this section, with additional details of the analyses for accelerator specific hazards.

IV-2.2.1 Radiological Hazards

CMTS1 presents radiological hazards as follows: capable of producing Prompt Ionizing Radiation, Residual Activation and low-level Radioactive Waste. It includes Radio Frequency Amplifiers producing non-ionizing radiation. Detailed shielding assessment and post-assessment documents 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], [2].

Additionally, risk reduction has been taken into account as described in the Risk Matrix tables within SAD Section I Chapter 04 and the Risk Matrix tables contained within this document.

IV-2.2.1.1 Prompt Ionizing Radiation

CMTS1 does not produce a beam. However, dark current electrons may be liberated by MultiPacting (MP) or Field Emission (FE) conditions, and subsequently accelerated by electric fields within the cavities. As these electrons strike internal surfaces within the cryomodule or the test stand, prompt ionizing radiation can be created.

To protect workers and the general public, the test stand enclosure is surrounded by sufficient shielding (concrete), and/or networks of interlocked radiation detectors to limit any prompt radiation exposure to acceptable levels. The Fermilab Senior Radiation Safety Officer has reviewed and approved the relevant shielding assessments to address ionizing radiation concerns.

The approved shielding assessment for CMST1 specifies and requires the following:

- All movable shielding blocks must be installed as specified. This is verified and configuration controlled by the RSO prior to operation.
- The radiation safety interlock system must be certified as working.
- Radiation detectors are installed as prescribed by the assigned Radiation Safety Officer (RSO) and interlocked to the radiation safety interlock system.

IV-2.2.1.2 Residual Activation

Surfaces which interact with accelerated electrons or secondaries may become activated. As of this writing, residual activation has not been observed in CMTS1. However, in theory it could occur. Of particular interest are windows and faraday cups located along the axis of the cavity string.

The CMTS1 enclosure may be accessed only in a Secured Area access state – interlocks are dropped and RF is inhibited when the enclosure is accessed, preventing exposure. Work within the enclosure is governed by a RWP and all qualified personnel must have the proper training, an O2 monitor, dosimetry badge, and pocket dosimeter. ALARA is used at all times.

Material within the CMTS1 enclosure is considered “impacted” per Fermilab’s established Radiological Protection Program (RPP) and as prescribed in the Fermilab Radiological Control Manual (FRCM). Any hardware brought out of the enclosure (including the cryomodules) that was present during powered RF testing are radiation scanned and categorized based on that measurement. The CMTF highbay around the CMTS1 enclosure is classified as a Controlled Area, suitable for the storage of the material (typically Class 0) removed from the enclosure.

IV-2.2.1.3 Groundwater Activation

Groundwater activation was not considered as part of the original shielding assessment for CMTS1, as it was not required for RGD Shielding Assessments.

IV-2.2.1.4 Surface Water Activation

Groundwater activation was not considered as part of the original shielding assessment for CMTS1, as it was not required for RGD Shielding Assessments.

IV-2.2.1.5 Radioactive Water (RAW) Systems

N/A.

IV-2.2.1.6 Air Activation

Air activation was not considered as part of the original shielding assessment for CMTS1, as it was not required for RGD Shielding Assessments.

IV-2.2.1.7 Closed Loop Air Cooling

N/A.

IV-2.2.1.8 Soil Interactions

N/A.

IV-2.2.1.9 Radioactive Waste

Radioactive waste produced in the course of CMTS1 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 CMTS1, interaction with dark current electrons or secondaries could result in activation of beam line or adjacent 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.

IV-2.2.1.10 Contamination

N/A.

IV-2.2.1.11 Beryllium-7

N/A.

IV-2.2.1.12 Radioactive Sources

N/A.

IV-2.2.1.13 Nuclear Material

N/A.

IV-2.2.1.14 Radiation Generating Devices (RGDs)

N/A.

IV-2.2.1.15 Non-Ionizing Radiation Hazards

CMTS1 includes RF amplifiers. The amplifiers for CMTS1 operate at 1.3GHz. These amplifiers pose a non-ionizing radiation hazard. They are designed, installed and verified per the requirements of FESHM 4320 Radio Frequency Hazards.

This RF 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.

At initial assembly, all joints in the system were scanned with an RF detector to ensure the absence of RF leaks. Continuous monitoring with antennae inside and outside the enclosure ensure the stability of the system. The amplifiers are interlocked to these antenna and will trip off if excessive RF field is detected.

The areas inside the enclosure cannot be accessed while RF is on – pulling an enclosure key for access inhibits RF and ensures the absence of RF hazard.

IV-2.2.2 Toxic Materials

IV-2.2.2.1 Lead

CMTS1 includes lead shielding bricks around each of the faraday cups. These lead shielding bricks are fully wrapped, appropriately labeled, and covered in an additional layer of Herculite. The bricks are not typically handled or disturbed operationally. However, in rare instances where a need to handle these bricks arise, they are handled only by individuals with lead handling training and a hazard assessment is generated for the work.

See Risk Matrix tables within SAD Section I Chapter 04.

IV-2.2.2.2 Beryllium

N/A.

IV-2.2.2.3 Fluorinert & Its Byproducts

N/A.

IV-2.2.2.4 Liquid Scintillator Oil

N/A.

IV-2.2.2.5 Pseudocumene

N/A.

IV-2.2.2.6 Ammonia

N/A.

IV-2.2.2.7 Nanoparticle Exposures

N/A.

IV-2.2.3 Flammables and Combustibles

IV-2.2.3.1 Combustible Materials

See Risk Matrix tables within SAD Section I Chapter 04.

IV-2.2.3.2 Flammable Materials

See Risk Matrix tables within SAD Section I Chapter 04.

IV-2.2.4 Electrical Energy

IV-2.2.4.1 Stored Energy Exposure

Cryomodules under test may include superconducting magnets, piezo-based tuners, and incidental inductance or capacitance within electrical systems capable of storing electrical energy.

Of these, capacitor banks associated with magnet power supplies have the most significant energy storage. These are housed in racks that require a written LOTO procedure to access. A Ross Relay is used to short the output of the capacitor bank when AC power is removed from the rack or when interlocks are not made up. A window allows for visual confirmation of capacitor bank shorting without opening the rack.

CMTS1 does not include any exposed busway or electrical connections – all electrical surfaces are fully insulated and/or enclosed.

See Risk Matrix tables within SAD Section I Chapter 04.

IV-2.2.4.2 High Voltage Exposure

High voltage may be present in coupler bias systems, ion pumps, vacuum gauges, and AC distribution to power systems such as RF amplifiers. All HV distribution is fully enclosed and labeled.

HV field connectors are SHV-style, the conductor is not exposed during mate-demate. HV cables are color-coded red and labeled.

Power systems with high voltage AC distribution require LOTO for access to rack/cabinet internal areas.

See Risk Matrix tables within SAD Section I Chapter 04.

IV-2.2.4.3 Low Voltage, High Current Exposure

Low-voltage/high current systems power magnets within the cryomodules and demagnetization systems. Power supply racks are fully enclosed and require LOTO for entry. CMTS1 does not include any exposed busway or electrical connections – all electrical surfaces are fully insulated and/or enclosed.

See Risk Matrix tables within SAD Section I Chapter 04.

IV-2.2.5 Thermal Energy

IV-2.2.5.1 Bakeout

N/A.

IV-2.2.5.2 Hot Work

N/A.

IV-2.2.5.3 Cryogenics

CMTS1 includes a cryogenic distribution system supplied by CMTF's Helium Cryoplant. Multiple cryogenic circuits exist within the cryomodule.

Cryogenic systems are designed, reviewed, tested and operated in accordance with governing codes and FESHM chapters. Documentation and hardware confirmation by the Cryogenic Safety Subcommittee is part of the Operational Readiness Clearance (ORC) process that is a prerequisite to system operation.

All circuits include pressure relief provisions, primary reliefs exhaust outside the enclosure (in some cases outside the building) to minimize ODH risks within the enclosure.

All circuits within the building are fully enclosed, the system does not include open dewars or other features where facility workers might have direct exposure to cryogens. Work on the cryogenic systems or adjacent volumes (such as the cryomodule's insulating vacuum volume) requires LOTO of relevant cryogenic circuits. Fermilab practice is to achieve at least double-isolation (i.e. redundant isolation) during LOTO work.

Oxygen Deficiency Hazard (ODH) conditions may occur during failure or accident scenarios. The enclosure is classified as ODH-1, and includes controls as described in Section IV-2.4.2 below. The CMTF highbay includes active ventilation systems to maintain Engineered ODH-0 conditions at all times.

This hazard has been evaluated within the common Risk Matrix table included in SAD Section I Chapter 04, Safety Analysis. Work in CMTS1 involving this hazard implements the controls specified in the common Risk Matrix table. No unique controls are in use.

IV-2.2.6 Kinetic Energy

IV-2.2.6.1 Power Tools

CMTS1 does not include any extraordinary hazards of this kind. Standard hazards and mitigations apply as described in other chapters of the SAD.

This hazard has been evaluated within the common Risk Matrix table included in SAD Section I Chapter 04, Safety Analysis. Work in CMTS1 involving this hazard implements the controls specified in the common Risk Matrix table. No unique controls are in use.

IV-2.2.6.2 Pumps and Motors

CMTS1 does not include any extraordinary hazards of this kind. Standard hazards and mitigations apply as described in other chapters of the SAD.

This hazard has been evaluated within the common Risk Matrix table included in SAD Section I Chapter 04, Safety Analysis. Work in CMTS1 involving this hazard implements the controls specified in the common Risk Matrix table. No unique controls are in use.

IV-2.2.6.3 Motion Tables

N/A.

IV-2.2.6.4 Mobile Shielding

N/A.

IV-2.2.7 Potential Energy

IV-2.2.7.1 Crane Operations

This hazard has been evaluated within the common Risk Matrix table included in SAD Section I Chapter 04, Safety Analysis. Work in CMTS1 involving this hazard implements the controls specified in the common Risk Matrix table. No unique controls are in use.

IV-2.2.7.2 Compressed Gasses

CMTS1 does not include any extraordinary hazards of this kind. Standard hazards and mitigations apply as described in other chapters of the SAD.

CMTS1/CMTF have compressed air systems, a gaseous nitrogen system, and compressed gas from dewars and cylinders.

This hazard has been evaluated within the common Risk Matrix table included in SAD Section I Chapter 04, Safety Analysis. Work in CMTS1 involving this hazard implements the controls specified in the common Risk Matrix table. No unique controls are in use.

IV-2.2.7.3 Vacuum/Pressure Vessels/Piping

Each cryomodule tested in CMTS1 does have a Vacuum Vessel (the external cryostat). Inside the Vacuum Vessel, each cryomodule jacketed cavity is considered to be a Pressure Vessel. Both the Vacuum Vessel and the Cavities are designed and operated in accordance with the governing codes (ASME BPVC) and FESHM requirements. All systems include pressure relief provisions as required by the code. Documentation is maintained in the FEHSM Engineering Notes associated with each Vacuum and Pressure Vessel. Verification of these notes is part of the process for Operational Readiness Clearance that precedes their operation in CMTS1.

This hazard has been evaluated within the common Risk Matrix table included in SAD Section I Chapter 04, Safety Analysis. Work in CMTS1 involving this hazard implements the controls specified in the common Risk Matrix table. No unique controls are in use.

IV-2.2.7.4 Vacuum Pumps

CMTS1 does not include any extraordinary hazards of this kind. Standard hazards and mitigations apply as described in other chapters of the SAD.

CMTS1/CMTF have mechanical vacuum pumps such as scroll pumps, turbo pumps, and screw pumps. Also present are UHV pumps such as ion pumps and NEGs.

This hazard has been evaluated within the common Risk Matrix table included in SAD Section I Chapter 04, Safety Analysis. Work in CMTS1 involving this hazard implements the controls specified in the common Risk Matrix table. No unique controls are in use.

IV-2.2.7.5 Material Handling

This hazard has been evaluated within the common Risk Matrix table included in SAD Section I Chapter 04, Safety Analysis. Work in CMTS1 involving this hazard implements the controls specified in the common Risk Matrix table. No unique controls are in use.

IV-2.2.8 Magnetic Fields

IV-2.2.8.1 Fringe Fields

This hazard has been evaluated within the common Risk Matrix table included in SAD Section I Chapter 04, Safety Analysis. Work in CMTS1 involving this hazard implements the controls specified in the common Risk Matrix table. No unique controls are in use.

IV-2.2.8.2 Confined Spaces

N/A.

IV-2.2.8.3 Noise

This hazard has been evaluated within the common Risk Matrix table included in SAD Section I Chapter 04, Safety Analysis. Work in CMTS1 involving this hazard implements the controls specified in the common Risk Matrix table. No unique controls are in use.

IV-2.2.8.4 Silica

This hazard has been evaluated within the common Risk Matrix table included in SAD Section I Chapter 04, Safety Analysis. Work in CMTS1 involving this hazard implements the controls specified in the common Risk Matrix table. No unique controls are in use.

IV-2.2.8.5 Ergonomics

This hazard has been evaluated within the common Risk Matrix table included in SAD Section I Chapter 04, Safety Analysis. Work in CMTS1 involving this hazard implements the controls specified in the common Risk Matrix table. No unique controls are in use.

IV-2.2.8.6 Asbestos

N/A.

IV-2.2.8.7 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 CMTS1 involving this hazard implements the controls specified in the common Risk Matrix table. No unique controls are in use.

IV-2.2.9 Access & Egress

This hazard has been evaluated within the common Risk Matrix table included in SAD Section I Chapter 04, Safety Analysis. Work in CMTS1 involving this hazard implements the controls specified in the common Risk Matrix table. No unique controls are in use.

IV-2.2.9.1 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 CMTS1 involving this hazard implements the controls specified in the common Risk Matrix table. No unique controls are in use.

IV-2.2.10 Environmental

IV-2.2.10.1 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 CMTS1 involving this hazard implements the controls specified in the common Risk Matrix table. No unique controls are in use.

IV-2.2.10.2 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 CMTS1 involving this hazard implements the controls specified in the common Risk Matrix table. No unique controls are in use.

IV-2.2.10.3 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 CMTS1 involving this hazard implements the controls specified in the common Risk Matrix table. No unique controls are in use.

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

For the purpose of this chapter, we recognize two classes of "Members of the Public"

The first class of the Public is the "General Public." The General Public is invited to public areas of the Fermilab site, which are more than 1km away from CMTF. Members of this group would not be expected to be anywhere near the CMTF building. The safety of the General Public is maintained by enforcing a physical separation and significant distance between them and CMTS1. This physical separation is enforced by the following:

- "Non-Public Area" signs throughout the site and along all roads leading to CMTF
- Security presence in non-public areas
- Locked exterior doors at CMTF
- Locked enclosure doors within CMTS1.

As described throughout this chapter, no physical or radiological effluent from CMTF poses a hazard to the General Public.

The second class of the Public is the "Tourists," persons invited by Fermilab to tour CMTS1/CMTF due to a business, collaboration, policy, or public engagement need. These persons may enter the CMTF facility or CMTS1 enclosure. Provisions ensuring the safety of tourists include:

- Tourists are escorted at all times by Fermilab escorts who are responsible for their safety
- Tourists are given safety briefing(s), including hazards they might encounter and mitigations
- If Tourists enter the enclosure, it is only during Other – Secured Area Access, with the approval of the RSO, and with temporary dosimetry issued by the RSO. By definition, CMTS1 is non-operational and RF amplifiers are powered down during Supervised Access conditions.
- If Tourists enter an ODH-1 area, it is only with the approval of the DSO. Tourists are issued required PPE, trained on its use, and escorted at all times by ODH-qualified escorts as prescribed by FESHM 4240.
- Fermilab escorts ensure that Tourists are not brought into close proximity with any unduly hazardous conditions or work.

See discussion and Risk Matrix tables within SAD Section I.

IV-2.4. Summary of Credited Controls

IV-2.4.1 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 movable concrete shielding blocks and penetration shielding.

IV-2.4.1.1 Shielding

A preliminary shielding assessment served as the basis to define the necessary shielding for the enclosure. The as-built shielding was modeled and used as a basis for the final approved shielding assessment [2]. Elements required by the shielding assessment are further described below. There are labyrinths at the north and south ends of the enclosure for access which have interlocked doors for access.

IV-2.4.1.1.1 Permanent Shielding Including Labyrinths

N/A.

IV-2.4.1.1.2 Movable Shielding

The CMTS1 enclosure is constructed primarily from movable shielding in the form of standardized concrete blocks. These are designed to be moved by crane with built-in lifting lugs. In general, the walls of CMTS1 are 3' thick (two blocks 1.5' thick) with access points on the north and south ends. The assigned RSO controls locks for the movable shielding (i.e., the roof blocks) and ensures they are in place and secured before permitting operation.

IV-2.4.1.1.3 Penetration Shielding

There are 47 penetrations total, as described in the shielding assessment [2]. Waveguide and utility penetrations are along the west end of the enclosure and credit for them being filled is not taken in the shielding assessment. Cryogenic and ODH penetrations are along the north end of the ceiling, and again do not have credit taken for any material in the penetration.

IV-2.4.1.2 Fencing

N/A.

IV-2.4.1.2.1 Radiation Area Fencing

N/A.

IV-2.4.1.2.2 Controlled Area Fencing

N/A.

IV-2.4.2 Active Engineered Credited Controls

Active engineered controls allow for cryomodule testing within acceptable parameters. These controls are automatic systems which limit or prevent operations should any established parameters be exceeded.

At CMTS1, the solid-state amplifier (SSA) interlock monitors various systems which, if established parameters are exceeded, will prevent further operation by inhibiting RF and alert test stand operators. If measured radiation on an interlocked detector exceeds a trip limit, one of the two enclosure doors are breached, or if any key is pulled from the CMTS1 key tree the Safety System will inhibit the SSAs and RF will not be permitted.

IV-2.4.2.1 Radiation Safety Interlock System

The radiation safety interlock system comprises of various radiation detectors which are interlocked to the SSAs within FRCM compliance requirements and outlined in the final shielding assessment [2]. Multipacting electrons or field emission may generate radiation in a cryomodule under test due to RF fields generated by the SSAs. Should radiation levels rise above acceptable safety thresholds, the interlock system will disable RF power from the SSAs and thus prevent any further prompt radiation from being generated.

Before permits from the radiation safety interlock system can be issued, the following criteria must be met in order to power the SSAs and deliver RF to the test stand: enclosure shielding is in place, roof blocks are in place and secured with a RSO lock, gate leading to the roof has been locked, qualified and authorized personnel have searched and secured the cave – making up the test stand cave interlocks, all interlocked keys have been returned to the CMTS key tree, and all radiation detectors are operating normally and below trip limits.

IV-2.4.2.2 ODH Safety System

CMTS1 is classified as an Oxygen Deficiency Hazard Class 1 area [3]. An excerpt from the ODH analysis document describes the mitigations:

> *The ODH fan will be located at the north end of the cave ceiling near the entrance and blow clean air from the CMTF building into the cave. The fan specifications are provided in the Appendix. Ventilation occurs at the south end of the cave through the emergency exit. Plastic drapes will be hung at the entrance to force air flow through the ventilation. In order to protect occupants, the ODH fan will always be on during a cave entrance and is interlocked with the entrance key interlocks. The ODH fan will also be interlocked to turn on in the case of an ODH alarm, regardless of entry. The PLC has flow sensor switches that activate when the fans run and will periodically test the fans every 7 days (168 hrs), but it has no control otherwise. The 120VAC operating power for the chassis is backed up by UPS and the Fan is backed up by the CMTF generator back-up system. The chassis is fail safe in the respect that if it loses power or its DC power supply fails the ODH system will alarm. All external cabling is designed such that it is fail safe.*
>
> *Two ODH heads are mounted, one on each end of the cave to monitor the oxygen concentration inside the cave. The ODH heads are mounted approximately two feet below the ceiling. There is no source of cold nitrogen in the cave therefore a set of ODH heads*

mounted near the floor is not required. Accompanying the heads at each location will be a siren and strobe light.

The system will use standard ODH (newer type with blue readout) chassis, heads, horns and strobes. The chassis will have discrete (relay contact) inputs from the ODH chassis contacts, local fan "on" buttons, cave access interlock contacts and plc fan test outputs. The chassis has outputs to energize the fan contactors, provide operational status signals to the plc and provide signals for FIRUS. Once operational, the use of two sirens in the cave configuration will have some audiometric assessment to ensure that ES&H db levels are not exceeded.

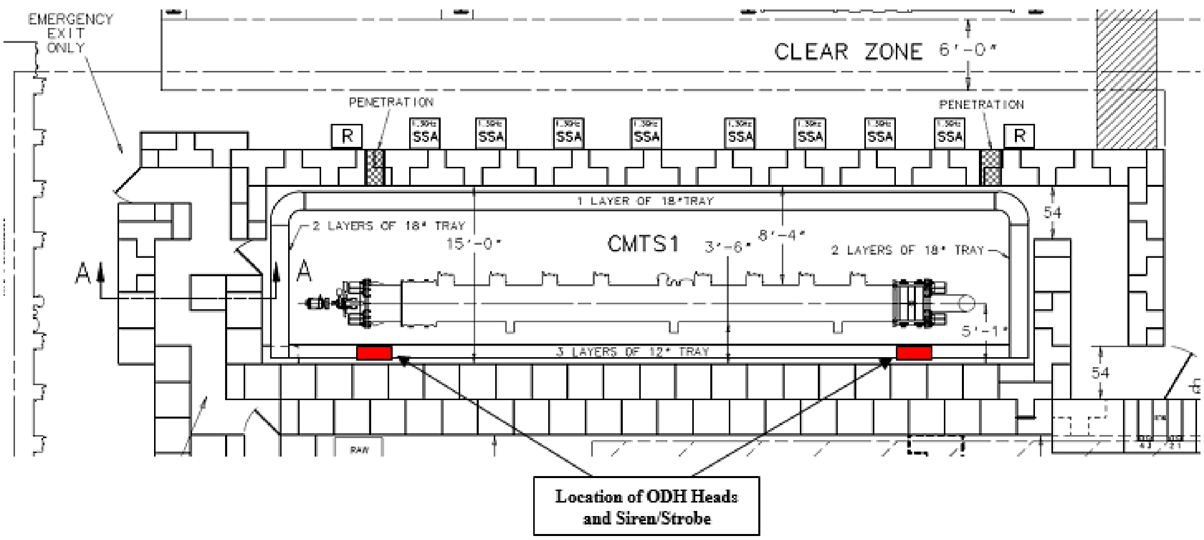

Figure 4. ODH Schematic of CMTS1

Additionally, the CMTF high bay (with the exception of the cryo pit) is an engineered class 0 area [4].

IV-2.4.3 Administrative Credited Controls

IV-2.4.3.1 Operation Authorization Document

CMTS1 operation was authorized by the SRSO. Approval documentation is stored with the CMTS1 Shielding Assessment [2].

IV-2.4.3.2 Staffing

PIP2IT operations are managed by PIP-II Project Staff, led by the PIP-II Operations Coordinator. Operations are performed by a small group of trained operators who are experts on SRF systems operation, and specifically on the cryomodules under test. This operations group coordinates operations support from other project staff and matrixed Accelerator Directorate and APS-TD staff as required.

Main Control Room (MCR) staff support Search and Secure, access management, emergency response, and system operational monitoring as required.

CMTS1 operations are managed by LCLS-II-HE Project Staff, led by the LCLS-II-HE Operations Coordinator. Operations are performed by a small group of trained operators who are experts on SRF systems operation, and specifically on the cryomodules under test. This operations group coordinates operations support from other project staff and matrixed Accelerator Directorate and APS-TD staff as required.

Authorized CMTS1 staff support Search and Secure, access management, emergency response, and system operational monitoring as required.

IV-2.4.3.3 Accelerator Operating Parameters

CMTS1 operating parameters and limits are described in the Shielding Assessment [2], LCLS-II-HE Acceptance Criteria [7], and the Operational Parameters for the CMTS1 Cave memo [8]. Cavities are operated both individually and concurrently at nominal gradient (20.8 MV/m) and up to the admin. limit (26 MV/m). The superconducting magnet package, containing a quadrupole magnet and vertical and horizontal dipole corrector magnets, are also tested for one hour during the Unit Test. Operations limits are expressed in terms of design, project goals, and maximum allowable radiation as enforced by RSO-designated trip limits on interlocked radiation detectors inside and outside the test enclosure. Should any radiation limits be exceeded, the radiation safety interlock system will disable RF power and prevent further prompt radiation.

IV-2.5. Defense-in-Depth Controls

N/A.

IV-2.6. Machine Protection Controls

N/A.

IV-2.7. Decommissioning

The two primary safety aspects of decommissioning this facility will be energy isolation and radiologically activated materials.

Prior to removal of mechanical systems such as piping or electrical systems such as cabling or racks, energy isolation will be required. This will be performed utilizing LOTO at the appropriate isolation points and zero-energy verification in a zone common with the hardware to be removed. This work will be performed in accordance with Fermilab's contemporary LOTO program and FESHM requirements.

Significant material activation is not expected. However, it cannot be ruled out. After cryomodule operations, all material within the enclosure is considered "impacted" per Fermilab's radiological material classification scheme. At removal, it will be surveyed, classified and stored appropriately in compliance with Fermilab's contemporary Radiological Protection Program (RPP) and as prescribed in the Fermilab Radiological Control Manual (FRCM).

IV-2.8. Summary and Conclusion

Specific hazards associated with the operation of CMTS1 are identified and assessed in this chapter of the Fermilab SAD. The designs, controls, and procedures to mitigate hazards specific to operation of the CMTS1 are identified and described. CMTS1 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 CMTS1 operations and the credited controls established to mitigate those hazards demonstrate that the area can be operated in a manner that will produce minimal hazards to the health and safety of Fermilab workers, researchers, members of the public, and the environment.

IV-2.9. References

[1] Fermilab Radiological Control Manual
[2] CMTS Final Shielding Assessment and Addendum, A. Leveling, 2016 and 2019
[3] CMTS Test Cave ODH Analysis, B. Hansen, 2015, Teamcenter #EN02072
[4] CMTF Hi-Bay ODH, J. Dong, 2022, Teamcenter #EN01878
[5] 2016 12 01 Approval of CMTS In-Phase Testing, W. Schmitt, 2016
[6] LCLS-II-HE cryomodule operation at CMTS 030521, W. Schmitt, 2021
[7] LCLS-II-HE 1.3 GHz Cryomodule Performance Requirements and Minimum Acceptance Criteria, D. Gonnella, 2021, Document No. LCLSII-HE-1.2-PP-0255-R0
[8] Operational Parameters for the CMTS1 Cave, B. Russell, 2023

IV-2.10. Appendix – Risk Matrices

Risk Assessment methodology was developed based on the methodology described in DOE-HDBK-1163-2020. Hazards and their potential events are evaluated for likelihood and potential consequence assuming no controls in place, which results in a baseline risk. A baseline risk (i.e., an unmitigated risk) value of III and IV does not require further controls based on the Handbook. Events with a baseline risk value of I or II do require prevention and/or mitigation measures to be established in order to reduce the risk value to an acceptable level of III or IV. Generally, preventive controls are applied prior to a loss event, reflecting a likelihood reduction, and mitigative controls are applied after a loss event, reflecting a consequence reduction. For each control put in place, likelihood or consequence can have a single “bin drop”, resulting in a new residual risk (i.e., a mitigated risk). This risk assessment process is repeated for each hazard for Facility Workers (FW), Co-Located Workers (CLW), Maximally-Exposed Offsite Individual (MOI), and MOI when on a tour. 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 IV-2.4 of this Chapter as well as SAD Chapter VII-A.03 *Accelerator Safety Envelope – CMTS1.*