PROTON IMPROVEMENT PLAN II INTEGRATION TEST (PIP2IT) ACCELERATOR

SECTION VI CHAPTER 03 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 Proton Improvement Plan II Integration Test (PIP2IT) Accelerator 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), the PIP2IT was prepared and reviewed by the staff of the Accelerator Directorate, Accelerator Complex Technology Division, Mechanical Support Department in conjunction with PIP2IT 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.

☐ ____
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
C. Baffes, A. Cravatta, B. Hartsell M. Geelhoed D. Crawford	0	August 10, 2023	• Initial release of the PIP2IT 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
PIP-II IT	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. PIP2IT

IV-2.1. Introduction

This Section VI, Chapter 02 of the Fermi National Accelerator Laboratory (Fermilab) Safety Assessment Document (SAD) covers the PIP2IT test stand within the CMTF Facility

IV-2.1.1 Purpose/Function

The PIP-II Integrated Test Stand (PIP2IT) is a cryomodule test stand, which is configurable to test four different styles of cryomodule for Fermilab's PIP-II project. PIP2IT includes two separate test stands. The 325MHz test stand can be configured to test the SSR1 or SSR2 cryomodule. The 650MHz test stand can be configured to test the LB650 or HB650 cryomodule. At this writing, only the 650MHz test stand is operational. In the future, it will be possible for the 650MHz and 325MHz test stands to operate simultaneously (i.e. for two cryomodules to be tested at a time). 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 2K 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.

IV-2.1.2 Current Status

PIP2IT within the CMTF Facility is currently: **Operational**. At this writing, only the 650MHz test stand is operational. In the future, the 650MHz and 325MHz test stands will be operational simultaneously.

IV-2.1.3 Description

PIP2IT includes two cryomodule test stands, the 325MHz test stand and the 650MHz test stand.

The 325MHz test stand includes:

- A single 325MHz cryomodule, either the 8-cavity SSR1 or 5-cavity SSR2 cryomodule (unit under test)
- Eight 325MHz 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.

The 650MHz test stand includes:

- A single 650MHz cryomodule, either the 4-cavity LB650 or 6-cavity HB650 cryomodule (unit under test)
- Up to six 650MHz 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, instrumentation readbacks and controls meeting the cryomodule's interfaces and allowing operation and validation of cryomodule function and performance.

Both the 325MHz and 650MHz test stands are located within a single enclosure. An enclosure Safety System creates an interlocked exclusion area around the cryomodule(s) under test. The enclosure includes shielding and interlocked radiation detectors to limit radiation outside the enclosure.

The 325MHz and 650MHz test stand are separated by a >1m air gap, and the axes of the two cryomodules are offset from each other. In the case of simultaneous operation, this precludes the possibility of dark current acceleration in multiple cryomodules.

In order for a cryomodule to be brought into PIP2IT, 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.

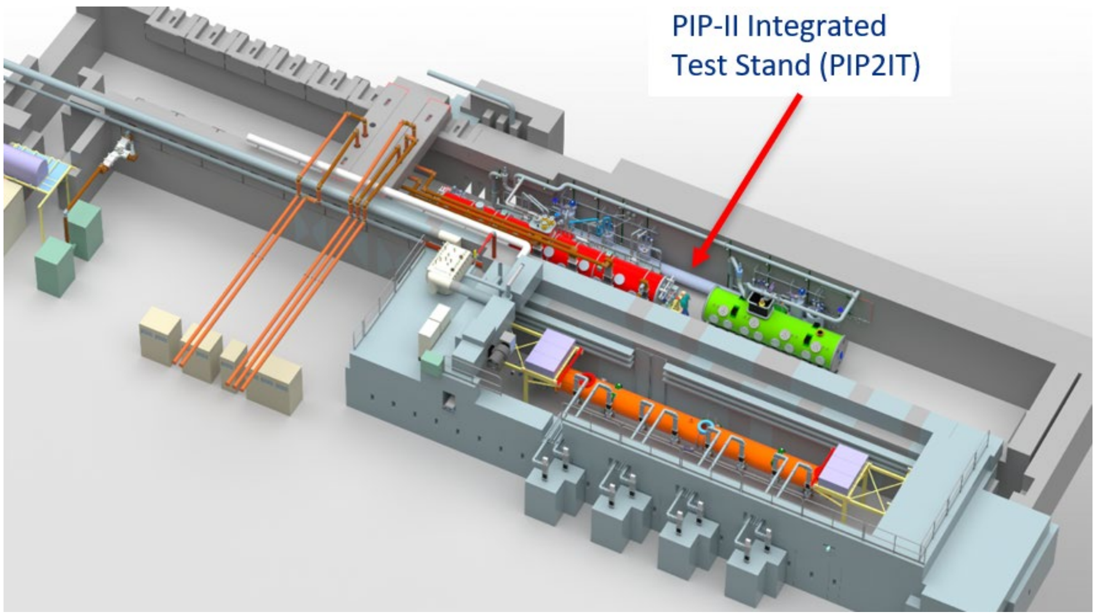

Figure 1. PIP2IT Test Stand within the CMTF Facility

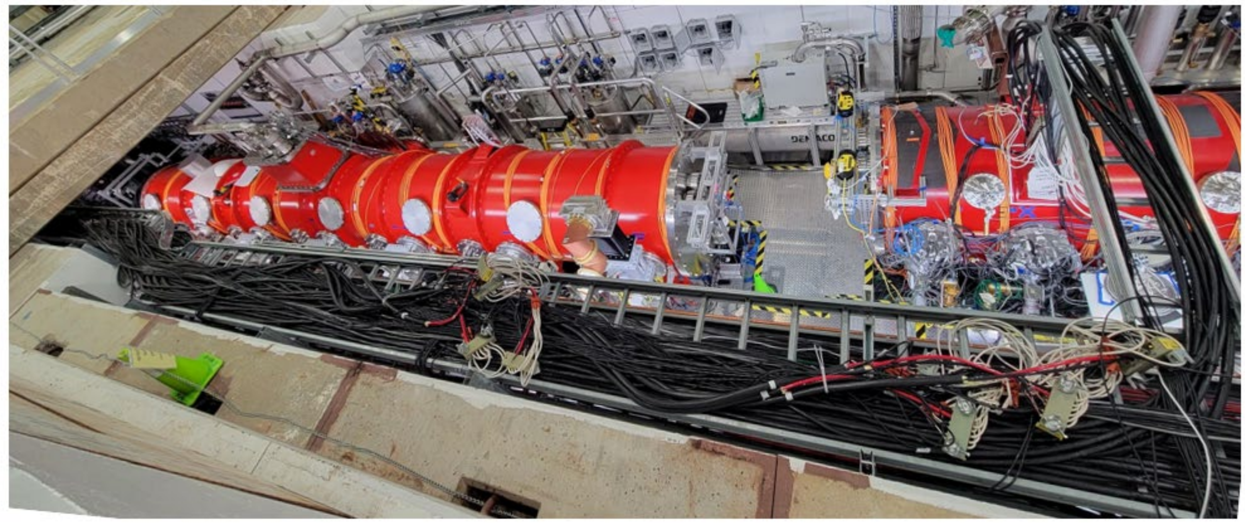

Figure 2. PIP2IT Test Stands, as viewed through a temporarily-opened roof. The 650MHz test stand and HB650 cryomodule are at left. The 325MHz test stand and SSR1 cryomodule are at right

IV-2.1.4 Location

The PIP2IT test stand within the CMTF facility is located on the Fermilab site in Batavia, IL.

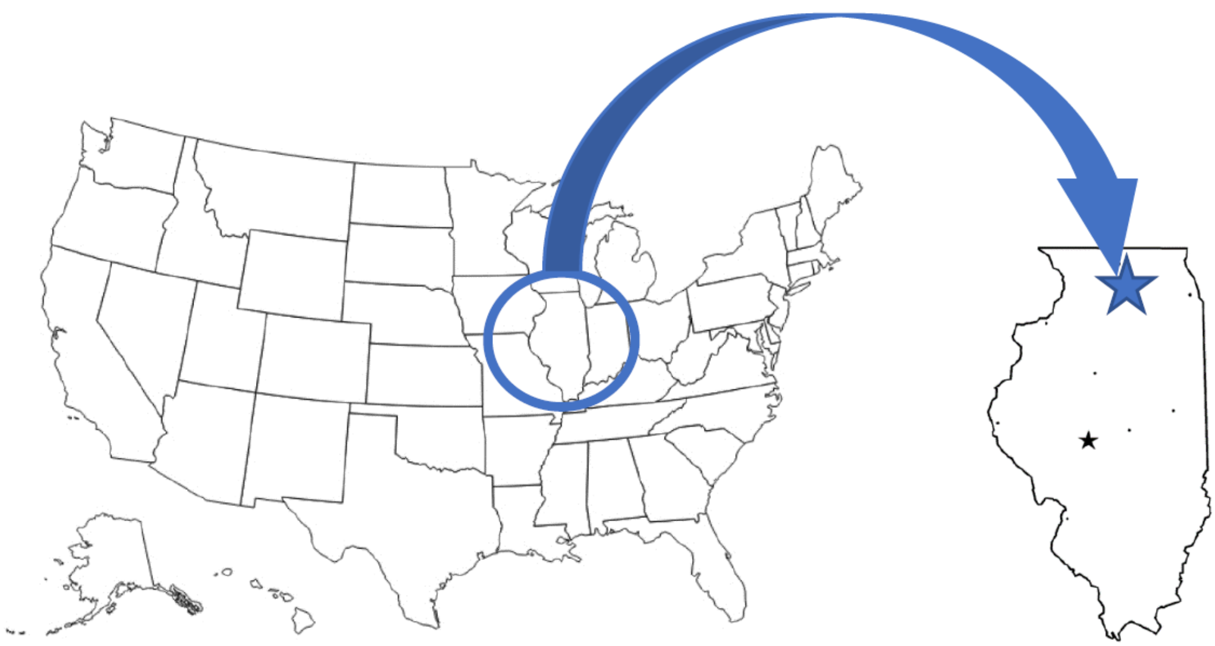

Figure 3. Regional view showing the location of the Fermilab site in Batavia, IL.

PIP2IT is located in the CMTF Building on the Fermilab site.

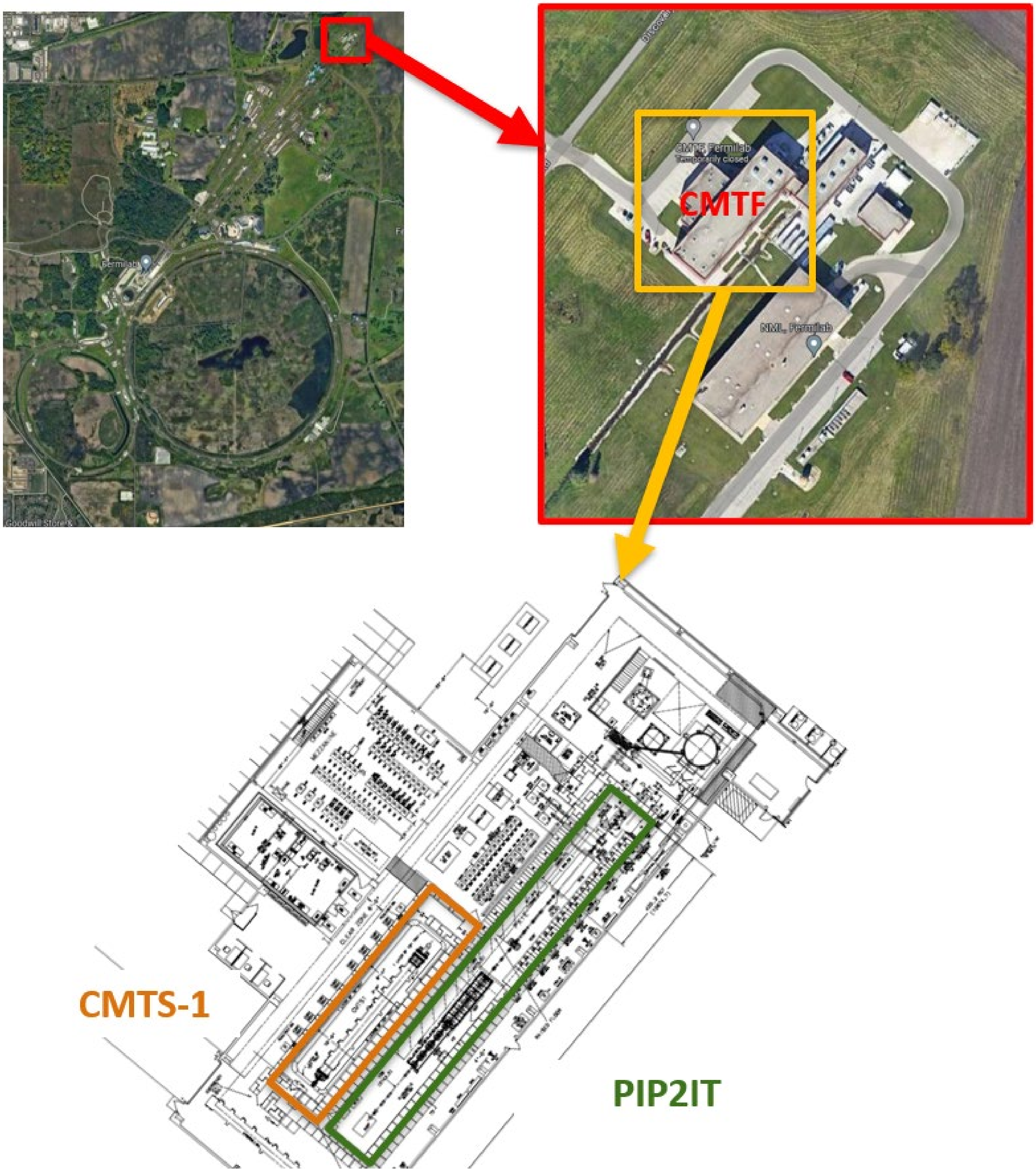

Figure 4. Aerial view of the Fermilab site, indicating the location of PIP2IT.

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.

PIP2IT is managed by the Fermilab PIP-II Project team, with matrixed support from Accelerator Directorate, ES&H and APS-TD staff for PIP2IT systems (e.g. RF system, Cryogenics System, Safety System, etc).

IV-2.1.6 Operating Modes

The operational and non-operational modes of PIP2IT may be described as follows:

- Operational Modes
  - Single-Cavity Testing
    - In this mode, only one cavity is in operation. At this writing, this is the current operational mode of PIP2IT (configured for HB650 single-cavity testing in the 650MHz test stand).
  - Multi-Cavity Testing
    - In this mode, more than one cavity is in operation simultaneously. This mode carries the potential for coherent acceleration of electrons. Note that in PIP2IT, electrons velocity should approach the speed of light, but cavity β is <1. As such, coherent electron acceleration should be minimal.
  - 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. Note that in PIP2IT, electrons velocity should approach the speed of light, but cavity β is <1. As such, coherent electron acceleration should be minimal.
- Non-Operational Modes
  - Controlled Access
    - In this mode, RF is inhibited and the cave is accessible. Interlocks remain made-up
  - Supervised Access
    - In this mode, interlocks are dropped, a radiation survey is performed, and RF is locked out.

IV-2.1.7 Inventory of Hazards

The following table lists all the identified hazards found in the PIP2IT 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 PIP2IT. 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 PIP2IT.

	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 PIP2IT are summarized in this section, with additional details of the analyses for accelerator specific hazards.

IV-2.2.1 Radiological Hazards

PIP2IT 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. A detailed shielding assessment [3] addresses these hazards and provide a detailed analysis of the facility demonstrating the required shielding, controls and interlocks to comply with the Fermilab Radiological Control Manual (FRCM) [1].

IV-2.2.1.1 Prompt Ionizing Radiation

PIP2IT 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 PIP2IT 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 PIP2IT. However, in theory it could occur.

The PIP2IT enclosure may be accessed in either Controlled Access or Supervised Access conditions. In Controlled Access, personnel carry a Log Survey Meter (LSM) to be able to detect any residual activation and proceed in an ALARA manner. In Supervised Access, an enclosure survey is performed by the Radiation Safety organization, and a map is provided. In either case, work within the enclosure is governed by a RWP.

Material within the PIP2IT 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 PIP2IT 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 PIP2IT, as it was not required for RGD Shielding Assessments.

IV-2.2.1.4 Surface Water Activation

Surface water activation was not considered as part of the original shielding assessment for PIP2IT, 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 PIP2IT, as it was not required for RGD Shielding Assessment.

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 PIP2IT 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.

See Risk Matrix tables within SAD Section I Chapter 04.

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

PIP2IT includes RF amplifiers. The amplifiers for PIP2IT operate at 325 MHz and 650 MHz. 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 antennae 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

N/A.

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.

PIP2IT 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. PIP2IT 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

PIP2IT 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.

See Risk Matrix tables within SAD Section I Chapter 04.

IV-2.2.6 Kinetic Energy

IV-2.2.6.1 Power Tools

PIP2IT does not include any extraordinary hazards of this kind. Standard hazards and mitigations apply as described in other chapters of the SAD.

See Risk Matrix tables within SAD Section I Chapter 04.

IV-2.2.6.2 Pumps and Motors

PIP2IT does not include any extraordinary hazards of this kind. Standard hazards and mitigations apply as described in other chapters of the SAD.

See Risk Matrix tables within SAD Section I Chapter 04.

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

See Risk Matrix tables within SAD Section I Chapter 04.

IV-2.2.7.2 Compressed Gasses

PIP2IT does not include any extraordinary hazards of this kind. Standard hazards and mitigations apply as described in other chapters of the SAD.

PIP2IT /CMTF have compressed air systems, a gaseous nitrogen system, and compressed gas from dewars and cylinders.

See Risk Matrix tables within SAD Section I Chapter 04.

IV-2.2.7.3 Vacuum/Pressure Vessels/Piping

Each cryomodule tested in PIP2IT 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 PIP2IT.

See Risk Matrix tables within SAD Section I Chapter 04.

IV-2.2.7.4 Vacuum Pumps

PIP2IT does not include any extraordinary hazards of this kind. Standard hazards and mitigations apply as described in other chapters of the SAD.

PIP2IT /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.

See Risk Matrix tables within SAD Section I Chapter 04.

IV-2.2.7.5 Material Handling

See Risk Matrix tables within SAD Section I Chapter 04.

IV-2.2.8 Magnetic Fields

IV-2.2.8.1 Fringe Fields

See Risk Matrix tables within SAD Section I Chapter 04.

IV-2.2.8.2 Confined Spaces

N/A.

IV-2.2.8.3 Noise

See Risk Matrix tables within SAD Section I Chapter 04.

IV-2.2.8.4 Silica

See Risk Matrix tables within SAD Section I Chapter 04.

IV-2.2.8.5 Ergonomics

See Risk Matrix tables within SAD Section I Chapter 04.

IV-2.2.8.6 Asbestos

N/A.

IV-2.2.8.7 Working at Heights

See Risk Matrix tables within SAD Section I Chapter 04.

IV-2.2.9 Access & Egress

See Risk Matrix tables within SAD Section I Chapter 04.

IV-2.2.9.1 Life Safety Egress

See Risk Matrix tables within SAD Section I Chapter 04.

IV-2.2.10 Environmental

IV-2.2.10.1 Hazard to Air

See Risk Matrix tables within SAD Section I Chapter 04.

IV-2.2.10.2 Hazard to Water

See Risk Matrix tables within SAD Section I Chapter 04.

IV-2.2.10.3 Hazard to Soil

See Risk Matrix tables within SAD Section I Chapter 04.

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 PIP2IT. 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 PIP2IT

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 CMTF due to a business, collaboration, policy, or public engagement need. These persons may enter the CMTF facility or PIP2IT 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 Supervised Access conditions, with the approval of the RSO, and with temporary dosimetry issued by the RSO. By definition, PIP2IT 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 [3]. The as-built shielding was modeled and used as a basis for the final approved shielding assessment. 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 PIP2IT 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 PIP2IT 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 69 penetrations in total, as described in the shielding assessment [3]. These are 6 circular penetrations on the roof, the South Emergency Exit Labyrinth, the North Access/Egress Labyrinth, 4 cryogenic penetrations upstream of the HB650 cryomodule, the southeast cryogenic penetration, and the penetration blocks section, which consists of two rows of shielding blocks containing 28 circular penetrations located on the East and West walls. Radiation simulations for each of the penetrations are documented in the shielding assessment.

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 PIP2IT, many such controls will inhibit the High Power RF (HPRF) amplifiers should off-nominal conditions be encountered. Of most interest in this document, the Safety System will inhibit RF if measured radiation at interlocked detectors exceeds trip limits, or if the enclosure is breached (e.g. by an opened door). In these cases, RF is inhibited, and test stand operators are notified.

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 [3]. 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 PIP2IT key tree, and all radiation detectors are operating normally and below trip limits.

IV-2.4.2.2 ODH Safety System

PIP2IT is classified as an Oxygen Deficiency Hazard Class 1 area [2]. An excerpt from the ODH analysis document describes the mitigations:

> *The PIP2IT cave is 130' long, 15' wide and 10' in height. The ODH system consists of the ODH fan, ODH monitors, interlocks, and switches. The ODH fan is located at the north entrance of the cave at the ceiling and blows fresh air from the CMTF high bay into the cave. The fan specifications are provided in Appendix I. When the cave is closed, the fresh air sweeps through the cave and exits the cave at the emergency exit at the south end of the cave. The north entrance (door and concrete blocks) is enclosed by plastic sheets in order to force air to sweep through the cave instead of escaping from the entrance. A controlled access key used to interlock the beam/radiation sources (from turning on while a person is in the test cave) is used to interlock ODH fan operations. Once this key is pulled out from the controlled access key lockbox, it will turn the ODH fan ON and provide constant ventilation during planned access to the cave. The ODH fan is also interlocked to be turned on in case of an ODH alarm, regardless of the entry status. Three ODH heads are mounted in the cave. Two heads are mounted closer to the Cryomodules to monitor the oxygen concentration. One head is mounted at the entrance of 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. At each end of the cave, there are siren and strobe light. The ODH system uses standard ODH (newer type with blue readout) chassis, heads, horns, and strobes. The chassis has 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 to FIRUS. At 19.5% alarm, the chassis will have Output 1 for Cryo troubleshooting with the message "Contact Emergency Call List (Cryo/ODH) for the building." and Output 2 for Emergency and Fire department dispatch at 18% alarm with the message "ODH - Dispatch Fire Department and Access Emergency Call List (Cryo/ODH) for the building.".*

The ODH fan is tested automatically daily (every 24 hrs, use 168 hrs as fan test period in calculation) by TD-Cryo PLC system. The auto-test system has a flow switch sensor. If the ODH fan is signaled to be turned on but no positive response from the flow switch, the PLC will send an alarm to ACNET (P:CODHPIP2FALM) and this alarm is on the Main Control Room critical alarm list. The Cryo-coordinator will be called for the fan failure. Text messages and emails will be sent to CMTF spokesperson, Cryo-division head, and Cryo-operation head. The Out-of -service procedure will be performed until the fan is repaired. See ED0023898 for more information on PIP2IT cave ODH fan operation. CMTF ODH system test procedure can be found by ED0012656. The 120VAC operating power for the chassis is backed up by UPS and the ODH Fan is backed up by the CMTF generator backup system. The ODH chassis is configured to be failed 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.

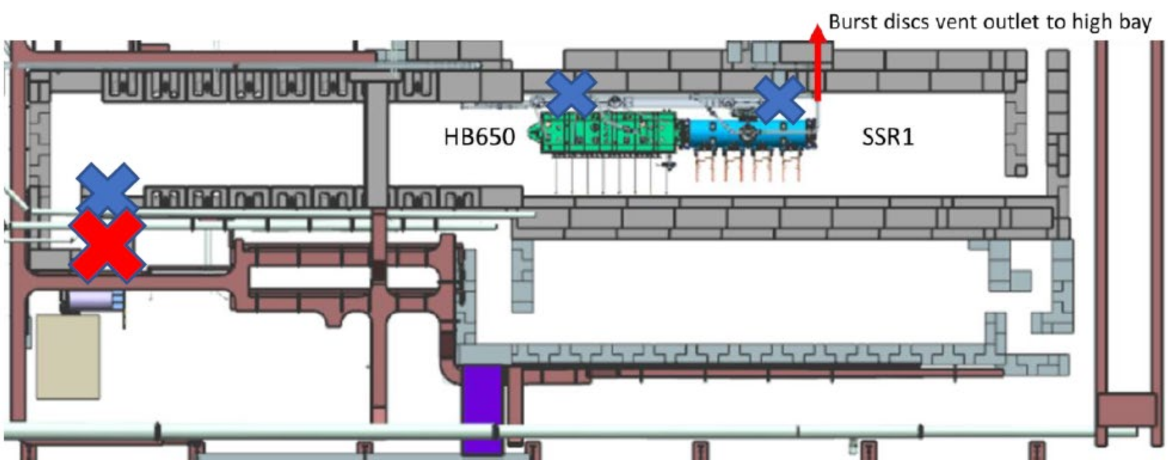

Figure 5. ODH Schematic of PIP2IT. Red X indicates fan location. Blue Xs indicate ODH head location

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

PIP2IT Operation was authorized by the SRSO. Approval documentation is stored with the PIP2IT Shielding Assessment [3].

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.

Authorized PIP2IT staff support Search and Secure, access management, emergency response, and system operational monitoring as required.

IV-2.4.3.3 Accelerator Operating Parameters

PIP2IT Operations parameters are described in the PIP2IT Shielding Assessment [3]. Each cavity is operated up to its acceptance accelerating gradient, typically ~20% greater than the design accelerating gradient given in the table below. Operations limits are expressed in terms of maximum allowable radiation, and enforced by RSO-designated trip limits on interlocked radiation detectors outside the test enclosure. Trip limits are described in [3], chipmunk detectors are configured to trip the beam off at when 0.3mrem/hr is observed in unlimited occupancy areas of the CMTF highbay, and when 5mrem/hr for is observed in the minimal occupancy enclosure roof area. In practice, the operation team uses non-interlocked FOX detectors to understand the radiation field with finer spatial resolution, and control cavity operations parameters below trip limits.

Table 2. Nominal cavity parameters for cavities tested at PIP2IT (SSR1, SSR2, LB650, HB650). Note that acceptance criteria gradients are typically 20% larger than the nominal gradients listed here

	HWR	SSR1	SSR2	LB650	HB650
β_{opt} (β_G for LB650 and HB650)	0.11	0.22	0.47	0.61	0.92
Frequency, MHz	162.5	325	325	650	650
Effective Length, cm	20.7	20.5	43.8	70.4	106.1
Accel Gradient, MV/m	9.7	10.0	11.4	16.9	18.8
E_{peak}, MV/m	44.9	38.4	40.0	40.3	38.9
B_{peak}, mT	48.3	58.1	64.5	74.6	73.1
R/Q, Ω	272	242	297	340	610
G, Ω	48	84	115	193	260
Q_0 @ 2K, $\times 10^{10}$	0.85	0.82	0.82	2.4	3.3

IV-2.5. Defense-in-Depth Controls

N/A.

IV-2.6. Machine Protection Controls

N/A.

IV-2.7. Decommissioning

DOE Field Element Manager approval shall be obtained prior to the start of any decommissioning activities for PIP2IT. 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 PIP2IT are identified and assessed in this chapter of the Fermilab SAD. The designs, controls, and procedures to mitigate hazards specific to operation of the PIP2IT are identified and described. PIP2IT 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 PIP2IT 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] PIP-II IT Cave ODH Analysis, J. Dong, 2022, Teamcenter #EN02827
[3] PIP-II IT Cryomodule Test Stand Shielding Assessment, J.P. Carneiro, 2023, PIP-II Doc DB 6565
[4] CMTF Hi-Bay ODH, J. Dong, 2022, Teamcenter #EN01878

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.04 *Accelerator Safety Envelope – PIP2IT.*