PIP2IT High Energy Beam Transport Hazard Analysis Report

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Document Approval

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Acronyms and Abbreviations

ASE Accelerator Safety Envelope

ANSI American National Standards Institute

ASME American Society of Mechanical Engineers

ASTM American Society for Testing and Materials

CMTF Cryomodule Test Facility

DocDB Document Database

DOE Department of Energy

ES&H Environment, Safety and Health

ESH&Q Environment, Safety, Health and Quality

Fermilab Fermi National Accelerator Laboratory

FESHM Fermilab Environment, Safety and Health Manual

HA Hazard Analysis

HAR Hazard Analysis Report

HEBT High Energy Beam Transport

HWR Half-Wave Resonator

LCW Low Conductivity Water

LOTO Lockout/Tagout

MEBT Medium Energy Beam Transport

NEC National Electrical Code

NFPA National Fire Protection Association

NRTL Nationally Recognized Testing Laboratory

ODH Oxygen Deficiency Hazard

OSHA Occupational Safety and Health Administration

PDR Preliminary Design Report

PIP-II Proton Improvement Plan – II

PIP2IT PIP-II Injector Test

PHAR Preliminary Hazards Analysis Report

PPE Personnel Protective Equipment

RF Radio Frequency

SRF Superconducting Radio-Frequency

SSR1 Single Spoke Resonator Type I

TC Teamcenter

TRS Technical Requirements Specification

WFE Warm Front-End

# Introduction

This High Energy Beam Transport (HEBT) Hazard Analysis Report (HAR) summarizes the risks within the PIP2IT HEBT during assembly and installation of the beam line.

The intent is to assure that hazards are identified and, as much as possible, mitigated prior to assembly and installation. Because the HEBT is merely an extension of the existing beam line at the Cryomodule Test Facility (CMTF), most of the hazards and their mitigations have been previously documented in the “Fermilab PXIE 2.1 MeV Beam – Commissioning, Operations and Safety Analysis” [1], which contains a detailed hazard analysis of the entire PIP2IT facility. At the same time, the Baseline Hazards List (from the PIP-II HAR [2]) was utilized to verify that all potential hazards were being considered.

## PIP-II Injector Test

The PIP-II Injector Test facility (PIP2IT) is an integrated system test of the front-end of the PIP-II superconducting linac. The injector includes a Warm Front-End section (WFE) and 2 superconducting RF cryomodules (Half-Wave Resonator (HWR) and prototype Single-Spoke Resonator Type I (protoSSR1)). The WFE has been extensively studied and has demonstrated that it was capable of delivering a beam with properties consistent with those defined in the Preliminary Design Report (PDR). Meanwhile, the cryomodules’ fabrication is on-going and the PIP2IT cave is being outfitted to receive them. For assessing the cryomodules’ performance with beam, a High Energy Beam Transfer line is needed downstream to measure the properties of the accelerated beam and safely dispose of it into a high-power dump.

## Site

The PIP2IT beam line is located within the PIP2IT enclosure, as depicted on Figure 1.

A picture containing device, screenshot

Description automatically generated

**Figure 1: Plan view of the PIP2IT cave and complete beam line.**

The PIP2IT cave is constructed of concrete shield blocks, with labyrinth entrances at both ends. Both entrances are equipped with interlocked gates (not shown).

## High Energy Beam Transport line

The HEBT design has been developed in accordance with the HEBT Technical Requirements Specification (TRS) document [3] and is a temporary beam line, which will not be part of the PIP‑II linac, although some of the components might be re-used in diagnostics lines at PIP-II. A model of the HEBT is shown on Figure 2. The HEBT includes a pair of transverse focusing elements (quadrupoles), dipole correctors (horizontal/vertical steering), a suite of beam diagnostics and a beam dump. There are several vacuum pumping stations (currently 3, with the possibility of adding another one later on the 4-way cross vacuum chamber) along with a couple of vacuum valves (one ‘slow’ and one “Fast Acting Valve). Beam diagnostics include Beam Position Monitors (BPM), an AC Current Transformer (ACCT), a Time-of-Flight BPM (TOF BPM), a Resistive Wall Current Monitor (RWCM) and a Fast Faraday Cup (FFC). There are a couple of vacuum chambers that may host either wire scanners or a double-slit emittance scanner, or possibly both. Provision is made for the possibility of installing a diamond detector (for beam loss and halo characterization), a laser wire - should a prototype be available - and a Feschenko-style Beam Shape Monitor (BSM). Note that most of the diagnostics, as well as the high-power dump, have been used in the Medium Energy Beam Transport line (MEBT).

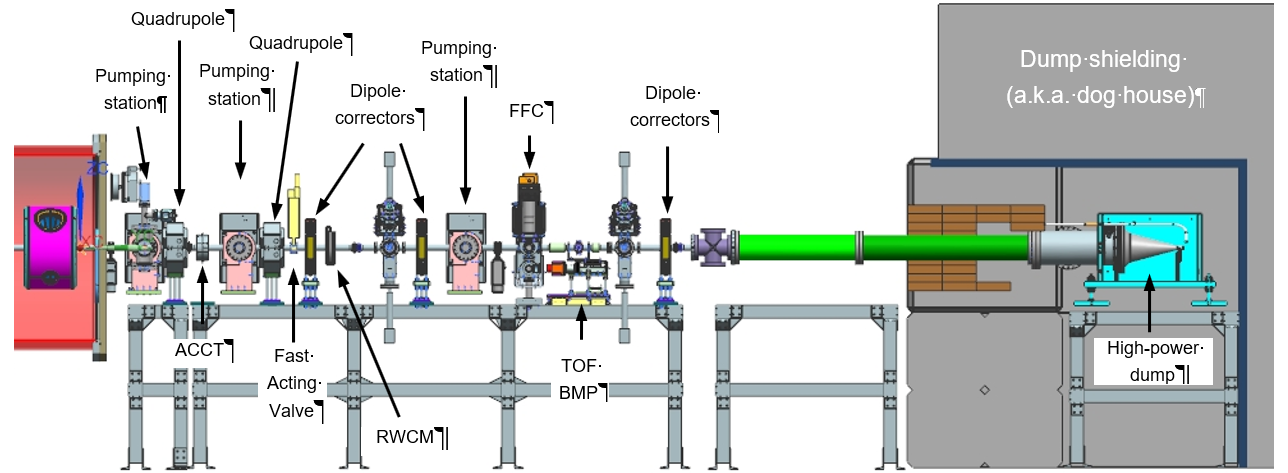


Figure 2: Model of the High Energy Beam Transport Line.

# Hazard Analysis and Risk Assessment

## Introduction

This HAR documents the residual risk after incorporating the proposed mitigations and serves as a checklist for the HEBT design process. The proposed design mitigating factors will be built in as required or appropriate as the design progresses. The following is a synopsis of potential hazards that can be associated with the assembly and installation of the HEBT. The results of these evaluations confirm that the potential risks from the HEBT assembly and installation are acceptable.

It is important to note that for this HAR, beam operation is not considered and that, even with the HEBT components energized, there is no possibility for generating radiation (RF and X-ray included). Hence, in this context, the HEBT hazards under consideration are a subset of those detailed in Ref. [1], which also includes hazards from beam operation at 2.1 MeV. Furthermore, the HEBT is completely within “Zone 1” of Ref. [1] (i.e. the PIP2IT cave), eliminating hazards identified in Ref. [1], which are associated with auxiliary equipment outside of the PIP2IT cave.

## Electrical Hazards (PIP-II HA-6[[1]](#footnote-1))

Electrical systems are found throughout the PIP2IT beamline including the HEBT. High voltages (ion pumps), and magnet power supplies, present hazards if not managed properly. Mitigation of electrical hazards is achieved through engineered controls such as isolation and insulation, combined with policies, procedures and training for work on these systems. Laboratory policy prohibits manipulative work on energized systems without an expressed authorized approval.

The design, upgrade, installation, and operation of electrical equipment will be conducted in compliance with the following:

* National Electrical Code, NFPA 70
* OSHA 29 CFR, Part 1910, Subpart S, Electrical
* FESHM 9000 Series Chapters, Electrical Safety

Also, important to the PIP-II Project is the prevention of electrical faults that could damage equipment or impact operations.

Design criteria and operational controls incorporated to mitigate these risks are given in Section 3. The pre-mitigation risk is categorized as Critical and the post-mitigation risk is categorized as Moderate.

## Cryogenic and Oxygen Deficiency Hazards (PIP-II HA-8)

The HEBT does not contain components that require cryogens or that could lead to ODH conditions. However, it is expected for the cryomodules upstream of the HEBT to be operating “cold” (i.e. with cryogens flowing through their structures) during part of the HEBT installation. Thus, cryogenic and oxygen deficiency hazards will exist. These hazards, corresponding analyses and mitigation are covered in Ref. [4] for the entire PIP2IT cave and are not part of this HAR.

## Beamline Hazards (PIP-II HA-11)

Hazards from the HEBT beamline includes vacuum/pressure, cooling water system, compressed gases, mechanical components (moving instrumentation, valves and actuators), and material handling.

Vacuum and pressure systems are generally safe during operation. However, there are several locations that have ceramic-to-metal seals which pose hazards that include debris from implosion, high voltage, and compressed gas. Sensitive areas of the vacuum system will be clearly identified and or guarded to prevent inadvertent contact and damage.

Cooling water is used to protect beamline components and the high-power dump from overheating. The flow of cooling water to beamline systems will be interlocked to the appropriate power supplies or beam abort systems. Thermal switches will also be interlocked to system power supplies.

Piping and labeling of compressed gas systems will comply with applicable codes.

Electrical equipment and associated power supplies for vacuum pumps, vacuum gauges, detectors, and beam position monitors are integral to the accelerator and beamlines. The electrical hazards for these devices and mitigating controls are described in Section 2.2 Electrical Hazards.

Mechanical hazards posed by rotating machinery such as pumps, blowers, and fans are well recognized. Proper guarding will be designed for these systems. Existing procedures require equipment to be locked out before guards are removed for servicing of the equipment. Pinch points shall be covered or labeled. Assembly pinch points will be addressed during design. Pneumatic actuators shall have the cylinder vented and cycled to its rest state before maintenance. All pneumatic devices shall have local shut-off valves.

Positioning and movement of some of the equipment and components require the use of forklifts, moveable tables, cranes, and specialized lifting equipment. Use of lifting equipment is governed by Fermilab standards and procedures. Rigging operations are performed by properly trained and licensed operators using approved lifting equipment.

Design criteria and operational controls incorporated to mitigate these risks are given in Section 3. The pre-mitigation risk is categorized as Serious and the post-mitigation risk is categorized as Minor.

## Material Handling Hazards (PIP-II HA–15)

The consequences of hazards encountered in material handling include serious injury or death to equipment operators and bystanders, damage to equipment, and interruption of the program. These hazards could be initiated by a dropped or shifted load, equipment failure, improper procedures, or insufficient training/qualification of operators. Lessons learned from DOE and OSHA suggests that the post mitigation risk will remain relatively high even though the probability of occurrence will be reduced through strict operational controls.

The HEBT assembly and installation will demand a significant amount of manual and mechanical material handling. The material/equipment being moved is typically one of a kind, potentially of high dollar or programmatic value, and may not have dedicated lifting points or an obvious center of gravity.

The HEBT design will seek to reduce the amount of manual material handling. For example, a major source of potential injury at research facilities is moving cylinders of compressed or liquified gases. Material receiving, and storage will be located close to the CMTF facility loading/delivery dock. A staging area will be available to break material down into manageable quantities for distribution throughout the PIP2IT facility.

Design criteria and operational controls incorporated to mitigate these risks are given in Section 3. The pre-mitigation risk is categorized as Critical and the post-mitigation risk is categorized as Moderate.

# Risk Assessment Summary Tables

The following tables provide a summary of the hazards, design criteria and operational controls incorporated to mitigate these risks, and pre- and post-mitigation risk categorizations for the hazard categories identified in this HAR.

Risk Assessment Summary for Electrical Hazards

|  |
| --- |
| **HAZARD ANALYSIS** |

SYSTEM: PIP2IT HEBT HAZARD ID: PIP-II – HA- 6   
SUBSYSTEM: Accelerator Systems, Experimental Systems  
HAZARD: Electrical

HAZARD INITIATOR(S): Electrical shock/arc flash from exposed conductors, defective equipment, substandard equipment or improper procedure.

HAZARD CONSEQUENCE: Death, permanent injury, equipment damage.

RISK ASSESSMENT PRIOR TO MITIGATION:

|  |
| --- |
| **Severity**  **1**-Critical  **2**-High  **3**-Medium  **4**-Low  **5**-Minimal |

PROBABILITY  A-Annually  D-Once in thirty years  
  B-Once in two years  E-Less than once in one hundred years  
  C-Once in ten years

|  |
| --- |
| **Risk Assessment Code**  **1**-Critical  **2**-Serious  **3**-Moderate  **4**-Minor  **5**-Negligible |

MITIGATING FACTORS (DESIGN)

* Protect equipment and cables from mechanical and other hazards
* Implement Lockout/Tagout capability into design of energized equipment
* No exposed bus or conductors

MITIGATING FACTORS (OPERATIONAL)

* Engineering and beamline design reviews
* Operation of equipment at <50 volts where feasible
* FESHM procedures for electrical safety
* Electrical safety training
* Manipulative work on exposed energized equipment prohibited without directorate approval

RISK ASSESSMENT FOLLOWING MITIGATION:

|  |
| --- |
| **Severity**  **1**-Critical  **2**-High  **3**-Medium  **4**-Low  **5**-Minimal |

PROBABILITY  A-Annually  D-Once in thirty years  
  B-Once in two years  E-Less than once in one hundred years  
  C-Once in ten years

|  |
| --- |
| **Risk Assessment Code**  **1**-Critical  **2**-Serious  **3**-Moderate  **4**-Minor  **5**-Negligible |

Are any controls (design or operational) required to be incorporated into the ASE? Y  N

**COMMENTS**: Risks associated with work in this area are conventional, and will be comparable to those in other similar above-ground enclosures (e.g. HINS, FAST)

Risk Assessment Summary for Accelerator/Beamline Hazards

|  |
| --- |
| **HAZARD ANALYSIS** |

SYSTEM: PIP2IT HEBT HAZARD ID: PIP-II – HA- 11   
SUBSYSTEM: Accelerator and Beamline Systems  
HAZARD: Catastrophic loss of vacuum, cooling water or compressed air

HAZARD INITIATOR(S): Loss of control of beam due to equipment failure, inadequate or improper procedure, fire, operator error.

HAZARD CONSEQUENCE: Personnel injury, equipment damage or programmatic impact.

RISK ASSESSMENT PRIOR TO MITIGATION:

|  |
| --- |
| **Severity**  **1**-Critical  **2**-High  **3**-Medium  **4**-Low  **5**-Minimal |

PROBABILITY  A-Annually  D-Once in thirty years  
  B-Once in two years  E-Less than once in one hundred years  
  C-Once in ten years

|  |
| --- |
| **Risk Assessment Code**  **1**-Critical  **2**-Serious  **3**-Moderate  **4**-Minor  **5**-Negligible |

MITIGATING FACTORS (DESIGN)

* Engineered systems in place to protect beamline from vacuum, cooling water and compressed air faults
* Vacuum faults cause beamline machine protection systems to close valves thus inhibiting beam
* Elevated magnet temperature sensed by a Klixon will turn off the magnet power supply
* Cooling water temperature, flow and pressure at the dump will be monitored and excess heat or flow interruption will turn off the beam
* Compressed air keeps beam valves open. Loss of compressed air closes valves and the beamline machine protection system inhibits beam as a result

MITIGATING FACTORS (OPERATIONAL)

* Systems design review

RISK ASSESSMENT FOLLOWING MITIGATION:

|  |
| --- |
| **Severity**  **1**-Critical  **2**-High  **3**-Medium  **4**-Low  **5**-Minimal |

PROBABILITY  A-Annually  D-Once in thirty years  
  B-Once in two years  E-Less than once in one hundred years  
  C-Once in ten years

|  |
| --- |
| **Risk Assessment Code**  **1**-Critical  **2**-Serious  **3**-Moderate  **4**-Minor  **5**-Negligible |

Are any controls (design or operational) required to be incorporated into the ASE? Y  N

**COMMENTS**: Risks associated with work in this area are conventional, and will be comparable to those in other similar above-ground enclosures (e.g. HINS, FAST)

Risk Assessment Summary for Material Handling Hazards

|  |
| --- |
| **HAZARD ANALYSIS** |

SYSTEM: PIP2IT HEBT HAZARD ID: PIP-II – HA- 15   
SUBSYSTEM: Accelerator Systems, Experimental Systems  
HAZARD: Material Handling

HAZARD INITIATOR(S): Dropped or shifted load, equipment failure, inadequate or improper use of procedure.

HAZARD CONSEQUENCE: Severe injury or death to equipment operator and bystanders, equipment damage, program interruption.

RISK ASSESSMENT PRIOR TO MITIGATION:

|  |
| --- |
| **Severity**  **1**-Critical  **2**-High  **3**-Medium  **4**-Low  **5**-Minimal |

PROBABILITY  A-Annually  D-Once in thirty years  
  B-Once in two years  E-Less than once in one hundred years  
  C-Once in ten years

|  |
| --- |
| **Risk Assessment Code**  **1**-Critical  **2**-Serious  **3**-Moderate  **4**-Minor  **5**-Negligible |

MITIGATING FACTORS (DESIGN)

* Hoists and attach points designed to ASME/ASTM/ANSI standards
* Adequate aisle space for maneuvering loads
* Barriers
* Steps and discontinuities will be marked with high visibility marking

MITIGATING FACTORS (OPERATIONAL)

* Hoists proof tested after installation and any modification
* Routine inspection and maintenance of all hoists and rigging equipment
* Only trained and qualified personnel allowed to use hoists and forklifts
* Hoists are locked to prevent unauthorized use.
* Pre-use inspection as required by hoist operators to assure proper operating conditions
* Equipment access will be planned and coordinated with other activities

RISK ASSESSMENT FOLLOWING MITIGATION:

|  |
| --- |
| **Severity**  **1**-Critical  **2**-High  **3**-Medium  **4**-Low  **5**-Minimal |

PROBABILITY  A-Annually  D-Once in thirty years  
  B-Once in two years  E-Less than once in one hundred years  
  C-Once in ten years

|  |
| --- |
| **Risk Assessment Code**  **1**-Critical  **2**-Serious  **3**-Moderate  **4**-Minor  **5**-Negligible |

Are any controls (design or operational) required to be incorporated into the ASE? Y  N

**COMMENTS**: Risks associated with work in this area are conventional, and will be comparable to those in other similar above-ground enclosures (e.g. HINS, FAST)

# References

[1] Fermilab PXIE 2.1 MeV Beam – Commissioning, Operations and Safety Analysis,  
PIP-II-doc-40

[2] PIP-II Hazard Analysis Report, PIP-doc-2836

[3] PIP2IT High Energy Beam Transport Technical Requirements Specification, TC# ED0008220

[4] PIP2IT Cave ODH Analysis, TC# EN02529

1. *In parentheses are the PIP-II HA Hazard Identifiers from Ref. [2]* [↑](#footnote-ref-1)