PIP-II Vacuum System

Functional Requirements Specification

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**Document Approval**

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Revision History

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| Revision | Date of Release | Description of Change |
| - | 7-9-2019 | Initial release |
| A | 11-6-2019 | Updated vacuum levels in requirements A002 and A007 to align with PRD. Added new requirements B005 through B014. |
| B | 1-2-2024 | Changed units in Table 6.1 from Torr to mbar to maintain PIP-II consistency. Quantified magnetic permeability in Requirement B005, removed requirement for domestic hardware in B010, included titanium material for studs in B011. |

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# Purpose

An FRS describes the project needs and/or requested behavior of a system or component. The document typically outlines what is needed by the end user as well as the requirements and requested properties of inputs and outputs. The FRS specifies the functions that a system or component must perform and establishes consensus among stakeholders on what the system is expected to provide.

# Scope

This FRS addresses the functional requirements of the vacuum systems for the Warm Front End (including Ion Source), superconducting Linac, Beam Transport Line to the Booster and the Beam Dump. There are vacuum gate valves to isolate each region as necessary for commissioning or operation. Environments adjacent to the Cryomodules must be designed to preclude a significant particle influx in the event of an unexpected loss of vacuum.

The vacuum system shall be designed to minimize the influx of gases due to atmospheric leaks, outgassing from either the vacuum surfaces or the matrix of the vacuum enclosures.

The following schematic highlights each unique vacuum space in the PIP2 Accelerator.

BTL (to Booster)

BAL (to Dump)

UHV, Low Particulate

Transition

HV

WFE

(IS-LEBT-RFQ-MEBT)

SRF LINAC

(HWR, SSR1, SSR2, LB650, HB650)

**Figure 1. PIP-II Vacuum System Regions**

# Acronyms

|  |  |
| --- | --- |
| BAL | Beam Absorber Line |
| BTL | Beam Transfer Line |
| CM | Cryomodule |
| DPI | Differential Pumping Insert |
| EPDM | Engineering Process Document Management |
| FAV | Fast Acting Valve |
| FEM | Fermilab Engineering Manual |
| FESHM | Fermilab ES&H Manual |
| FRCM | Fermilab Radiological Control Manual |
| FRS | Functional Requirements Specification |
| HEBT | High Energy Beam Transport |
| HV | High Vacuum |
| HWR | Half Wave Resonator |
| IS | Ion Source |
| L2 | WBS Level 2 |
| L3 | WBS Level 3 |
| LEBT | Low Energy Beam Transport |
| MEBT | Medium Energy Beam Transport |
| PIP-II | Proton Improvement Plan II Project |
| SRF | Superconducting Radio Frequency |
| RFQ | Radio Frequency Quadrupole |
| TC | Teamcenter |
| UHV | Ultrahigh Vacuum |
| WBS | Work Breakdown Structure |
| WU | Warm insert Unit |

# Reference

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| --- | --- | --- |
| **#** | **Reference** | **Document #** |
| 1 | PIP-II Vacuum Systems Engineering Process Document Management (EPDM) | ED0007863 |
| 2 | [Fermilab Engineering Manual](http://directorate-docdb.fnal.gov/cgi-bin/RetrieveFile?docid=34) (FEM) | - |
| 3 | [Fermilab Environmental Safety and Health Manual](http://eshq.fnal.gov/manuals/feshm/) (FESHM) | - |
| 4 | Fermilab Radiological Control Manual (FRCM) | - |
| 5 | PIP-II Physics Requirement Document | ED0010228 |

# Key Assumptions

None.

# Functional Requirements

**Table 6‑1. Vacuum Level Requirements**

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| --- | --- |
| **Requirement #** | **Requirement Statement** |
| F-121.3.18-A001 | Vacuum shall provide appropriate pumping such that the Ion Source shall achieve a vacuum level of <10-6 mbar at the downstream end of the ion source vacuum chamber. |
| F-121.3.18-A002 | Vacuum shall provide appropriate pumping such that the LEBT shall operate at a vacuum level of <5x10-7 mbar. |
| F-121.3.18-A003 | Vacuum shall provide appropriate pumping such that the RFQ shall operate at a vacuum level of <5x10-7 mbar. |
| F-121.3.18-A004 | Vacuum shall provide appropriate pumping such that the MEBT shall operate at a vacuum level of <5x10-7 mbar. |
| F-121.3.18-A005 | Vacuum shall provide appropriate pumping such that the region of the MEBT between the DPI and the HWR shall operate at a vacuum level of <1x10-9 mbar and shall be particle free. |
| F-121.3.18-A006 | Vacuum shall provide appropriate pumping such that the SRF Linac shall be designed to achieve a vacuum of <5x10-7 mbar range before cool-down at the Ion Pump located in the warm insert unit (WU). |
| F-121.3.18-A007 | Vacuum shall provide appropriate pumping such that the BTL/BAL shall operate at a vacuum level of <5x10-8 mbar, be compatible with the SRF Linac at the upstream end (<10-9 mbar), and the Booster vacuum system at the downstream connection (<5x10-8 mbar). |
| F-121.3.18-A008 | Vacuum shall provide pumping stations to maintain and monitor the insulating vacuum of the CMs with proper protection. |

**Table 6‑2. Vacuum Best Practices Requirements**

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| **Requirement #** | **Requirement Statement** |
| F-121.3.18-B001 | Vacuum shall apply best practices of low particulate vacuum for cleaning vacuum equipment and components near cryomodules. |
| F-121.3.18-B002 | Vacuum shall apply best practices of low particulate vacuum for cleanroom assembling and on-site installing the vacuum equipment and components near cryomodules. |
| F-121.3.18-B003 | Vacuum shall apply best practices of low particulate vacuum for slow pumping /venting vacuum equipment and components near cryomodules. |
| F-121.3.18-B004 | Vacuum shall apply best practices for cleaning all components that share the beam vacuum environment. |
| F-121.3.18-B005 | Plated or coated vacuum components shall not be allowed in areas that require low particulate vacuum. |
| F-121.3.18-B006 | All beam pipes in UHV regions shall be electropolished and hydrogen degassed. |
| F-121.3.18-B007 | In vacuum areas sensitive to magnetic fields and/or radiation, 316L stainless steel components shall be used. |
| F-121.3.18-B008 | In low particulate vacuum regions, standard unplated ConFlat® copper gaskets shall be used with the ConFlat® flanges. |
| F-121.3.18-B009 | For vacuum systems, bolts and studs shall be made of 316L unplated stainless steel. |
| F-121.3.18-B010 | For vacuum systems, nuts shall be made of 651 silicon bronze. Studs for blind holes shall be titanium 6Al-4V. |
| F-121.3.18-B011 | For vacuum systems, nuts, bolts and studs shall be ultrasonically cleaned prior to installation. |
| F-121.3.18-B012 | All-metal valves or valves with radiation resistant elastomer seals shall be used in UHV regions. |
| F-121.3.18-B013 | All devices that are part of the beamline vacuum system shall be certified by vacuum personnel prior to installation into the beamline. |

**Table 6‑3. Segmentation and Instrumentation Requirements**

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| **Requirement #** | **Requirement Statement** |
| F-121.3.18-C001 | Vacuum shall provide proper segmentation to reduce the impact of vacuum failure, or failure in other systems that may impact the vacuum environment in the beamline. |
| F-121.3.18-C002 | Vacuum shall provide instrumentation to monitor the status of the vacuum in every vacuum segment throughout the accelerator during operation and provide appropriate instrumentation to diagnose failures. |
| F-121.3.18-C003 | Vacuum shall provide appropriate instrumentation such that a signal can be provided to Controls and/or Machine Protection and a response can be made in the event of a vacuum failure. |
| F-121.3.18-C004 | Vacuum shall provide instrumentation and FAVs as necessary at each end of the superconducting sections of the accelerator to minimize the risk of particulate migration toward cryomodules in the event of a vacuum failure in warm regions. |

# Safety Requirements

The system shall abide by all Fermilab ES&H (FESHM) and all Fermilab Radiological Control Manual (FRCM) requirements including but not limited to:

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| Pressure and Cryogenic Safety |
| * FESHM Chapter 5031 Pressure Vessels |
| * FESHM Chapter 5031.1 Piping Systems |
| * FESHM Chapter 5031.5 Low Pressure Vessels and Fluid Containment |
| * FESHM Chapter 5031.6 Dressed Niobium SRF Cavity Pressure Safety |
| * FESHM Chapter 5032 Cryogenic System Review |
| * FESHM Chapter 5033 Vacuum Vessel Safety |
| Electrical Safety |
| * FESHM Chapter 9110 Electrical Utilization Equipment Safety |
| * FESHM Chapter 9160 Low Voltage, High Current Power Distribution Systems |
| * FESHM Chapter 9190 Grounding Requirements for Electrical Distribution and Utilization Equipment |
| Radiation Safety ANSI ASC A14.3  -2000  Safety Requirements for Fixed Ladders |
| * FRCM Chapter 8 ALARA Management of Accelerator Radiation Shielding |
| * FRCM Chapter 10 Radiation Safety Interlock Systems |
| * FRCM Chapter 11 Environmental Radiation Monitoring and Control |
| General Safety |
| * FESHM Chapter 2000 Planning for Safe Operations |

Any changes in the applicability or adherence to these standards and requirements require the approval and authorization of the PIP-II Technical Director or designee.

In addition, the following codes and standards in their latest edition shall be applied to the engineering, design, fabrication, assembly and tests of the given system:

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| ASME B31.3 Process Piping ANSI ASC A14.3  -2000  Safety Requirements for Fixed Ladders |
| ASME Boiler and Pressure Vessel Code (BPVC) |
| CGA S-1.3 Pressure Relief Standards |
| NFPA 70 – National Electrical Code |
| IEC Standards for Electrical Components |

In cases where International Codes and Standards are used the system shall follow FESHM Chapter 2110 Ensuring Equivalent Safety Performance when Using International Codes and Standards and requires the approval and authorization of the PIP-II Technical Director or designee.

Additional Safety Requirements that are not listed in the general list above are included in the Requirements table in the Functional Requirements section.