PIP-II Vacuum

Physics Requirement Document (PRD)

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Document Approval

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Revision History

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| Revision | Date of Release | Description of Change |
| - | 10-18-2019 | Initial release |
| A | 10-25-2019 | Changed vacuum pressure requirements in Table 6-1 for the RFQ and MEBT from <1E-7 to <5E-7 Torr. Added SRF, BTL and Linac Installation/Commissioning L2’s and Cryomodule L3’s to the approval list. Updated Section 9 to more clearly state the thresholds for opening and closing the fast acting valves. |
| B | 1-22-2020 | Corrected Table 6-1 to extend the “CF only: metal gasket only” statement in the “Vacuum seals joints” row to also cover MEBT-DS. |
| C | 1-16-2024 | Changed units from Torr to mbar. Updated Table 6-1 and Section 9.1interlock requirements. Section 10: removed domestic hardware requirement, changed SiBr studs to titanium, added magnetic permeability limits, added weld guidance.  |

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# Purpose

Physics Requirement Documents (PRDs) contain the summary parameters and configuration definitions for systems, sub-systems, and devices that impact higher-level requirements established in the PIP-II Global Requirements Document (GRD) [1]. PRDs establish a traceable link to lower-level requirements, i.e., Functional Requirements Specifications (FRSs) and Technical Requirements Specification (TRSs), that affect the PIP-II beam or machine performance. In the aggregate, the PRDs for the PIP-II Project contain the essential parameters and configuration developed through the preliminary design phase to enable completion of the PIP-II accelerator and complex design.

# Scope

This document describes the high-level parameters for the PIP-II vacuum system.

# Acronyms

|  |  |
| --- | --- |
| BAL | Beam Absorber Line |
| BTL | Beam Transfer Line |
| CC | Cold Cathode |
| CG | Convection Gauge |
| CM | Cryomodule |
| CF | ConFlat® Flange |
| FAV | Fast Acting Valve |
| FRS | Functional Requirements Specification |
| GRD | Global Requirements Document |
| HB | High Beta |
| HV | High Vacuum |
| HWR | Half Wave Resonator |
| IG | Ion Gauge |
| L2 | WBS Level 2 System |
| L3 | WBS Level 3 System |
| LB | Low Beta |
| LEBT | Low Energy Beam Transport |
| MEBT | Medium Energy Beam Transport |
| PIP2IT | PIP-II Injector Test |
| PIP-II | Proton Improvement Plan II Project |
| PRD | Physics Requirements Document |
| RFQ | Radio Frequency Quadrupole |
| RGS | Residual Gas Analyzer |
| SRF | Superconducting Radio Frequency |
| SSR | Single Spoke Resonator |
| TC | Thermocouple |
| TRS | Technical Requirements Specification |
| UHV | Ultra-High Vacuum |
| WFE | Warm Front End |

# Overview

This document describes high-level requirements for the vacuum systems for the PIP-II Linac, including the warm front end (WFE) and the beam transfer line (BTL). Operating vacuum pressures are included. The vacuum requirements will be used as input for the vacuum systems design.

The PIP-II linear accelerator has assorted vacuum needs from the Ion Source through the various accelerating stages to the beamline that carries the H- particles to the Booster accelerator including the Beam Dump. The high-level drivers for the vacuum system are its impact on the beam performance (stripping, scattering, residual radiation) as well as the integrity of the superconducting radiofrequency (RF) cryomodules (CM), due to the presence of particulates and accumulation of gases.

The complete PIP-II vacuum system consists of three regions, see Figure 4‑1:



Figure 4‑1. PIP-II Vacuum System Regions

1. WFE, which is composed of the Ion source, Low Energy Beam Transport (LEBT), Radio Frequency Quadrupole (RFQ) and Medium Energy Beam Transport (MEBT).
2. SRF Linac, which is composed of the HWR, SSR1, SSR2, LB650 and HB650 CMs and the warm units in between the CMs.
3. BTL to Booster and beam abort line (BAL).

The first two regions have been prototyped in an experiment referred to here as PIP2IT. As PIP2IT is a prototype of the PIP-II front end, it will be used to validate the design concept and help decrease technical risks. PIP2IT’s vacuum system design philosophy will also be validated and will provide design guidance for PIP-II, especially the quantitative requirement of low particulate vacuum.

The environments adjacent to the CMs must be designed to preclude a significant particle influx in the event of an unexpected loss of vacuum. This is driven by the need to ensure the performance of the CMs over the long run but still be practical and cost effective.

# Basis for the requirements

Based on beam loss due to H- stripping [3], the general residual gas (H2-dominated) upper pressure limits were set to a range of 1x10-2 mbar to 1x10-7 mbar for the WFE and 5x10-8 mbar for the BTL.

However, in the areas adjacent to the CMs, the pressure will be limited to 1x10-7 mbar at room temperature, and 1x10-9 mbar when at 4 K and colder in order to reduce the gas flux entering the CMs and condensing on the surfaces of the SRF cavities, based on the results of a Molflow simulation. The results of this simulation can be found in reference [4].

The cold sections of the SCL are the scope of SRF Cryogenics.

# Residual Vacuum Pressure Requirements for Beam Line Components

The pressures shown in Table 6‑1 should serve as a design goal for the vacuum system. The numbers assume beam operations with cold cryomodules, after initial outgassing and component break-in are complete. The residual pressure without beam should not exceed the specified numbers.

Table 6‑1. Beam vacuum operational requirements.

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | **Ion Source** | **LEBT** | **RFQ** | **MEBT** | **MEBT-DS** | **CMs** | **Warm Units** | **Trans.****Section** | **BTL** |
| Pressure (mbar) | <10-2 | <5x10-7 | <5x10-7 | <5x10-7 | <1x10-9 | <10-10 | <1x10-9 | <1x10-9 | <5x10-8 |
| Leak check sensitivity (mbar-l/s) | 2x10-9 | 2x10-9 | 2x10-9 | 2x10-9 | 2x10-10 | 2x10-10 | 2x10-10 | 2x10-10 | 2x10-10 |
| Vacuum seals/joints | Metal gasket or elastomer, CF or KF | CF only: metal gasket only | Weld or Metal gasket |
| Parts processing | UHV |
| Gauges | Ion gauge | CC gauge | Ion gauge |
| Low particulate practice | No | No | No | No | Yes | Yes | Yes | Yes | No |
| Controllers | Equipped with RS485 to communicate with control system via a PLC |

# Fast Acting Valves (FAV)

The fast acting (closing) valves (FAV) are required at both ends of the SRF Linac in order to reduce the risk of a large amount of gas in-rush into the CM’s during a vacuum incident in the WFE or BTL. Each FAV will have two pressure sensors for redundancy. The closing time shall be within 10 ms after the detection of a vacuum fault. This closing time was determined to be sufficient from a study during a prior PIP2IT run. The results of this study which include a justification for this closing time estimate can be found in reference [5].

There are two competing influences for determination of the location of the FAV:

1) the volume of gas between the FAV and the CM should be held to a minimum, and

2) the FAV will generate particles upon closure and should be located as far away as practical from the CMs.

In order to reduce the risk of a large influx of particles into the particle free region, as well as those particles created during the rapid closing of FAV, the length of unprotected WFE should have the FAV located at about one meter away from the CMs at the end of SRF Linac. The location of the FAV’s is shown in reference [6].

# Particulate free area definitions

## Definition of particulate-free environment and procedures

The definition of “particulate free” means that the level of particles present will be minimized to a level that is reasonably achievable. Particulate-free environment was established by an ultrahigh vacuum (UHV) cleaning process and cleanroom assembly. An ISO 4 (Class 10) cleanroom is required for assembling beam vacuum devices or components. During installation of the vacuum elements into the accelerator, a portable clean room will be used, and clean room practices will be followed in reference [7] to minimize the migration of particulates into the superconducting accelerator beam vacuum region.

## Definition of particulate-free areas in the accelerator

All devices or components that share a common beam vacuum from the upstream transition region in front of HWR (the 1st CM), the entire SRF Linac (including the warm insert units in between CMs, and space-holds of future CMs) and the downstream transition region right after the SRF Linac, demarcate the ‘particle-free’ area.

1. The upstream transition is in the MEBT, at the gate valve adjacent to the differential pumping insert
2. At the downstream end, the plan is to have the particle-free transition at a gate valve just downstream from the 2nd HB650 upgrade slot (i.e., downstream of the quads and of the RF separator slot).

The downstream interface is documented in interface 2662-001, which is an interface between Vacuum, Linac Installation, and BTL, see reference [8].

# Operational interlock (any sensors must meet this specification) requirements

## CM-specific operational vacuum requirements

* CM beam line vacuum requires <5x10-7 mbar prior to the start of cool down
* Vacuum in the adjacent room temperature sections must be >5x10-8 mbar to close the CM gate valve (interlock) and for the CM gate valve permit to be removed
* Vacuum in the adjacent room temperature sections requires a pressure of <2x10-9 mbar to permit reopening of the CM gate valve

## Non-CM beam line operational requirements

* Vacuum in the BTL/BAL requires a pressure of >5x10-7 mbar to close the gate valve (interlock) and a pressure of <2x10-7 mbar to permit reopening of the gate valve
* Vacuum in the WFE, including the bunching cavities and the RFQ, requires a pressure >5x10-6 mbar to close the gate valve (interlock) and a pressure of <2x10-6 mbar to permit reopening of the gate valve

# Component and material vacuum requirements

**Materials** – Materials chosen for vacuum components must not only have a low outgassing rate with no contamination in general, but also must be resistant to radiation and corrosion and have low magnetic permeability, particulate generation, etc. in the specific environment. Plating or coating is not allowed in areas that require low particulate vacuum. Vacuum personnel shall be informed and/or involved in all material related decisions. The PIP-II Cryomodule Design Handbook [9] details approved materials and magnetic hygiene (including the use of materials with low relative magnetic permeability, µr) for the cryomodule beamline.

**Beam pipe** – All beam pipes in UHV regions must be electropolished, and an in-situ bakeout may be required. Beampipes in the SCL additionally need to be hydrogen degassed. 316L stainless steel with µr < 1.05 must be used in areas sensitive to corrosion, magnetic field and/or radiation. Welding should minimize the heat affected zone and use no filler, or filler with low magnetic permeability if it is required.

**Flanges** – ConFlat® (CF) flanges (70⁰ preferred) with µr < 1.05 are required in UHV and preferred in high vacuum (HV).

**Gauges** – Inverted magnetron cold cathode gauges (CC’s), thermocouple gauges (TC’s), ion gauges (IG’s), convection gauges (CG’s), capacitance manometers and residual gas analyzers (RGS’s) are required.

**Hardware** – In the low particulate vacuum regions, standard unplated CF copper gaskets should be used with the CF flanges. They should be ordered individually wrapped and UHV cleaned. Bolts and studs shall be made of 316L unplated stainless steel. Nuts should be 651 silicon bronze. Titanium 6Al-4V or 651 silicon bronze studs should be used for blind holes. Nuts, bolts and studs shall be ultrasonically cleaned prior to installation.

**Valves** – Manual and pneumatic gate valves are installed along the beamline for protection and commissioning purposes. All-metal valves or valves with radiation resistant elastomers are required in UHV regions. Some gate valves, including the FAVs are interlocked as part of machine protection.

**Cleaning** – All vacuum parts for PIP-II shall be UHV cleaned, even the parts for HV regions and bagged properly per procedure for low-particulate UHV cleaning and assembly [6] for parts used in regions which require low particulate vacuum.

**Certification** – All devices that are part of the beamline vacuum shall be certified by vacuum personnel, prior to being installed in the beamline. The certification must verify that the specific device meets the vacuum requirement. The specific procedures and criteria will be defined accordingly.

**Assembly and Installation** – The procedures for assembly and installation are specific to each region.

**Roughing and Venting** – Since there is a risk of particle migration towards a CM, the valve that isolates a CM from its vicinity shall remain closed during the period of roughing down and venting up in the adjacent regions. Turbo cart equipment with flow restrictions (50 mbar-l/s) and proper filtration shall be used for such activities, until the pressure is below 1 mbar. The location of pumping/venting ports should be chosen so that the risk of particle migration towards the CM is minimized.

# Reference Documents

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| **#** | **Reference** | **Document #** |
| 1 | PIP-II Global Requirements Document (GRD) | ED0001222 |
| 2 | PIP-II Preliminary Design Report (PDR) | PIP-II DocDB #2261 |
| 3 | Beam Loss in the Linac PRD | ED0010243 |
| 4 | PIP2IT MEBT DPI-FV design and 1st test results | PIP-II DocDB# 1342-v1 |
| 5 | Vacuum Design of PIP2IT HEBT Design Review | PIP-II DocDB# 4077-v1 |
| 6 | PIP-II Parameters PRD | ED0010216 |
| 7 | Producing Very Low Particulate UHV Components | ED0003571 |
| 8 | PIP-II Master ICD | ED0010433 |
| 9 | PIP-II Cryomodule Design Handbook | ED0011955 |