APS Engineering Standard Vacuum Designs

Prepared by:

Tim Clute, AES-MOM Engineer

Reviewed by:

AES/MED Group Leader

PDRC Chair

CRRT Chair

Approved by:

AES/MOM Vacuum Section Leader

AES/MOM Group Leader

AES/ADD

AES/DD

ASD/DD

XSD/DD

Revisions

Rev	Change	Date	Author of the change
0	New Standard	1 June 2018	Tim Clute
1	Added Beamline Vacuum Requirements, Additions to leak test and certification sections	31 March 2020	Tim Clute
2	Expanded references to include beamline vacuum systems. Section 1.1 and 5.1: Expanded to include more references to beamline components. Section 5.2: Noted that materials other than Beryllium are acceptable for beamline windows.	14 March 2022	Tim Clute
3	Changed section 2.1.3 to update welding standards	22 September 2022	Tim Clute
4	Removed AES Technical Operations Specialist as a reviewer. Added ASD Division Director and XSD Division Director as approvers. Removed APS/Deputy Director, Operations as an approver. Clarified text in 2.1.3. Updated Section 5.	04 March 2025	Tim Clute

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1. Introduction

Maintaining the quality of the accelerator and beamline vacuum system is essential for the reliable and safe operations of the APS.

The scattering of accelerated electrons by residual gases reduces beam lifetimes and increases unwanted bremsstrahlung radiation. To reduce this scattering, essentially all major parts of APS are operated under ultrahigh vacuum conditions. But, even under the best ultrahigh vacuum conditions achievable at APS, where the gas density within the accelerator vacuum systems has typically been reduced by ten trillion times, there are still millions of residual gas molecules per cubic centimeter. Better vacuum helps to maintain a more stable beam intensity, beam size, and beam position. This also applies to the photon beam supplied to the scientific stations, or hutches, were better vacuum maintains the beam intensity and improves the reliability of the experiments.

1.1. Policy

The Mechanical Operations and Maintenance Vacuum Group (MOM-VAC) is responsible for ensuring the integrity of the accelerator vacuum systems, front ends, and relevant sections of the beamlines (as described below). For the purposes of this policy, the accelerator is considered to include the LINAC, PAR, Booster, Storage Ring, and RF Systems. Beamline vacuum standards are also in place to help maintain a high quality and highly reliable vacuum system.

The MOM-VAC Group is responsible for the installation and maintenance of the accelerator and front end vacuum systems. Responsibility for the approval of designs and modifications of the vacuum systems is the responsibility of the PSC Design Review Committee (PDRC) in consultation with the MOM-VAC Group.

New designs or modifications to relevant vacuum systems that do not fully comply with the vacuum standards detailed in this document should be considered for approval in a graded manner by the MOM Group Leader. Relatively minor issues that are likely to meet with consensus agreement can be approved by the MOM Group Leader, with written notification provided in a timely manner to the PDRC Chair to document the noncompliance. Issues that require more discussion should be brought to the PDRC for consideration.

1.2. Scope

This design standard:

1) Provides a brief introduction to the basics of vacuum system design;

2) Establishes vacuum system requirements for accelerator systems and systems that might be integrated with an accelerator vacuum, including beamlines and front ends; and

3) Establishes methods and materials to assist personnel with the specification, design, fabrication and testing of vacuum systems and components.

Note: The mechanical support and cooling for vacuum systems are not in the scope of this document.

2. Vacuum Design Standards

Generally, the APS accelerator and associated systems operate in the ultra-high vacuum (UHV) range, which is defined as having a maximum pressure below 1×10^{-9} torr. Unless otherwise specified, it should be assumed that UHV vacuum compatibility is the standard for all systems described in this document.

Generally, lacking other design considerations, all components should be designed with the expected lifetime of at least 20 years.

2.1. Material Selection

2.1.1. Material Properties

UHV materials must meet certain specifications for use at the APS. Any material that does not meet these standards or is not called out in this document must be reviewed and approved as described in Section 1.1.

UHV materials will be non-porous, with an outgassing rate not to exceed 4×10^{-12} torr*liter/sec*cm^2 (after surface treatments, such as bake-out or plasma cleaning) and a relative magnetic permeability not to exceed 1.05. Generally, components should be able to withstand a maximum temperature of 200°C in order to survive vacuum bake-out procedure. Vacuum surfaces should have a finish not to exceed 63 microinches Ra prior to electropolish and 32 microinches Ra after.

No materials used in manufacturing may contain anything called out as prohibited in section 2.1.3 of this standard.

All vacuum components must come with a mill certification.

2.1.2. Known Acceptable Alloys and Materials

Pre-Approved Materials for use in UHV Systems

Material	Alloy or type
Stainless Steel	304, 304L, 316, 316L (or equivalent)
Aluminum	1100, 1145, 2024, 2219, 3003, 3004, 4032, 5083, 6061, 6063
Copper	Phosphorous Free, oxygen free electronic copper (Cu-OFC), Glidcop, UNS C18150 CuCrZr, UNS C10700 CuAg
Inconel	600, 718, 925
Alumina Ceramic	AL-995 High Density

2.1.3. Incompatible Materials

Due to high vapor pressures and incompatibility with non-evaporable getter (NEG) pumps, materials may contain no more than 0.05% of the following elements of alkali metals, zinc, tin, lead, sulfur, halogen gases, phosphorous and selenium in the APS vacuum system.

The ceramic Macor® is not acceptable for use in accelerator vacuum systems.

2.1.4. Fabrication

Fabrication techniques can have a positive or negative impact on a materials ability to function as part of a UHV system. The following specifications will help achieve this function.

- Use of silicone or sulfur based cutting fluids is strictly prohibited. Use water-soluble sulfur/silicone free cutting fluids like TRIM SOL® or equivalent.
- Machining operations that can cause contaminants to be embedded into the surface like rolling or sandblasting is prohibited. If glass bead blasting is thought to be required, approval from AES-MOM Vacuum group should be requested as described in Section 1.1. Grinding with resin bonded wheels, rouge, emery cloth, crocus cloth or similar abrasives are prohibited.
- The preferred type of weld is an internal weld. If geometry does not allow an internal weld, then a full penetration weld is recommended.
- Welding process to be used, welding process parameters (e.g., Essential and Non-essential variables) and restrictions shall be designated within the SOW or the

component/part drawing. Qualification and certification of the welding specification and welder/welding operator are the responsibility of the supplier.

- The following standards can be used as guidelines for welding:
  Specification for Fusion Welding of Aerospace Applications (AWS D17.1:2017)
  ASME BPVC Section IX (Latest Edition)

- Any joint between vacuum and anything but atmosphere must be brought to the attention of the APS-MOM Vacuum group as described in Section 1.1 and reviewed for possible risk to the APS accelerator. Specifically, vacuum to water joints are not allowed within the APS accelerator vacuum, inclusive of front ends and up to any beamline windows. Downstream of beamline windows can have water to vacuum joints.

2.2. Standard components used at APS

To help ensure reliable operations, recommended standard vacuum components have been identified. These components have proven performance and by standardizing, improve availability and reduce the costs of stocking spares. It is good practice to use standard components whenever practical.

2.2.1. Gauges

Monitoring the gas pressure in a vacuum system is essential to ensuring its performance. The recommended gauge is

Gauge Type	Standard Model
Atmosphere to UHV	Televac 4A Convection gauge used in partnership with a Televac 7FCS Quick Start Cold Cathode gauge These sensors can be paired using a Televac MX200 controller

One of the advantages of this system is for the MX200 to protect the cold cathode from starting at too high of a pressure since this can damage the gauge.

It is recommended that electronics be moved outside the accelerator tunnel when possible to avoid radiation damage.

2.2.2. Pumps

All vacuum systems require some form of pumping to reach and maintain the desired vacuum level. The technologies permitted as primary pumps at the APS are sputter-ion, titanium sublimation, cryogenic, “oil-free” turbomolecular and NEG. When a backing pump is required, it must be “oil-free”. Ion pumps should not be turned on until vacuum is in the 10^{-5} torr range.

Recommended Standard pumps:

Pump Type	**Standard Model**
Mechanical	Pfeiffer ACP Multi-Stage Roots Pump
Turbomolecular	Manufactured by Edwards Vacuum
Ion	Manufactured by Gamma Vacuum
Scroll	Not to be used as part of the accelerator

Since ion pumps are high voltage systems (>5,000 V), it is important to follow these APS procedures when working with them.

Accelerator Ion Pump/Cable/Controller Replacement	APS_1192749
Non-Accelerator Ion Pump/Cable Controller Replacement	APS_1710024

Follow manufacture recommendations when using non-evaporable getter (NEG) pumps. Note that it is harmful to all NEG pumps to vent while the NEG strip is still hot.

2.2.3. Flanges and Bolts

The APS recommends the use of the ConFlat© “knife-edge” style UHV flange to connect vacuum components. Other types of seals are allowed as long as they meet all requirements in this standard, including the leak rate requirement outlined in Section 3.2. Regardless of the type of seal, make sure to follow all manufacturer guidelines.Metal to metal seals are required for all accelerator component flanges.

Bolts should be silver plated to prevent galling and eliminate the need for high temperature thread lubricants (not allowed as part of UHV systems, see above). Vented bolts must be used in the case where a bolt is internal to a vacuum system to prevent a virtual leak.

2.2.4. Valves

Valves used at the APS can be put into two categories: isolation valves and pumpout valves. Isolation valves are used to isolate various sections of the vacuum system from the rest in order to vent for various reasons. Pumpout valves are attached to a section of the system in order to vent and pump back down. Valves being installed into the accelerator must be of the “all metal” variety. All valves must be able to survive a vacuum bake-out as described in Section 4.4 of this standard. Below are the recommended types of valves for various uses.

Valve Type	Standard Model
Isolation (gate) valves - accelerator	VAT Series 482
Isolation (gate) valves - beamline	VAT series 108
Isolation (right angle) - accelerator	VAT series 541
Isolation (right angle) - beamline	VAT series 284

2.2.5. Pneumatic Actuators

Many vacuum components within the APS require mechanical movement. When this is achieved using a pneumatic cylinder several design requirements must considered:

1. The cylinder must be permanently lubricated.
2. The cylinder must fail safe, i.e., if air or signal is lost, the device will close.
3. The cylinder signal will be 24 V DC and will ideally be designed to use AES-MOM standard solenoids.
    a. SMC supplied: VQZ2151S-5M1-C-X532
    b. SMC supplied: VF3143-5D1
4. Preferred vendor is SMC for entire cylinder.

2.2.6. Bellows

Bellows are a necessary part of any vacuum system in order to make up for error build up in assemblies, thermal expansion during bake outs and movement of components like photon shutters. Bellows are split into two distinct groups: formed bellows and welded bellows.

Formed bellows are useful in static situations where minimal thermal growth and no movement is expected. They must be able to withstand 100 cycles of heating from room temperature to 200°C while under vacuum. The bellows should be formed by hydroforming or mechanical forming, not roll forming.

Welded bellows are useful in situations of axial offset and/or when motion is required/expected and must be able to withstand 500,000 actuations from free length to extended length. Extended length should include any lateral offset allowed in the design.

All bellows must be leak tight per UHV leak testing as stated in Section 3.2. The recommended material for all bellows is stainless steel.

2.2.7. Residual Gas Analyzer (RGA)

RGA Type	Standard Model
RGA	Granville Phillips 835 Vacuum Quality Monitor (VQM)

The Granville Phillips 835 VQM is an ion trap RGA with a fast scan time and good reliability in and out of radiation environments. Quadrupole type RGA's are allowed at the APS.

The APS has standardized on an ion trap RGA but quadrupole RGA's are acceptable for use within the APS if necessary. Note that the two have different AMU responses and even different quadrupoles can respond differently. (See JVSTA 26, 1474 (2008) https://doi.org/10.1116/1.2990856.) For example, the quadrupole has a larger dynamic range than the ion trap. Therefore, specifying the quantity of hydrocarbon partial pressures will be different. The ion trap is more accurate in measuring hydrogen because it does not have a start pulse to interfere with the AMU=2 peak.

2.2.8. Requirements for in tunnel cables

Any cable that is going to be within the accelerator tunnel and thus exposed to radiation must be properly shielded according to the following specifications.

Insulation Material:	**Silicone**
Jacket Material:	Silicone
Type Shield and % Coverage:	T.C. braid; 90% over solid conductor
Overall Separator:	Glass Braid
Temperature Rating:	-80° to +150° C

2.2.9. Feedthroughs and Viewports

It is recommended that all feedthroughs and optical viewports be built into detachable flanges for change out in case of failure. They must meet all material requirements and leak rate requirements laid out in this standard.

2.3. Interlock Requirements

All systems associated with the accelerator vacuum will provide, including all beamlines, through EPICS, a vacuum measurement signal for continuous monitoring. This signal will also be available for alarm handling per the settings laid out in Section 2.3.1 of this standard.

A vacuum section is the volume between two gate valves. The interlocks for each gate valve will be based on vacuum pumps, one in each of the vacuum sections separated by that valve. This means that both pumps must read high pressure before a valve will close and both must read low pressure before it can be opened again.

2.3.1. Vacuum Interlock Settings

Current vacuum interlock settings are varied and complex. Any new or upgraded vacuum system installed into the APS will adhere to the following settings:

Pressure	Interlock Action
$<1\times10^{-7}$ torr Maximum in any part of the accelerator systems vacuum	Normal operating vacuum
$\geq1\times10^{-7}$ torr Maximum in any part of the accelerator systems vacuum	EPICS alarm handler display will turn yellow
$\geq10^{-5}$ torr As read on both sides of any Accelerator Valve	Accelerator system gate valves to close. Once the gate valve begins to close, a MPS trip occurs which sends a beam abort signal.
$>10^{-5}$ torr As read on both sides of Storage Ring Valve*	The FE photon shutter 1 closes, followed by the storage ring valve (SRV) closing. If the shutter does not close prior to the gate valve, a MPS trip occurs which sends a beam abort signal.
$>10^{-5}$ torr As read on both sides of Front-End Valve*	The FE photon shutter 2 closes, followed by the front-end valve (FEV) closing. If the shutter does not close prior to the gate valve, a MPS trip occurs which sends a beam abort signal.
$>10^{-5}$ torr As read on both sides of Beamline Isolation Valve*	The FE photon shutter 2 closes, followed by the beamline isolation valve (BIV) to closing. If the shutter does not close prior to the gate valve, a MPS trip occurs which sends a beam abort signal.

*Note that each gate valve involved with the front end must have a photon shutter upstream of it. This will allow for closing off some portion of a front end should an issue occur and allow the rest of the storage ring to function.

3. Certification of UHV Components

When a UHV component is received from a manufacturer for installation in an accelerator system or front end, it must be certified by the AES-MOM vacuum group prior to installation. The part will be processed by the vacuum group before final acceptance of the component is made.

The beamline vacuum must meet the requirements of Section 5 before being integrated with the front-end vacuum. As resources are available, the MOM vacuum group may assist in certifying beamline vacuum components.

APS Vacuum Certification Process:

1. Visual inspection
2. UHV clean
3. UHV leak check
4. Vacuum bake
5. RGA scan with base pressure measurement
6. UHV leak check

Steps in this process can be eliminated by as described in Section 1.1 if the manufacturer has provided a full vacuum certification report and proper transportation of the component.

Note that large numbers of components or assemblies such as bellows or front ends, can be batched cleaned, baked and RGA scanned.

3.1. Visual Inspection

When preparing to install a component or assembly into a UHV system such as the APS it is important to review several important features. The first of which is the sealing surface such as a Conflat® flange knife edge. The knife edge should be free of scratches or dings that might cause the seal to have a leak. This is true of most types of vacuum seals. It is important to note the method of sealing of a component and ensure no damage exists prior to installing. Another important feature of vacuum components are the convolutions of any bellows. Bellows should be free of damage or warping. Any damage to the bellows convolution can eventually lead to failure after an unknown number of cycles. Even bellows that are stationary by design receive heating cycles during operation.

3.2. UHV leak testing

A leak check is considered a pass when no leak is detected using a leak detector with a minimum sensitivity of $2x10^{-10}$ std cc/sec (helium) per leak meter division with a signal to noise ratio greater than one. The leak detector must be checked against calibrated leak before and after testing. In order to be approved a leak check must provide all data as required by the AES-MOM Leak Test Form (APS_1192756).

3.3. UHV cleaning

All components being installed into the APS vacuum must undergo a UHV cleaning procedure approved or performed by the AES-MOM vacuum group. The process used by the AES-MOM Vacuum Group begins with the component submerged in a heated tank with a solution of DI water and a water-soluble detergent. Generally, a 2% solution of Citranox is used on copper alloys and 2% solution of Ridoline-18 is used on stainless steel or aluminum alloys. Check with the AES-MOM group prior to cleaning to determine best solution to use. While circulating the solution, ultrasonic waves may be generated to help in the cleaning process. Certain large components may require a pressure wash prior to cleaning. Once the component is clean, it is dried using dry nitrogen and wrapped in lint free wipes and UHV foil. Components such as bellows require drying in a vacuum oven overnight to eliminate water vapor.

Manufacturers may have different cleaning processes; this is acceptable as long as the component passes a RGA scan as described in section 3.5.

3.4. UHV bake out

For information and guidelines on bakeouts, see APS documents APS_2010143 “Accelerator Vacuum Bake-Out” and APS_1710025 “Non-Accelerator Vacuum Chamber Bake-Out”. For design considerations, temperature bake-out can reach 200°C with a ramp rate of 20°C/hr.

3.5. Residual Gas Analysis and Specification

3.5.1. Specifications

All vacuum component and assemblies for the accelerator vacuum systems must be cleaned and baked before being tested for contamination. The RGA spectrum must be consistent with a contamination-free vacuum with a total pressure no greater than $1x10^{-9}$ torr and provided to the AES-MOM Vacuum Group for review.

AMU Range	Maximum Pressure Allowed
Sum of entire Range	$1x10^{-9}$ torr
Sum of peaks above 44	$5x10^{-11}$ torr
Any single peak above 44	$1x10^{-11}$ torr

The RGA scan of a contamination-free vacuum chamber at room temperature should have no more than the following residual gases:

Suspected gas	Mass peak (AMU)
H_2	2
H_2O	18, 17
CH_4	12, 13, 14, 15, 16
CO	28
N_2	28
CO_2	44

AMU signals from halogen gases (AMU = 19, 35, 37) should be investigated. The AMU signals for O_2 (AMU = 32) or Ar (AMU =40) or the AMU of 14 >12 indicate that there is an air leak or a virtual leak in the component or assembly. An AMU = 36 indicates H_2S contamination. Finally, an AMU = 6 indicates Li contamination.

4. UHV Assembly, Handling and Installation

4.1. UHV Assembly Guidelines

When working on UHV components, the following guidelines should be followed to help maintain the best possible vacuum.

1) Surrounding area should be kept free of welding, machining, or plumbing work.
2) All personnel should wear lint and powder free clean room rated nitrile gloves.
3) Any skin that may come in contact with a UHV surface should be covered.
4) Only tools that have been cleaned should touch a UHV surface.
5) After removing parts, wrap in lint-free cloth and new UHV aluminum foil (meets ASTM B-479, Sections 3.1.4 and 10.3.1).
6) Cap UHV surfaces when not working within the chamber with UHV foil to prevent contamination.
7) It is recommended to purge vacuum chamber with dry nitrogen prior to and during work. Dry nitrogen feed should have a 1 psig bleed valve to prevent over pressure.
8) Before sealing a UHV chamber, check to make sure no tools, assembly jigs, packing material, or other material has been left behind and that the chamber is free of debris, such as solvent wipes, etc.

4.2. UHV Chamber Interior Assembly

Work done on the internal vacuum surfaces of a UHV chamber (e.g., a safety shutter), will be done using degreased tools in a 10,000-level clean room (Federal Standard 209E). Personnel will wear appropriate clean room clothing and lint-free/powder free nylon UHV gloves. Also follow all guidelines laid out in section 5.1.

4.3. Storage

Parts that are being stored for a short time should be blanked off using silver plated hardware and kept in a clean room per section 4.2. Covering UHV surfaces with new oil free aluminum foil is acceptable when not working on a component or assembly.

Parts that are being stored for a long duration should be back filled with dry nitrogen, blanked off using silver plated hardware and then bagged or wrapped in Tyvek® (or equivalent).

4.4. Shipping

Each assembly shipped shall be identified by the purchase order number, assembly number and sequential identity or serial number.

Any moving components on an assembly must be firmly secured for shipment in a manner the precludes damage from motion or vibration.

Assemblies must be secured for shipment in a fashion that protects the assembly from dust, dirt and weather or water damage. The assemblies must be securely fastened, padded, boxed and/or crated for shipment in a suitable manner for prevention of shipment damage to any assembly and its weather/dust protection and ensure their safe delivery to the Laboratory.

UHV chambers shall be shipped to ANL sealed with blank flanges using silver plated hardware, backfilled with dry nitrogen to 0.5 PSIG max pressure. Chamber ports shall be covered in new oil free aluminum foil.

5. Beamline Vacuum Requirements

5.1. Purpose and Scope

The beamline vacuum standards help: 1) reduce the risk to the accelerator and front-end vacuum systems from beamline vacuum systems that are or may be integrated with the front-end vacuum and 2) ensure the quality of the beamline vacuum systems. Some beamlines are equipped with windows to isolate the beamline vacuum from the front end/accelerator vacuum.

This standard establishes requirements for vacuum barriers (windows, differential pumps, and isolation valves), and the beamline minimum vacuum requirements associated with vacuum segments between barriers.

Exceptions to the standard should be requested of the PDRC who will review the request with the MOM Group as appropriate.

5.2. Front End Interface

The front end typically terminates in a beamline first optic enclosure (FOE) a meter or so downstream of the ratchet wall. The front end is under the control of the APS MOM group.

The beamline front end provides the UHV transition from the APS storage ring through the ratchet wall to the portions of the beamline located on the APS Experiment Hall floor. Either a window assembly or a windowless differential pumping system with a beamline isolation valve (BIV) terminates the front end.

For a differential pumping system consisting of two ion pumps, the BIV will be controlled by the front-end equipment protection system (FEEPS). All differentially pumped beamlines are to be equipped with an APS approved residual gas analyzer (RGA) head downstream of the BIV.

It is considered good practice for a beamline designed to have a differentially pumped front end to use a temporary window during the initial stages of beamline commissioning. The use of a temporary window may be waived upon request at the discretion the Commissioning Readiness Review Team (CRRT) chair.

5.3. Beamline Partitions

5.3.1. Beryllium Windows

If a window assembly is used, it will have two 250-µm Be thick windows with the space between the two windows under vacuum maintained by independent pumping, or one 500-µm thick Be window.

Diamond windows of 200- µm thick with an aperture of 10 mm diameter have been approved.

Other materials and configurations are possible but must be designed to withstand 900 torr pressure differential and expected heat loads. Windows must also meet the same vacuum criteria as stated in section 3 of this policy.

5.4. Rules for Beamline Vacuum Design

- Generally, vacuum of <10^{-3} torr is required on beamline side of a front-end window assembly.
  - If for some reason there is a short term need to bring the x-ray beam directly into air immediately downstream of the FE window assembly (e.g., shielding verification), protection for a Beryllium window assembly from ozone must be provided. The duration of this state should be very limited, and it is recommended that it not exceed a total of 24 hours of shutter open time. Approval for this mode of operation should be sought as described in Section 1.
- If the front end is equipped with a differential pump:
  - The beamline must maintain <10^{-7} torr on the beamline side of the differential pump.
  - There must be at least one approved window between the front-end vacuum and any in-vacuum coolant joints, with the explicit exception of LN2 joints (which are allowed).
  - A beamline supplied vacuum reading will be monitored by FEEPS downstream of the BIV in compliance with section 2.3.
  - In order for the BIV to be opened, the AES-MOM Group will review and ensure that the beamline-supplied RGA spectrum meets the requirements given above in this document.
  - Beamlines with a differential pump must adhere to Sections 2 and 4 of this document.
- For beamlines in which white or pink beam will be propagated in atmosphere:
  - A minimum of two x-ray windows are required to isolate the upstream front end/beamline from atmosphere. For Be windows, each window must be at least 250 µm thick. Other window materials require approval as described in Section 1.1.
  - The downstream window must be protected from oxidation. Typically, an additional window (e.g., diamond, Kapton, aluminum, etc.) is added and an inert gas buffer maintained between this window and the downstream most isolation window. The protection scheme must be approved as described in Section 1.1.
  - The window assembly described above should be visually inspected at least every six months by the beamline staff. Any degradation of either isolation window should be reported immediately to the AES MOM Group Leader.

- For beamlines in which the monochromatic beam will be propagated in atmosphere, a single x-ray window is sufficient. For a Be window, the window must be at least 250 µm thick. Other window materials require approval as described in Section 1.1.
- Vacuum conditions in beam transports must be consistent with the shielding requirements. The shielding specifications for transport are generally for evacuated transport. Other non-evacuated conditions, such as He-filled transports, are considered special cases and must be addressed on a case-by-case basis. Any questions on the subject should be referred to the PRSC chair.

5.5. Interlocks and Equipment Protection System

Beamlines that share vacuum with the APS must comply with the interlock's settings stated in section 2.3.1 of this document and with requirements laid out in the rest of this document.

FEEPS is interfaced with the storage-ring EPS and the APS will specify which interlocks are required as part of the beamline EPS system. In case of an accidental break in the beamline vacuum system a vacuum trip will close the front-end shutters and gate valves. This will follow the interlock settings for the accelerator. Note that only authorized AES MOM staff can open any of the front-end valves.

5.6. Beamline Commissioning

Prior to commissioning a windowed beamline, a beamline must receive approval for commencement of commissioning operations from the APS CRRT. As part of this process, it must be demonstrated that all vacuum components are properly installed, all vacuum interlocks are set, and that acceptable vacuum performance has been reached in all relevant sections of the beamline.

During initial operations with white beam, degassing may be a significant issue. Vacuum performance should be closely monitored, and the x-ray power controlled to avoid vacuum trips to the extent possible.

5.7. Requesting the Installation of a Differential Pumping System

Beamlines using a front-end window assembly can be converted to using a differential pumping system, provided the requirements given above are met. Requests for such a conversion should be made to the PDRC and the AES MOM group.

6. FEEDBACK AND IMPROVEMENT

If you are using this document and have comments or suggested improvements for it, please go to the APS Policies and Procedures Comment Form* to submit your input to a

Procedure Administrator. If you are reviewing this document in workflow, your input must be entered in the comment box when you approve or reject the procedure.

Instructions for execution-time modifications to a document can be found in the following document: Field Modification of APS Policy/Procedure (APS_1408152).

* https://www.aps.anl.gov/Document-Central/APS-Policies-and-Procedures-Comment-Form

Appendix A: Vacuum Basic Concepts

Gas Sources

Vacuum leaks occur mostly on joints of vacuum parts. One can use permanent seals or demountable seals to join vacuum parts. Welding is widely used for permanent seals and for joining vacuum tubes to flanges. In the fabrication of permanent seals only those processes that produce non-porous welds, such as GTAW, electron & laser beam, are acceptable on UHV vessels and weldments. Demountable seals are specially designed to eliminate leaks through inclusions in the metal components.

Vacuum leaks through the vacuum vessel may be quite troublesome but they can be easily detected by a leak detector. In some cases, the leak may come from sources inside the vacuum vessel; this kind of leak is called a **virtual leak**. Virtual leaks are more difficult to detect since they are inside the vacuum chamber. A typical example of a virtual-leak source is the trapped air in a blind hole blocked by a screw. When the vacuum chamber is evacuated this trapped air will take a long time to be pumped out because of the very small conductance of the narrow helical crevice. This problem is easily solved by drilling a small venting hole to the trapped area. One should be aware of these problems. Any components to be placed in the vacuum chamber should be properly designed to avoid virtual leaks.

Surface outgassing is the most common problem for the construction of UHV vessels. By definition surface outgassing is the release of gas molecules adsorbed on internal surfaces in the vacuum system. There are several factors that determine the total amount of adsorbed (and desorbed) gases. One major factor is the surface condition. Both physical and chemical adsorption occur on the surface and the amount of gases adsorbed is proportional to the real microscopic surface area, not the geometric area. In general, one should avoid porous materials and make the surface dense and microscopically smooth. One example is machinable tungsten used at the front end of the APS beamlines. The material will be subject to strong bremsstrahlung radiation (radiation emitted by an electron in its collision with the nucleus of an atom). It is crucial to reduce the photon-induced desorption from this material. Ordinary tungsten is too hard to be machined. By using powder metallurgy techniques tungsten can be made machinable or made directly into a specified shape. In the process of powder metallurgy, however, enormous voids and grain boundaries may be created. For ordinary use this is not a concern; for ultrahigh vacuum it is another story. A special manufacturing process and heat treatment have to be used to eliminate voids as much as practical on surfaces of the finished tungsten parts. A significant difference in outgassing between ordinary and specially treated machinable tungsten has been found by the Engineering & Construction Group of APS. For an ordinary piece (~1" x 5" x 8") put in an ultrahigh vacuum chamber (~2500 in3) the vacuum could reach only 1×10^{-8} Torr with a 250°C bake and a 400 l/s ion pump. For the specially treated piece the vacuum reached 2×10^{-10} Torr with only a 150°C bake and a 200-l/s ion pump. The importance of surface conditions of UHV parts cannot be overstated.

Another factor affecting the amount of **adsorbed gases** is the cleanliness of the material used in ultrahigh vacuum and how it is cleaned. Components contaminated with grease, oil, fingerprints etc. will outgas too much for the system to handle and should be thoroughly cleaned before installation. The cleaning process is covered in Section 3.3. Care must be taken never to touch UHV components with bare hands. A single fingerprint can ruin the whole pre-bake and cannot be cleaned afterwards in the in situ bakeout after assembling. On a microscopic scale, a single fingerprint contains many high outgassing compounds, and it contributes to the time and effort required to reach low base pressures.

Under normal conditions adsorbed molecules are released into the vacuum system by thermal agitation. At room temperature this is a very slow process. In situ bakeout is usually necessary to degas the system and thus shorten the time needed to reach an ultimate vacuum. The bakeout process can greatly reduce water content in the vacuum system and hydrogen content in the bulk material. When the system is subjected to synchrotron radiation, more strongly bonded absorbed molecules are released by photon stimulated desorption and give a burst of gas load in the vacuum chamber. The system will clean itself gradually by synchrotron radiation. But the only way one can limit the initial gas load burst and shorten the self-cleaning time is to decrease the total amount of absorbed gases. This can be done by selecting the right materials, cleaning procedures, and vacuum degassing. The bottom line is to ensure a compacted surface and a dense oxide layer as thin as possible. To select the right materials for ultrahigh vacuum use we need to understand two more processes of outgassing, namely, volume outgassing and vaporization. **Volume outgassing** is the release of gases bonded to the surface from chemical and physical absorption from the materials exposed to the vacuum-side surface. There is always some gas content inside a material. For example, gases can be dissolved in a metal during the initial melting and casting. It also helps to vacuum-bake the material before assembly. Vaporization of some material inside the vacuum may also present a vacuum problem.

Vaporization is the thermally stimulated entry of molecules into the vapor phase and obviously it depends on temperature. If the kinetic energy of atoms or molecules bound together which makes up the bulk material is sufficient to overcome the binding energy, then the particles will escape into the gas phase. Since synchrotron radiation can deliver a lot of power and cause the temperature of the radiated area to rise substantially, we need to be aware of vaporization problems. The rate of vaporization depends only on the temperature and nature of the substance; the higher the temperature the higher the equilibrium vapor pressure becomes. The vapor-pressure vs. temperature curves for elements and some other materials can be found in most vacuum books. As a rule, the smaller the binding energy of the substance the higher the vapor pressure at a given temperature. Most plastics have high vapor pressure and should not be left in an ultrahigh vacuum system. Some metals, if their atomic subshells are all full, will have a high vapor pressure. Typical examples are zinc and cadmium. The same rule can be applied to mercury, magnesium, calcium, strontium, barium, etc. Other high vapor-pressure materials include sulfur, phosphorous, lead, selenium, etc. Materials containing these elements should be avoided for vacuum applications.

Appendix B: Vacuum Work Safety

As in any other work, safety issues should be kept in mind in vacuum-related work. Potential hazards include electrical hazards, hazardous materials, radiation, stored energy, vacuum vessels, etc. In order to ensure a safe work environment, several procedures and work control documents (WCD) have been developed for vacuum systems.

WCD Name	WCD #
Accelerator Vacuum System Assembly and Testing	52706
Accelerator Vacuum Chamber Bake-Out	52617
Accelerator Ion Pump/Cable/Controller Replacement	25172
Non-Accelerator Vacuum System Assembly and Testing	56055
Non-Accelerator Vacuum Chamber Bake-Out	52556
Non-Accelerator Ion Pump/Cable Controller Replacement	52704

All tasks performed at the APS should be accompanied by a WCD and preceded by a pre-job briefing with all parties involved to ensure the appropriate scope is understood. The pre-job briefing form can be found on the AES-MOM home page or by following this link.

Appendix C: References

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