Vacuum Handbook

MATERIAL PLASMA EXPOSURE EXPERIMENT

(MPEX)

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Vacuum Handbook
for the
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Change Log

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CONTENTS

1 OVERVIEW

1.1 GENERAL OVERVIEW

The performance of a vacuum system is highly dependent on the design of the vessel, pumping scheme, and components within the system. Therefore, it is essential that all components which form part of or are placed within a vacuum system conform to the design and fabrication standards in this document.

For the purpose of this document, vacuum regimes are defined as follows:

Regime	Range (torr)
Rough	Atmosphere to $1.0x10^{-3}$
High Vacuum (HV)	$1.0x10^{-3}$ to $1.0x10^{-7}$
Ultra High Vacuum (UHV)	$1.0x10^{-7}$ and lower

Following are guidelines for design of components in rough, high, and ultra-high vacuum. As this is not an exhaustive treatment of all aspects of the design process, please contact the Vacuum Systems Team (Section 6) with any questions not covered in this document.

1.2 SCOPE

This handbook covers design, material selection, fabrication, and special cleaning methods required for components intended for use within the vacuum systems of the MPEX. Vacuum acceptance tests for vessels and assemblies are also included. In the context of this document "component" means any of the following:

- a vacuum vessel
- any item forming all or part of the wall of a vacuum system
- any item totally immersed in a vacuum containment device
- material classification, use, and restriction for the MPEX device

1.3 TERMINOLOGY AND DEFINITIONS

Each Vacuum Handbook requirement has a unique and permanent identifier. The interface identifier is indicated at the beginning of the requirement, in square brackets. The convention for requirements identifiers is:

[VH.XXX]

where:

- VH is an abbreviation for Vacuum Handbook so as to distinguish from system requirements
- XXX is the sequential number for the requirement

Requirements are specified as follows:

[identifier] This is an example interface [ref1] [ref2] [ref3]

Where [identifier] is assigned as noted earlier in this chapter and [ref] may be a Project Requirement, Standard, drawing, schematic, or other reference that informs the interface.

Removed interfaces shall be designed with a strike through in the first revision after removal then completely removed in subsequent versions. The number shall not be re-used.

2 VACUUM DESIGN

2.1 VACUUM DESIGN CONSIDERATIONS

In order to design a component for vacuum service, there are several details that should be addressed:

- Material Selection and Finish
- Determination of conductance and pumping speed requirements based upon gas loads
- Use of standard equipment including flanges, hardware, seals/gaskets, pumps, gauges, valves
- Proper joint construction and weld design
- Proper seal selection and seal design

The MPEX project has other functional design considerations for components in vacuum service

- Interaction with the plasma beam
- Interaction with magnetic field lines.
- Interaction with microwaves
- Lithium and other alkali metals may be used in experiments on MPEX
- Vacuum bake out conditions
- Handling of irradiated or activated materials

2.2 PERMITTED MATERIALS FOR MPEX VACUUM SYSTEMS

There are limitations on the materials which are allowed inside the space of a vacuum system or create the vacuum boundary on MPEX. Furthermore, there are limitations on materials that interact with the plasma, are near the plasma, are within the influence of the MPEX magnetic fields, are in UHV/HV environments, are in rough vacuum environments, or are in contact with the demineralized cooling water.

Using the correct materials is critical to the proper function of MPEX. The MPEX materials list has been created as a guideline to assist in the correct choice of materials to meet the scientific requirements of the facility.

MPEX materials are classified for use using the following classes:

Class 1 – Plasma Interacting - materials that interact directly with the plasma during operation (High flux components)

Class 2 – Near Plasma – materials that may, but generally do not directly interact with the plasma (low flux components)

Class 3 – UHV/HV/Plasma Facing – materials that are in UHV or HV but do not interact with the plasma (shadowed/shielded from plasma)

Class 4 – Rough vacuum – materials that are used in the rough vacuum system

Class 5 – Atmosphere – materials used outside of the vacuum systems

Class 6 – Wetted Demin – components with wetted surfaces in the Demineralized Water loops

Class 7 – Magnetic Field Sensitive - components used inside the influence of the magnetic field lines

Materials are approved, restricted, or prohibited for each class and category using the following qualification system.

★ Material approved for usage

◆ Material restricted to specific use; program approval required

⦸ Material prohibited from use

Blank To be evaluated, material has not been evaluated for use in the classification

Components may fall under the limitations for use of multiple classes. For example, vacuum chambers inside of the magnets, and are water cooled fall under Class 3, 6, and 7 limitations. Material selection must be compatible with the limitations of all classes the component falls under.

Restricted materials are application specific. Contact the MPEX Vacuum Systems Team for approval of specific uses. The Vacuum Systems Team (Section 6) will review the material for vacuum compatibility and escalate to review with program science compatibility as needed.

Many materials are approved for certain classes but may not meet the temperature or other functional requirements of a specific use. Material selection must take all application specific requirements and environmental conditions into consideration.

Materials not shown on this list are not approved for use in the MPEX vacuum system. If a material is not on the list is needed, contact the MPEX Vacuum Systems Team. The Vacuum Systems team will review for vacuum compatibility and escalate the material to the science team as necessary for approved, restricted use, or prohibited status.

The MPEX material list is located in Appendix 1. If a material needs to be used that is not on the approved materials list or if there are any concerns as to whether a material is suitable for a particular use contact the MPEX Vacuum Systems Team (Section 6) for approval of specific uses. The Vacuum Systems Team will review for vacuum compatibility and escalate to review for program science compatibility as needed.

2.3 PROHIBITED MATERIALS FOR MPEX VACUUM SYSTEMS

In general, any material containing volatile organic compounds (VOC) should not be used in vacuum. Materials with high porosity or outgassing should not be used in vacuum.

1. The following materials that are not specifically formulated for HV/UHV applications shall not be used in vacuum or come in to contact with vacuum components in the form of jigs, fixtures, tools, packing etc.:
    - Copper-Zinc alloyed Brass
    - Soft Solder, Standard Hard Solder, or Electrical Solder and fluxes
    - Plastics (see materials list for acceptable plastic applications)
    - Glues, epoxies, and adhesives
    - Grease, oils, and other lubricants
    - Do not use silicon or sulfur based machining lubricants when machining any components (Use water soluble machining lubricants only)
    - GE Varnish
    - Anodized surfaces
    - Any material containing:
        - Zinc, Cadmium, Phosphorus, Sodium, Selenium, Potassium or Magnesium
    - Dirt and other contaminants

There are some vacuum compatible plastics, however the use of plastics should be limited and needs to be approved for specific use. Vacuum compatible plastics are listed with a restricted status in the materials list.

See Appendix 1 for specific material approvals, restrictions, and prohibitions.

If a material needs to be used that is not on the approved materials list, or is listed as prohibited but required by design, contact the MPEX Vacuum Systems Team (Section 6).

2.4 MAGNETIC FIELD MATERIAL RESTRICTIONS

The MPEX device uses precise magnetic fields to control the plasma. Materials that are magnetically permeable can alter the field and change the uniformity of the magnetic field lines that control the plasma.

[VH.001] Materials with a relative permeability that is greater than 1.03 at 200 Oersteds shall not be used within the cryostat and the vacuum chamber without formal project approval.

- NOTE: 304 SST (and several other 300 series alloys) does not meet the MPEX permeability spec in the work hardened form [4]. If 304 SST is to be used inside the influence of the MPEX magnet fields, it must be solution annealed after coldwork and verified that it meets the MPEX magnetic permeability specification. This includes fasteners and hardware. Cold worked 316 SST meets the MPEX magnetic permeability specification and is the preferred alternative to 304 SST

- NOTE: Attention must be paid to selecting the correct alloys of materials. For example, certain alloys of Tungsten are magnetic, and others are not. Sintered Tungsten alloys that use iron and nickel as a binding agent are magnetic. Non-magnetic alloys use copper and nickel as binding agents. Both materials fall under the same AMS-T-21014 classifications.

2.5 BAKE-OUT REQUIREMENTS

The main vacuum chamber needs to be vacuum baked during initial pump down from atmosphere to assure a clean vacuum environment. This will be achieved by recirculating heated water through the water jacketed vacuum chambers to bake the main vacuum chamber while the system is pumped down. The water may be up to 150C, at a low flow rate, with a minimum pressure of 55 PSI to abate boiling, and up to 90 PSI to give enough working pressure for flow. Components attached to the main vacuum chamber, or in vessel components (IVC) must meet the following requirements:

[VH.002] The main vacuum vessel and PMI chamber shall be capable of being baked to 150°C. [PR191-R]

[VH.003] The TEC shall be able to be baked to 150°C. [PR192-R]

[VH.004] The in-vessel high-heat-flux components shall be able to be baked to a minimum of 150°C. [PR193-R]

[VH.005] The capability for baking shall be provided while the superconducting magnets are at any temperature between 5 K and 293 K. [PR194-R]

[VH.006] The main vacuum vessel, PMI chamber, TEC, and in-vessel components shall be capable of being raised from ambient 20°C temperature to the baking temperature with 24 hours.

[PR195-R]

[VH.007] Following baking, the main vacuum vessel, PMI chamber, TEC, and in-vessel components shall be capable of being returned to ambient 20°C temperature within 12 hours.

[PR196-R]

[VH.008] The rate of change of the temperature of the main vacuum vessel, the PMI chamber, TEC, and in-vessel components shall not be greater than 15 K/hr during warm-up and -15 K/hr during cooldown, considering thermal stresses. [PR197-R]

[VH.009] All MPEX systems shall be designed to accommodate 100 baking cycles from the commissioning phase to the end of life of MPEX. [PR198-R]

2.6 MICROWAVE CONSIDERATIONS

Because of the microwave power that will be used for electron heating in MPEX, components in vacuum must be designed to account for possible stray radiation. Microwave absorptivity is low for permitted metals, and special care will not be required.

Design requirements for materials in the presence of microwaves are:

[VH.010] Non-metals should be shielded from microwave power with metallic shielding with gaps no larger than 1.3mm (0.051 inch).

[VH.011] Any port leading to sensitive components (such as windows and vacuum pumps) must include a screen or other mitigation technology to cut-off microwave power, also with gaps no larger than 1.3mm (0.051 inch).

[VH.012] Any exceptions must be made with the approval of the lead engineer in consultation with the microwave SME.

2.7 VACUUM COATINGS AND FINISHES

In general, no coatings or finishes are required for any vacuum vessel. However, in cases where a coating or finish is required, please contact the MPEX Vacuum Systems Team (Section 6) for recommendations. Some approved coatings for use in vacuum are included in Appendix 1.

Surface finishes can affect vacuum performance. Rough surfaces have more surface area where contaminants and hydroxyl layers can form affecting pump down time and ultimate vacuum pressure of the system. Smooth surface finishes are desirable.

[VH.013] Internal vacuum surfaces shall have a maximum surface roughness of 32 micro-inch Ra. Exceptions to this requirement must be approved in advance by the MPEX Vacuum Systems Team (Section 6).

[VH.014] All stainless-steel vacuum vessels and components in vacuum should be electropolished per ASTM B912 02 Passivation of Stainless Steels Using Electropolishing. Exceptions should be reviewed with the MPEX Vacuum Systems Team (Section 6).

2.8 CONDUCTANCE AND PUMPING SPEED REQUIREMENTS

Gas loads stem from multiple sources, all of which are independent of pumping speed. When designing a vacuum system or component, proper attention must be given to the pressure requirements and expected gas loads in order to determine what conductance and pumping speeds will be required. Overlooking the importance of these items could result in a vacuum system whose original design is ineffective and potentially irreversible.

Please direct questions regarding pumping speeds, pressures, and conductance to the MPEX Vacuum Systems Team (Section 6), which has the tools and expertise to ensure a successful design.

2.9 FABRICATION CONSIDERATIONS

Proper vacuum fabrication requires more detail to cleanliness than does typical fabrication performed in most standard machine shops. Grease, grit, grime, fingerprints, etc. can lead to leaky vessels or hamper the ability of vacuum pumps to work effectively. The single most effective way of ensuring that proper vacuum fabrication practices are done is to use shops that primarily focus on vacuum fabrication. Please consult with the MPEX Vacuum Systems Team (Section 6) for guidance on external fabrication vendors.

Moreover, the best practice for insuring quality construction of a vacuum vessel or component is to have it physically separated from the environment where tasks are being performed on other materials (carbon steel) where the shavings and dust can contaminate weld prep areas causing micro-inclusions that can lead to leaks.

The surface finishes of vacuum chamber walls and components contribute to the ability to adequately clean those components, as well as the ability to pump the vacuum system down to the desired pressure. Stainless steel components can be electropolished to achieve higher quality surface finishes than conventional manufacturing processes. Refer to section 2.7 for surface finish requirements.

Abrasive techniques to clean or attempt to improve the appearance of the surfaces of vacuum components must be kept to an absolute minimum and preferably avoided. The use of grinding wheels, wire brushes, files, harsh abrasives, sand, shot or dry bead blasting, polishing pastes and the like is prohibited under normal circumstances.

Preferred techniques are slurry blasting with alumina or glass beads in a water jet; gentle hand use of a dry fine stone or a fine stone lubricated with IPA, ethanol or alcohol and hand polishing with fine mesh alumina or silicon carbide in an IPA or ethanol carrier on a lint free cloth; hand polishing with Scotch-Brite (Alumina loaded, Grade A).

2.10 WELDING

Dirt, oil and other contaminates in the vicinity of the weld prep area will lead to inclusions in the weld and outgassing under vacuum. Therefore, ALL welded components MUST be cleaned to vacuum standards, using the appropriate method described in section 4, BEFORE being welded together.

Welding materials with a relative permeability that is greater than 1.03 should not be used within the cryostat and the vacuum chamber without formal project approval.

Although weld burns may be removed by using acid pastes; in general, such burns do not affect vacuum performance and are best left alone. Any scaling must be removed using the techniques outlined in the section 4 regarding cleaning below. If it is desired to remove burns, then slurry blasting with alumina in water or hand burnishing with alumina powder is a satisfactory alternative. Hand finishing with Scotch-Brite or a dry stone is also permissible. **Heavy abrading, grinding or wire brushing on surfaces exposed to vacuum is prohibited**.

To avoid the potential for creation of trapped volumes which could adversely affect vacuum performance, vacuum components must be fabricated using weld joint designs which involve single pass, full penetration welds or internal seal welds with external partial penetration or fillet skip welds to ensure adequate structural strength while allowing for effective leak testing. See figure 2.1 for the appropriate vacuum weld types and drawing callouts.

The use of internal seal welds with external skip welds is not directly addressed by ASME Section VIII, Division 1, but may be accepted if the design has been demonstrated by an engineering analysis to be capable of withstanding the anticipated loads under the provisions of paragraph U-2(g). The use of multiple pass full penetration welds which potentially contain voids or inclusions capable of becoming trapped volumes must be avoided. For more specific guidance regarding welding for vacuum systems, please consult the MPEX Vacuum Systems Team (Section 6).

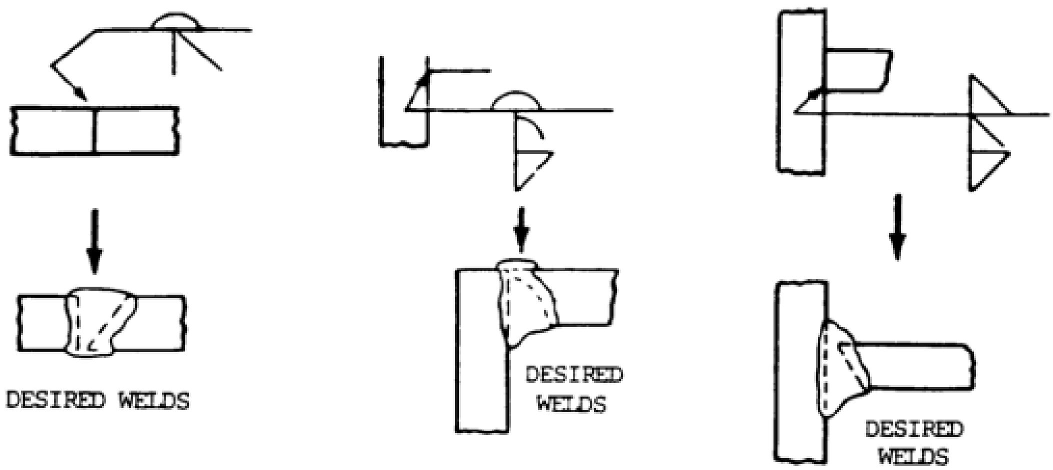


Figure 2.1 – Internal Seal Welds

2.11 SEAL DESIGN

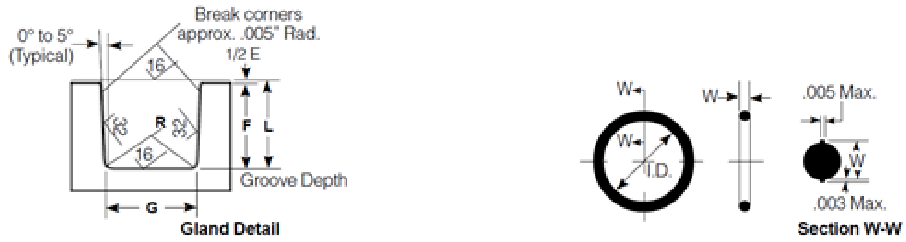
Depending upon the desired pressure within a vacuum vessel among other considerations, a variety of sealing techniques are possible. However, special attention must be made between the selection of rough, High Vacuum (HV), and Ultra High Vacuum (UHV) seals.

2.11.1 Elastomer Seals

Elastomer seals are most often used in rough and HV vacuum applications (Atmosphere to 1.0x10-7 Torr) but are forbidden on UHV applications. Viton ® is the MPEX material choice for elastomer seals. It has a temperature range of -20C to 205C (230C for short durations). Viton® elastomer seals should only be used in applications that fall within the temperature ratings noted. If a different material is required, it must be approved for the specific use by the MPEX Vacuum Systems Team (Section 6).

Please note that in areas of high temperature and/or elevated radiation that elastomer seals may not be the most suitable seal because of reduced life and/or complexity of replacement.

The MPEX Vacuum Systems Team highly recommends the use of standard flanges, rather than designing custom flanges and seals. However, if a custom flange must be made, please refer to the Parker Handbook (5705A) [1] on elastomer o-ring seal design. Figure .2 is a chart detailing gland design for static vacuum o-ring seals (taken from Parker 5705A O-Ring Vacuum Sealing Handbook, Chart IV, page 9). Furthermore, the o-ring groove itself should be vented on both the vacuum and atmosphere sides to eliminate trapped volumes of gas as well as facilitate leak testing. A surface finish of 16 micro-inches or better is recommended.



Design Chart IV For O-Ring Static Vacuum Seal Glands

O-Ring Size AS568A-	W Cross Section Nominal	W Cross Section Actual	L Gland Depth	Squeeze Actual	Squeeze %	E Diametral Clearance	G Groove Width	R Groove Radius	MAX. *Eccentricity
004 through 050	1/16	.070 ±.003	.050 to .052	.015 to .023	22 to 32	.002 to .005	.093 to .098	.005 to .015	.002
102 through 178	3/32	.103 ±.003	.081 to .083	.017 to .025	17 to 24	.002 to .005	.140 to .145	.005 to .015	.002
201 through 284	1/8	.139 ±.004	.111 to .113	.022 to .032	16 to 23	.003 to .006	.187 to .192	.010 to .025	.003
309 through 395	3/16	.210 ±.005	.170 to .173	.032 to .045	15 to 21	.003 to .006	.281 to .286	.020 to .035	.004
425 through 475	1/4	.275 ±.006	.226 to .229	.040 to .055	15 to 20	.004 to .007	.375 to .380	.020 to .035	.005

Figure 2.2 – Gland design for static vacuum o-ring seals [1]

2.11.2 O-Ring Vent Grooves

The purpose of an o-ring vent groove is to provide means for leak checking and/or venting trapped gas from a trapped volume. Vent grooves are required when an o-ring is used to isolate vacuum or gas(s). Vent grooves would not be required on the side of the o-ring that is isolating a liquid – shown below in Figure 2.3.

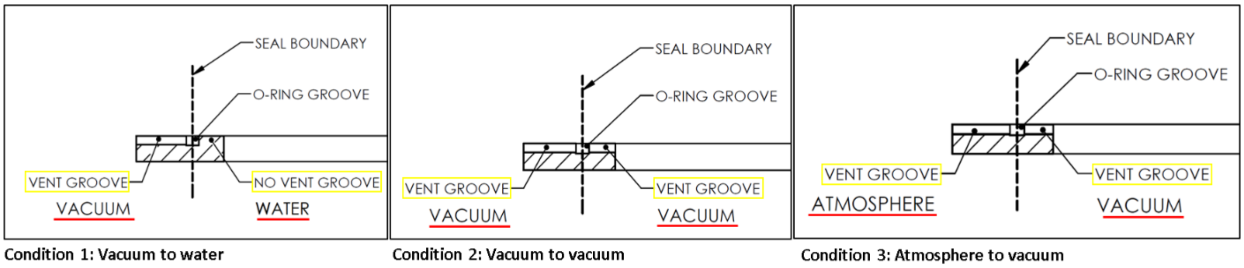


Figure 2.3 – Vent grooves

- Reference "ORD 5700 Parker O-Ring Handbook" [1] for gland/groove design.
- Width of the vent groove are ½ times the o-ring diameter
- The depth of a vent groove should be 90-95% the depth of the o-ring groove

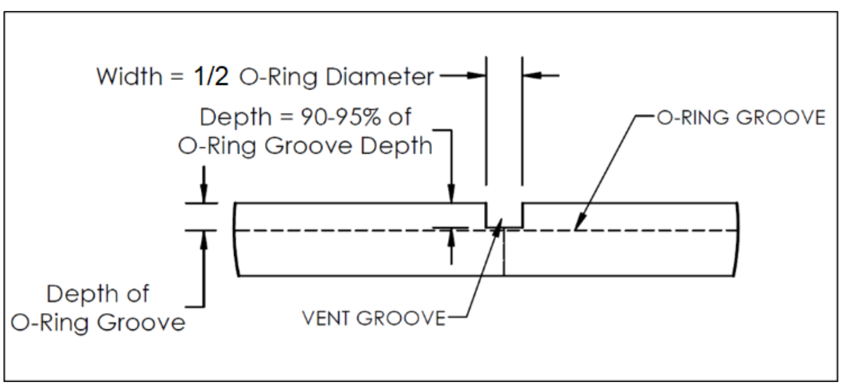


Figure 2.4 – O-ring groove with vent groove

The following specifies the minimum recommended quantity of vent grooves for circular or 4-sided o-ring flange design:

- For a circular o-ring flange design it is recommended to have a minimum of 2 vent grooves at 0º and 180º for flange diameters under 12 (inches). Flange diameters greater than 12 (inches), but less than 48 (inches) require 4 vent grooves at 0º, 90º, 180º, and 270º. Flange diameter greater than 48 (inches) would require grooves every 36 (inches) around the circumference of the flange.

- For non-circular o-ring flanges, vent grooves are recommended every 36 (inches), with a minimum of 2 vent grooves per seal design.

Figure 2.5 – Example of o-ring groove with vent groove

2.11.3 Metal Seals

Since most vacuum systems do not exceed high vacuum, the use of metal seals will probably be limited to use on systems that are at high temperatures, located in areas of elevated radiation or in areas of Ultra High Vacuum.

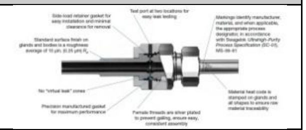
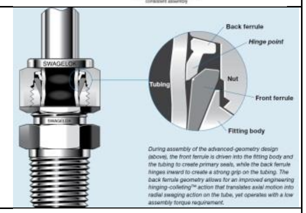
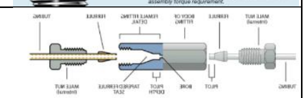
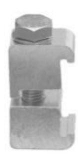
Conflat (CF) flanges and gaskets are the most common combination for UHV systems. CF assemblies utilize an OFHC copper gasket that is pierced by a knife edge between two mating flanges. CF assemblies are robust, reliable, and can withstand a wide range of temperatures.

Other metal sealing options are available such as the EVAC Ce-Fix assembly and HelicoFlex spring energized metal seal. However, please consult with the MPEX Vacuum Systems Team (Section 6) on the best metal seal to use.

2.12 VACUUM FLANGES AND FITTINGS

Table show types of flanges and fittings that will achieve various pressures indicated in the "Application/Notes" column.

Table 2.1 – Types of flanges

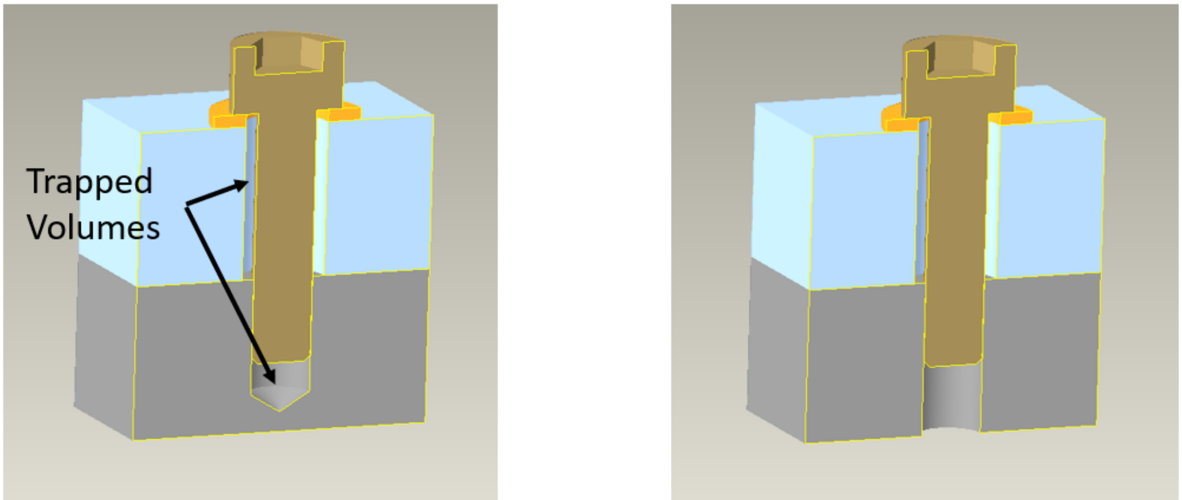
FLANGE TYPE	FASTENER TYPE	SEAL TYPE	APPLICATION / NOTES	PICTURE
VCR	Custom male/female nut system	Custom crush gasket, typically copper or silver	1000's of PSI to UHV (size dependent) 1/16" to 1" sizes	
Swagelok	Custom male/female nut system	Custom single-use ferrule, typically stainless steel, brass, or Teflon.	1000's of PSI to Atm (size dependent) 1/16" to 2" sizes	
Valco GC fittings	GC high pressure fitting	Zero dead volume fittings for gas chromatography	10,000 PSI to UHV 1/32" to 1/4" tubing	
ISO-LF Type K	Single or Double Claw Clamps  	Viton Seal on an aluminum centering ring 	Atm to $1.0x10^{-7}$ Torr. Vacuum tubing greater than 2" in diameter. Bakeable with appropriate seal to 150°C.	
ISO-LF Type F	Double Claw Clamps 	Viton Seal on an aluminum centering ring 	Atm to $1.0x10^{-7}$ Torr. Vacuum tubing greater than 2" in diameter.	
ISO-CF	*Standard ¼" or 5/16" fine-thread SS hardware, silver-plated to prevent galling.*	*CF Gasket, typically copper.* 	*Atm to $1.0x10^{-13}$ Torr.* *Vacuum tubing greater than 1" in diameter.* *(-)200°C to 450°C.*	
CeFix	CeFix custom chain-clamping system	CeFix custom metal seals, typically aluminum.	Atm to UHV 16mm to 250mm Bakeable to 200°C	

If there is a need to use another type of flange, seal, or fastener please consult with the MPEX Vacuum Systems Team (Section 6) concerning other options.

2.13 FASTENERS

All fastener materials with a relative permeability that is greater than 1.03 should not be used within the cryostat and the vacuum chamber or any area that may influence the MPEX magnetic field lines without formal project approval (see section 2.4). 304 and 18-8 stainless steel fasteners are typically cold rolled, and work hardened. Work hardened 304 and 18-8 stainless steels can have a relative permeability between 1.05 and 10 [4]. 310 stainless steel, 316/316L stainless steel, Grade 660 (UNS S66286, A286) stainless steel, or titanium are the preferred material choices for fasteners.

Trapped volumes and virtual leaks due to the use of fasteners must be avoided to prevent contamination and pump out problems. Blind tapped holes, and blind holes for pressed in pins create trapped volumes and virtual leaks. Furthermore, blind holes are traps for contaminants and the solvents used to clean the contaminants, both of which are undesirable in a vacuum environment. In general, blind holes for fasteners should not be used in vacuum systems or components. The pilot drill for a tapped hole should drill through the material to provide a vent. This is the preferred method for venting fastener holes. The threaded contacts do not have 100% engagement (typically ~75%) and allow both volumes shown in Figure 2.6 to be pumped out through the threads. In special cases such as roll formed threads in place where 100% thread engagement is possible, additional venting precautions should be taken



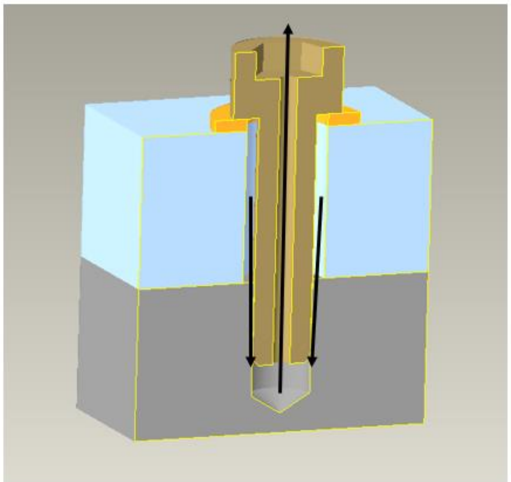
Blind holes create trapped volumes — Through holes eliminate trapped volumes

Figure 2.6

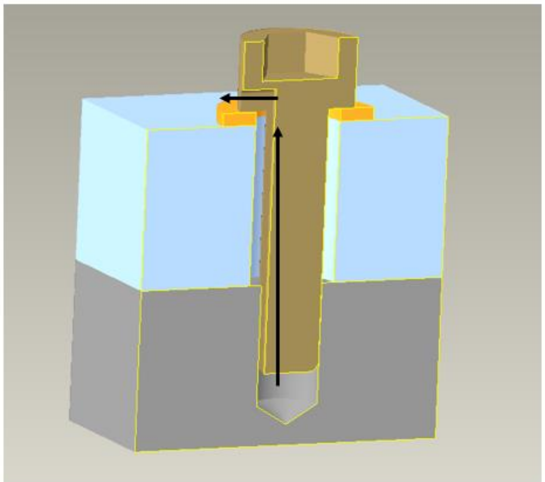
In some instances, there is no option other than a blind hole. In these cases, the design must provide a vent path for trapped volumes. Special attention needs to be placed on cleaning contaminants and solvents from blind tapped holes. Vented hardware allows trapped gas to escape when being pumped. Several types of vented hardware exist. These range from vented screws (small hole through the center) and slotted screws (a long slot cut the length of the screw) to vented washers and nuts.

Figure 2.7 - Center Hole Vented and Slot Vented Screws
(Image from UC Components)

Figure 2.8 – Vented Nut and Washer
(Image from UC Components)



Vent path for center hole vented screws

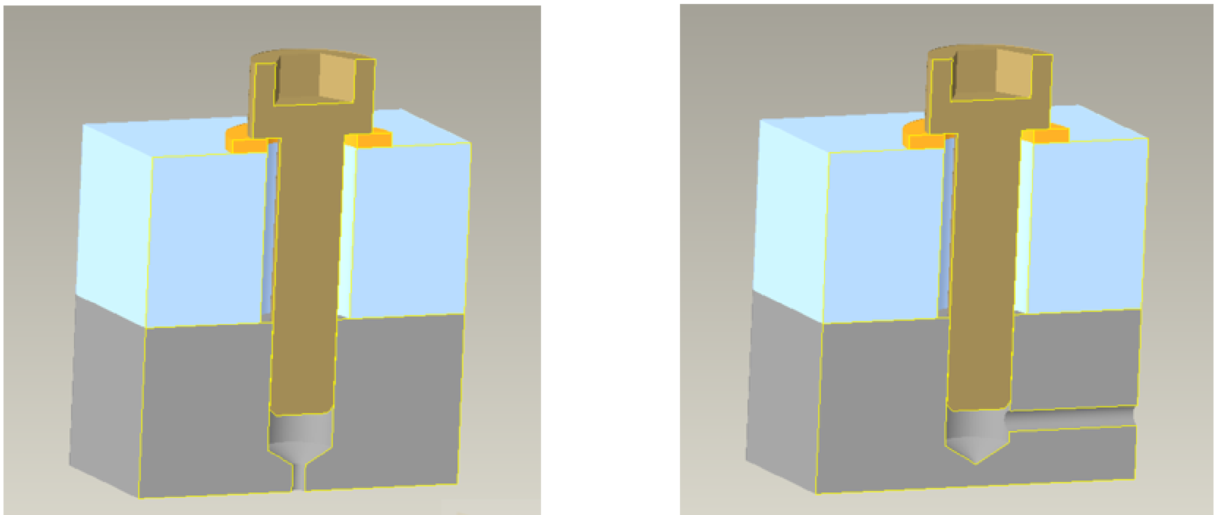


Vent path for slot vented screws

Figure 2.9

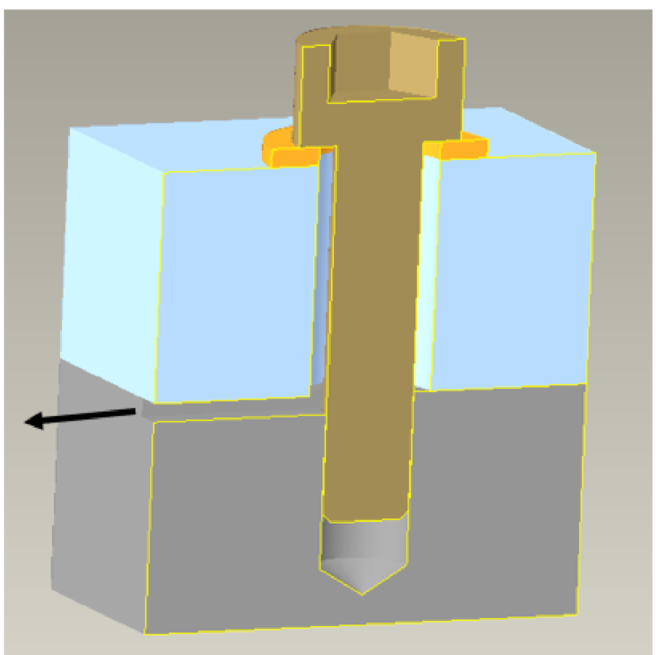
Figure 2.9 shows how vented screws relieve the trapped volume. Caution should be taken when using vented hardware. Vented screws with a hole through the center reduce the cross-sectional tensile area. Hole vented screws cannot use standard torque specifications. The standard torque of 90% proof strength of a full cross section will cause the vented screws to fail. Slot vented screws have a much smaller impact on the tensile cross-sectional area. Vented screws are not recommended for use in structural or load bearing joints requiring graded hardware.

Alternatives to vented hardware are to provide either a small, axial, or cross drilled vent hole into the pilot drill of the tapped hole (figure 2.10), or to provide a vent path for the trapped volume between the mating components (figure 2.11). These methods are preferred for structural joints using graded hardware when blind holes are necessary.



Axially drilled vent hole Cross drilled vent hole

Figure 2.10



Mating face vent groove

Figure 2.11

similarly, a vent hole or groove, hole vented dowel pins, dowel pins with one flat edge, and slotted (not coiled) spring pins can be used to vent blind pin holes.

Other fastener considerations for vacuum include addressing galling of mating components. When fasteners and tapped holes are cleaned for vacuum service, lubricants from manufacturing processes that would otherwise prevent galling are removed. This makes vacuum hardware particularly susceptible to galling. Stainless steel hardware in stainless tapped holes will gall and seize in place after tightened. It is difficult, if not impossible to remove the hardware once this happens. One seized fastener can ruin an entire assembly. Mitigation steps need to be taken. There are several ways to prevent this problem:

1. Silver plated hardware – Silver plated hardware tends to be limited to a single use, as tightening the hardware causes the plating to come off
2. MoS2, WS2, Tin, and graphite coated screws provide better gall protection than silver. However, there are many processes to apply these coatings. Any processes using organic binders are not permitted. PVD and high-pressure spray coatings are preferred. These coatings typically can be used for multiple insertions but should be discarded and replaced at the first sign of galling. Care must be taken with dry coatings such that particulate migration does not become a problem.
3. A small amount of low vapor pressure vacuum grease such as Apiezon L, can be applied to screws prior to insertion to prevent galling. This is a proven, effective technique; however, vacuum greases do not have high operating temperatures. The use of vacuum grease must be approved for each individual use by the MPEX Vacuum Systems Team (Section 6). Vacuum grease may be used on bolts that connect flanges at atmosphere, but the maximum flange temperature must not exceed the temperature rating of the grease. Any use of vacuum grease must consider what temperature the grease will see during MPEX operation and the MPEX vacuum bakeout process. The grease must be rated for the highest temperature it will be exposed to.

Vented hardware is available through McMaster Carr (www.mcmaster.com) and U-C Components (www.uccomponents.com) and Extreme Bolt (https://www.extreme-bolt.com/vented-screws.html).

[VH.015] - 302, 303, 304, 321, and 347 sst, as well as 18-8 sst shall not be used where class 7 materials are required (refer to section 2.2)

[VH.016] - Vented screws shall not be used in structural or load bearing joints requiring graded hardware.

[VH.017] - All fasteners and corresponding tapped holes shall meet UNC, UNF, or UNEF 2A (internal thread) or 2B (external thread) standards.

2.14 PUMPS

Although there are a variety of pumps and pumping systems available by a myriad of vendors, the Vacuum Systems Team has standardized on a list of particular pumps. By standardizing on specific pumps, it is much easier and cost effective to maintain spares and maintenance kits as well as train technical staff on operation, installation, and maintenance. Listed below in Table .2 are the standard pumps supported by the Vacuum Systems Team. If uncertain of needs or questions about the performance or use of a particular pump, please contact the MPEX Vacuum Systems Team (Section 6).

Table 2.2– Standard pumps

PUMP	Manufacturer	TYPE	APPLICATION / NOTES	PICTURE
TriScroll 300/600	Agilent (Varian)	Dry Scroll	1E-2 Torr Base Pressure 9/18 CFM 110/220 VAC 60Hz	
ACP 15/28	Pfeiffer Vacuum	Multi-Stage Roots	7.5E-2 Torr Base Pressure 14-27 m3/hour 110 VAC 60Hz	
Screwline SP250/SP630	Oerlikon (Leybold)	Dry Screw	~1E-2 Torr Base Pressure 177/371 CFM 240/480 VAC 60Hz 3Ph	
RUVAC WS1001/WS 2001	Oerlikon (Leybold)	Roots-Type Blower ***(Used in series with SP250/630)***	~1E-3 Torr Base Pressure 589/1207 CFM 240/480 VAC 60Hz 3Ph	
Titan Series	Gamma Vacuum	Ion Pump	<1E-11 Torr Base Pressure ~10 – ~1000 L/s 110 or 208/240 VAC 60Hz	

Cryo-Torr Series	Brooks (CTI Cryogenics)	Cryogenic Pump	UHV Base Pressure, dependent on load 1000's L/s for condensable gases 110 or 208/240 VAC 60Hz	
MaxCool 4000 Series	Brooks (Polycold)	Cryo-Cooler	UHV Base Pressure, dependent on load 1000's L/s for condensable gases 240/480 VAC 60Hz 3Ph	
HiPace Series	Pfeiffer	Turbomolecular	<1E-10 Torr Base Pressure ~80 – ~2300 L/s 110 or 208/240 VAC 60Hz	

2.15 GAUGES

In order to standardize gauging on all vacuum systems, gauges have been selected for use within the MPEX vacuum systems).

[VH.018] All gauges in rough vacuum systems utilize a KF25 connection.

[VH.019] All vacuum gauges shall be as defined in table 2.3

Table 2.3 – Standard gauges

VACUUM LEVEL	GAUGE TYPE	MANUFACTURER	MODEL NUMBER
Rough(1)	Convection-Enhanced Pirani	MKS	10-3170027SH
Rough(2)	Capacitance Manometer	MKS	626 Series
High and Ultra-High	Cold Cathode	MKS	104210004

(1) For indication only. Use only where qualitative pressure data is required.

(2) Use where accurate pressure data (< ±50%) is required.

2.16 VACUUM VALVES

There are a large variety of vacuum valves that will be used across the ORNL site. Please consult with the MPEX Vacuum Systems Team (Section 6) regarding the use of vacuum valves. (What is the intention of this section?) Is it to specify the functional requirements for the vacuum valves or performance requirements relative to the I&C system?

2.17 EXHAUST FOR VACUUM PUMPS

The use of Victaulic Press pipe is highly recommended on exhaust systems primarily because of its low installation cost and ease of installation. To terminate the exhaust, a KF flange should be used. The vacuum valve of choice for isolating the exhaust system is the VAT Series 22 vacuum valve.

[VH.020] All throughput pumps exhausting to atmosphere shall be HEPA filtered on the exhaust port.

2.18 PRESSURE RELIEF DEVICES

Due to the variability and complexity of each vacuum system, it is impossible to settle on a single standard for pressure relief. The Vacuum Systems Consensus Guideline for Department of Energy Accelerator Laboratories – BNL-81715-2008-IR Section VI, Part D [2] contains pressure relief device guidance that is applied at other facilities. Please consult the MPEX Vacuum Systems Team (Section 6) for sizing and implementation of a Pressure Relief Device for each specific project. A PRD is required for any system that can be potentially connected to a pressurized source such as process gas and nitrogen purge or vent gas supply (and internal volumes of LHe from the superconducting magnet systems. Please consult the MPEX Vacuum Systems Team (Section 6) for sizing and implementation of a Pressure Relief Device for each specific project.

2.19 PRINT NOTATIONS AND STATEMENTS OF WORK

2.19.1 Print Notations for Rough Vacuum Application (Atmosphere to 1.0×10^{-3} Torr):

All parts shall be fabricated in accordance with good vacuum practice which shall, as a minimum include the following:

1) Removal of all contamination e.g., scale, dirt, grease, and oil prior to fabrication.
2) Use only water soluble, non-sulfurous bearing cutting oils for machining.

3) Washing of all parts with detergent to remove cutting oils prior to final washing and rinsing with de-ionized water.
4) Helium leak testing of all fabricated parts which shall show a total leak rate less than 1.0E-7 Torr-L/second using a MSLD.
5) Fabricated components shall be packaged in a way to protect all sealing surfaces and to stop contamination from entering vacuum volume. Use of aluminum foil over flanges and sealing small items in a polyethylene bag is preferred.
6) Please refer to sections 3, 4, and 5 for specifics on the fabrication and handling of vacuum components.
7) [*For stainless steel components*]
   a. Electropolish per ASTM B912 02 *Passivation of Stainless Steels Using Electropolishing*

2.19.2 Print Notations for High Vacuum Application ($1.0x10^{-3}$ to $1.0x10^{-7}$ Torr):

All parts shall be fabricated in accordance with good vacuum practice which shall, as a minimum include the following:

1) Removal of all contamination e.g., scale, dirt, grease, and oil prior to fabrication.
2) Use only water soluble, non-sulfurous bearing cutting oils for machining.
3) Washing of all parts with detergent to remove cutting oils prior to final washing and rinsing with de-ionized water.
4) Metal seals should be used (where utilized in end-use) when performing the final helium leak test.
5) Helium leak testing of all fabricated parts which shall show a total leak rate less than 1.0E-8 Torr-L/second using a MSLD.
6) Fabricated components shall be packaged in a way to protect all sealing surfaces and to stop contamination from entering vacuum volume. Use of aluminum foil over flanges and sealing small items in a polyethylene bag is preferred.
7) Please refer to sections 3, 4, and 5 for specifics on the fabrication and handling of vacuum components.
8) [*For stainless steel components*]
   a. Electropolish per ASTM B912 02 *Passivation of Stainless Steels Using Electropolishing*

      OR,

   b. Tin coating by PVD (Physical Vapor Deposition) per AMS2444A

9) [*Optional if component is within the MPEX magnetic field lines*] Supplier must verify that all materials and fabrication process steps result in all components (including hardware) having a magnetic permeability of <1.03 at 200 Oersteds

2.19.3 Print Notations for Ultra High Vacuum Application ($1.0x10^{-7}$ to $1.0x10^{-9}$ Torr):

All parts shall be fabricated in accordance with good vacuum practice which shall, as a minimum include the following:

1) Removal of all contamination e.g., scale, dirt, grease, and oil prior to fabrication.
2) Use only water soluble, non-sulfurous bearing cutting oils for machining.
3) Washing of all parts with detergent to remove cutting oils prior to final washing and rinsing with de-ionized water.
4) Metal seals shall be used when performing the final helium leak test.
5) Helium leak testing of all fabricated parts which shall show a total leak rate less than 1.0E-9 Torr-L/second using a MSLD.
6) The vessel or assembly total out-gassing rate shall be measured after 10 hours of pumping from atmosphere. The out-gassing rate must not exceed 1.0E-9 Torr/liter/sec/cm^2.
7) Fabricated components shall be packaged in a way to protect all sealing surfaces and to stop contamination from entering vacuum volume. Use of aluminum foil over flanges and sealing small items in a polyethylene bag is preferred.
8) Please refer to sections 3, 4, and 5 for specifics on the fabrication and handling of vacuum components.
9) [*For stainless steel components*]
   a. Electropolish per ASTM B912 02 *Passivation of Stainless Steels Using Electropolishing*

10) [*If component is within the MPEX magnetic field lines*] Supplier must verify that all materials and fabrication process steps result in all components (including weld affected areas and hardware) having a magnetic permeability of <1.03 at 200 Oersteds

2.19.4 Statements of Work

It is recommended for complicated assemblies or large vessels that a Statement of Work (SOW) is written to provide guidance to vendors more detailed than print notations or more specific than a specification. For assistance in detailing important vacuum information in a SOW, please contact the MPEX Vacuum Systems Team (Section 6).

2.20 VACUUM VENDOR SELECTION

It has been the experience of the SNS Vacuum Systems Team (who have informed the MPEX team) that a limited number of capable vacuum fabricators exist in the United States. Moreover, each fabricator tends to have a niche as it relates to materials and sizes of vacuum vessels and components. It is highly recommended that the MPEX Vacuum Systems Team (Section 6) be consulted when choosing potential vendors.

2.21 LEAK DETECTION

Any vessels and/or vacuum components covered by this document will be required to pass a helium leak test of appropriate sensitivity. The specific leak detection procedure and/or technique to be used is highly dependent upon the size, construction, and intended use of each item. Refer to section 5 for guidelines on leak detection.

Employing the wrong testing methodology can result in an invalid test result. Please consult with the MPEX Vacuum Team (Section 6) to determine the appropriate testing methodology to use.

3 FABRICATION, PACKING, AND HANDLING OF VACUUM COMPONENTS

3.1 MECHANICAL OPERATIONS ON VACUUM SURFACES

3.1.1 Preferred Fabrication Processes

Conventional machining (milling, drilling, and turning), sheet metal fabrication (stamping, punching, forming, laser cutting, water jet cutting), forging and welding are the preferred methods for fabrication of approved materials.

[VH.021] Only water-soluble cutting fluids are permissible.

[VH.022] Internal vacuum surfaces shall achieve a surface roughness no greater than 32 micro-inches Ra.

3.1.2 Preferable Material Removal Techniques

Finish machining by conventional turning or milling is preferred. Other permitted techniques to meet surface finish requirements are slurry blasting with alumina or glass beads in a water jet; gentle hand use of a dry fine stone or a fine stone lubricated with IPA, ethanol or alcohol and hand polishing and lapping with fine mesh alumina or silcon carbide (600 grit or higher) in an IPA or ethanol carrier on a lint free cloth; hand polishing with Scotch-Brite (Alumina loaded, Grade A); electropolishing.

3.2 LESS PREFERABLE MATERIAL REMOVAL TECHNIQUES

Abrasive techniques to clean or attempt to improve the appearance of the surfaces of vacuum components must be kept to an absolute minimum and preferably avoided.

[VH.023] The use of grinding wheels, wire brushes, files, harsh abrasives, sand, shot or dry bead blasting, polishing pastes and the like is prohibited under normal circumstances without the prior approval of MPEX in writing.

3.3 GUIDANCE FOR PREPARING COMPONENTS FOR WELDING

Pay attention to the cleanliness of fabricated parts that are to be welded. Dirt, oil and other contaminates in the vicinity of the weld prep area will lead to inclusions in the weld and out-gassing under vacuum. Therefore, ALL welded components MUST be cleaned to vacuum standards, using the appropriate methods described in this specification, BEFORE being welded together.

Moreover, the best practice for insuring quality construction of a vacuum vessel or component is to have it physically separated from the environment where tasks are being performed on other materials (carbon steel) where the shavings and dust can contaminate weld prep areas causing micro-inclusions that can lead to leaks.

[VH.024] All vacuum seal welds shall fall into one of three classifications for proper vacuum welding (reference section 2.8):

1) Full penetration weld
2) Seal weld on the interior of the vessel only
3) Seal weld on the interior of the vessel with skip (stitch) welds on the exterior

[VH.025] Vacuum welds shall NEVER be on the exterior and not fully penetrate, nor should there be a full weld on both the interior and exterior of the joint.

3.4 MAGNETIC PERMEABILITY OF WELDS AND WELD AFFECTED AREAS

MPEX uses magnetic fields to control the plasma used during experiments. MPEX therefore has a magnetic permeability requirement for all materials in the magnetic field sensitive areas of the machine (refer to section 2.4) to assure magnetic field uniformity. This includes weld materials and weld affected zones.

[VH.026] All base materials, weld materials, welds, and weld affected areas that fall under material classification 7 (refer to section 2.2) shall meet the MPEX program magnetic permeability requirement of 1.03 or less (refer to section 2.4).

[VH.027] All welding materials and processes for welds that fall under material classification 7 (refer to section 2.2) shall have the magnetic permeability of the process validated with a test sample prior to the start of fabrication.

[VH.028] All final welds that fall under material classification 7 (refer to section 2.2) shall be verified to have met the MPEX magnetic permeability requirement (refer to section 2.4).

3.5 TREATMENT OF WELD BURNS

Although weld burns may be removed by using acid pastes; in general, such burns do not affect vacuum performance and are best left alone. Any scaling must be removed using the techniques outlined in Section 3.1.1 and 3.1.2. If it is desired to remove burns, then slurry blasting with alumina in water or hand burnishing with alumina powder is a satisfactory alternative. Heavy abrading, grinding or wire brushing is prohibited. Hand finishing with Scotch-Brite or a dry stone is also permissible.

3.6 ALTERNATIVE MANUFACTURING PROCESSES

3.6.1 Additive manufacturing (3D Printing)

Additive manufacturing is a rapidly developing technology and industry. There are vastly different fabrication processes that all fall under the additive manufacturing umbrella. Many metal additive manufacturing processes use laser sintering. Depending on the supplier and processes used, the components can be porous, have inherent virtual leaks, have rough surface finishes, and are difficult to clean.

[VH.029] Any components for use in vacuum that will be fabricated using additive manufacturing processes must be qualified and approved by the MPEX Vacuum Systems Team (Section 6)for each specific application, supplier, and process.

3.6.2 EDM (Electrical Discharge Machining)

EDM processes should be approved for specific applications by the MPEX vacuum systems team (section 6) and should only use processes that use DI water as the dielectric.

3.6.3 Castings

The use of castings is not permitted.

3.6.4 Sintered Powdered Metals

Sintered powdered metals should be avoided. Use of sintered powdered metals must be approved on a case-by-case basis by the MPEX vacuum systems team (section 6) for specific uses. Exceptions are listed in Appendix 1.

3.6.5 Abrasive Honing

Abrasive honing is not permitted

3.6.6 Other Processes

Other processes not listed here should be reviewed with the MPEX vacuum systems team (section 6)

3.7 HARDWARE AND FASTENERS

Refer to section 2.12 for guidelines on the use of fasteners.

3.8 MARKING AND LABELING

3.8.1 Marking of vacuum components

Marking out or marking for identification should be carried out with clean dry scribers or vibrating engravers only, never by acid etching or marker pen. Laser etching is permitted on exterior, non-vacuum surfaces. Vacuum surfaces should only be marked if it is essential to do so and never on sealing surfaces.

3.8.2 Proper labeling materials

Self-adhesive labels, tapes etc. should only be used if essential to do so and may only be fixed to non-vacuum surfaces. Ensure the adhesive used is soluble in acetone and alcohol.

3.9 QUALITY ASSURANCE

[VH.030] All components, materials, and deliverables shall follow the quality requirements identified in the MPEX Quality Assurance Program Plan (MPEX-12-PLAN-001).

3.10 HANDLING AND PACKING

3.10.1 Proper handling

Once components have been cleaned, care should be taken that the vacuum surfaces are never touched by bare skin. Clean gloves should always be worn when handling components in order to avoid contamination. White nylon or cotton gloves are preferred. Colored gloves should be tested to ensure that the dyes do not leach out when exposed to the solvents used. Powdered gloves of any description should not be used since the powder can migrate into the components. Good practice is to use lint free gloves inside nylon gloves. Refer to section 4.6.1.5 for further recommendations regarding proper attire when handling clean components. If working inside a large chamber, it is advisable to use a dust collection step-off pad to prevent tracking of dirt and grime into the chamber.

3.10.2 Cleaning process

Cleaning processes are outlined in section 4. Once components have started the cleaning process, they should complete the cycle without a break. If an unavoidable delay occurs between stages, then care must be exercised that the component is thoroughly dry before storage, and all seal faces and ports are covered as in Section 3.5.3 below. There must never be a break between any chemical cleaning stage and a subsequent water washing stage.

Suppliers with custom or proprietary HV/UHV cleaning procedures and processes that may differ from the guidelines in section 4 can submit their cleaning process for approval by the appropriate MPEX engineer.

3.10.3 Packing

After the component has been cleaned and is thoroughly dry it must be packed carefully to ensure that it remains clean and free from damage.

[VH.031] Components to be used at UHV, other critical vacuum components as defined by MPEX engineers, and vacuum chambers shall be vacuum baked at high vacuum after electropolishing and cleaning at 250℃ for at least 24hrs and until a pressure below 1.33×10^{-6} mbar (1×10^{-6} torr) is achieved. Approved exceptions to the temperature bake out requirement are when materials in the component are not rated for 250℃. The material must then be baked out at a temperature it is rated for. It is preferred that bakeout be done in a vacuum oven. In the case of vacuum chambers with metal seals that are too large for a vacuum oven, heaters may be applied to the vacuum chamber and the vacuum chamber pumped down internally to the specification noted in this paragraph.

[VH.032] Vacuum chambers shall have shipping flanges attached to all ports with metal seals to protect all seal faces and/or knife edges (clean used metal gaskets are acceptable).

[VH.033] The chambers shall be purged with nitrogen as soon after bakeout as possible and charged with 1-5 psig of nitrogen for shipment. One flange shall have a 5-psi poppet style check valve (reference Swagelok SS-CHS8-5) to avoid over pressure due to temperature changes during shipping. Vacuum Chambers should be wrapped in polyethylene to avoid contamination during shipping.

[VH.034] Vacuum components shall be either wrapped in UHV aluminum foil, sealed in a polyethylene bag, nitrogen purged and sealed in polyethylene bag or some combination of these. Use guidelines below for packing requirements

- Components for rough vacuum or high vacuum use shall be wrapped in UHV aluminum foil (food grade aluminum foil is prohibited) or sealed in a polyethylene bag.
- All sealing surfaces not protected by a metal gasket and shipping flange shall be wrapped in UHV aluminum foil.
- Components for use in UHV or critical components that have been vacuum baked, shall be wrapped in aluminum foil to protect sealing surfaces, and sealed in a nitrogen purged polyethylene bag.
- Packing shall have individual compartments for each component. Batching multiple parts (other than hardware) in a single compartment is prohibited. Exceptions must be approved by the appropriate MPEX engineer.
- Packing must secure components, so they remain clean and are not damaged during shipment.

- Components and vessels that will be shipped on a wooden pallet or in wooden crate or container shall be wrapped in an additional layer of polyethylene prior to being placed on the pallet or in the container to prevent contamination.

3.11 SHIPPING

Care must be taken during shipping to prevent damage to components when being delivered to MPEX.

[VH.035] All components and chambers shall be shipped in a closed container or trailer.

[VH.036] All vacuum chambers and other large components shall be shipped in either a soft ride trailer or have appropriately sized shock mounts or other appropriate shock mitigation integral to the packaging. As a general rule, large is defined as being too large to ship in a crate or container that one person could carry (<50 lbs.) or maneuver with a simple hand truck dolly (not a hand fork truck).

[VH.037] Any vessels or components shipped on an open-air carrier (ex. flatbed trailer) must have approval of the appropriate MPEX engineer. Additional precautions to keep components clean must be taken.

4 CLEANING OF FABRICATED COMPONENTS

4.1 GENERAL CLEAINING STEPS

Except as noted in this section, fabricated components should use the following cleaning steps. Optional steps in *italics* are either fabrication process dependent or additional cleaning steps required for functionality of components.

1. Mechanical clean consisting of wipe down of debris or low pressure compressed air cleaning to remove shavings, dust, and other contamination. Particular attention should be focused on removing debris from tapped holes and blind holes or features.
2. *Removal of weld scale or other heavy contamination*
3. *Degreasing of heavily soiled materials to remove machining lubricants and solvents*
4. Hot water rinse
5. Ultrasonic detergent bath or detergent washdown if components are too big for ultrasonic bath
6. Hot water rinse with demineralized water (deionized water is an acceptable alternative)
7. Dry components by drip dry in air, dry using filtered, compressed, dry, air supplied by an oil free compressor, or dry using filtered compressed nitrogen from liquid supply. Tapped holes and blind features should be blown out with air or nitrogen.
8. *High temperature air bake out (if special circumstances require)*
9. *250 C Vacuum bake out for 24 hrs. (or component compatible bake out temperature)*

10. *Plasma/GDC cleaning of critical surfaces*

Each individual design application should evaluate the need for special cleaning steps.

Fabrication processes should be evaluated for special cleaning steps as well.

Once the cleaning process has started, all parts should be handled with clean, powder free and lint free gloves. Only lint free wipes should be used when wiping down or drying parts.

4.2 SMALL COMPONENTS

Small components should be thoroughly degreased in a vapor degreaser or ultrasonic bath prior to detergent washing.

Once fabricated, a trial assembly should be undertaken to ensure all components fit together correctly. Any machining, filing, or welding operations should take place before cleaning. Only when cleaning is complete should the final assembly take place. From this point forward, observe the procedures laid out in Section 3.7.1 to avoid any contamination.

4.2.1 Machining of small components

The cleaning procedure for small components will remove normal machining fluids. Only water-based machining fluids are permissible.

4.2.2 Cleaning of small stainless-steel components

Follow ALL of the steps in this sequence:

4.2.2.1 Removal of loose surface scale and dirt

The component should be machined, and any surface scale or dirt removed using Scotch-Brite. The use of a polishing paste is forbidden. If a polished finish is required, then electro polishing should be considered.

4.2.2.2 Degrease heavily soiled components

If the component is heavily soiled with machining fluids, greases, or oils then it should be cleaned in a vapor degreaser or agitated in an ultrasonic bath for at least 10 minutes whilst immersed in a suitable solvent. If there is still evidence of contamination, wipe clean with alcohol until all traces are removed. Repeat the vapor wash, or ultrasonic clean, and from this point on, handle the component with clean plastic gloves and only rest on clean aluminum foil or clean, lint-free surface. Solvent and degreasing chemicals should be chosen based on the contaminant that needs to be removed and the compatibility with the remaining cleaning processes.

4.2.2.3 Hot water wash

Wash component under a hot water tap to ensure all traces of solvent are removed. Allow to drip dry on clean lint free white paper roll.

Tapped holes are difficult to clean and remove contamination from the threads. Tapped holes should be manually swabbed with detergent using an appropriately sized pipe cleaner followed by hot a water wash

4.2.2.4 Detergent wash

Place components in an ultrasonic bath filled with hot (approx. 50ºC) alkali detergent (Citranox) and agitate for 60 minutes. If an ultrasonic bath is not available, then components should be soaked for a minimum of 5 hours. This wash must be carried out in a dedicated system only used for this process and the cleaning detergent shall be changed regularly.

4.2.2.5 Final hot water wash

Repeat rinse with warm demineralized or DI water (approx. 30°C -50°C) three times to ensure all traces of detergent have been completely removed. Allow to drip dry on clean, lint-free surface.

4.2.3 Cleaning of small non-ferrous metal components

The procedure for cleaning small non-ferrous metal components is the same as for stainless steel except for the detergent wash stage. A cleaning agent suitably formulated for cleaning non-ferrous metals must be used which is compatible with the material being cleaned.

4.2.4 Cleaning of wires

4.2.4.1 General guidance

Wires in vacuum must be insulated with ceramic. Enamel insulation and GE varnish SHALL NOT BE USED. Electrical connections should be spot welded or crimped.

The use of vacuum compatible wire insulation such as Kapton must be reviewed with the vacuum systems team prior to use. Kapton is UHV compatible but does not have a high working temperature and is limited to use in areas that will remain within the working temperature limit of the material.

4.2.4.2 Cleaning procedure

All wires should be cleaned by wiping the wire several times through a piece of lint free paper roll soaked in alcohol. Wipe the wire evenly on all sides and use a fresh piece of paper until it remains clean after wiping.

4.2.5 Cleaning of ceramic and machinable glass

4.2.5.1 <u>General guidance</u>

Use only demineralized water as a coolant when machining ceramics and machinable glass as cutting fluids will contaminate the components and render them unsuitable for vacuum service.

4.2.5.2 <u>Cleaning procedure</u>

Remove any surface contamination by wet slurry blasting with alumina powder, or by hand polishing with fine mesh alumina powder in an acetone, ethanol, or isopropyl alcohol carrier. Continue to clean in the same manner as for small stainless-steel components (from 4.1.2.4 onwards).

4.3 CLEANING OF LARGE COMPONENTS AND ASSEMBLIES

4.3.1 General Guidance

Any component or assembly requiring cleaning to vacuum standards that is too large to fit into a vapor degreaser or ultrasonic bath shall be cleaned as described below.

4.3.2 Cleaning of large stainless-steel components

4.3.2.1 <u>Removal of loose scale and dirt.</u>

Use Scotch-Brite or a 300 series stainless steel wire brush to clean heavily soiled areas prior to degreasing.

4.3.2.2 <u>Degrease using suitable solvent</u>

Where the component is too large to fit into a vapor degreaser or ultrasonic bath, swab first with Acetone followed with IPA or ethanol solvent on a lint free cloth. The cloth should only be wiped in one direction. Back and forth wiping can redeposit contaminants that were removed. Change the cloth frequently.

Note: From this point forward, observe the procedures laid out in Section 3.7.1 to avoid any contamination.

4.3.2.3 <u>Demineralized water wash</u>

Repeat rinse, two or three times, with hot demineralized water to remove all traces of detergent. As a final check flood, the component with demineralized water over the entire surface. Any areas not covered in water indicate remaining grease which must be removed by starting the cleaning process again.

Note: Any subsequent cleaning prior to sealing the vacuum boundaries should be done using IPA, lint free wipes and lint free gloves.

4.4 CLEANING OF LARGE NON-FERROUS METAL COMPONENTS

For cleaning large non-ferrous metal components follow the procedure for large stainless-steel components except for the alkaline solution wash. Substitute this with a cleaning agent specially formulated for cleaning non-ferrous metals.

4.5 CLEANING OF VACUUM BELLOWS

4.5.1 General guidance

Great care should be taken when cleaning thin-walled metal bellows, particularly those of edge welded construction. Solvent residues trapped between the convolutions, either inside or out, can result in corrosion which will cause leaks to develop. Similarly, if any particulates are deposited in the convolutions then mechanical puncturing may happen.

4.5.2 Cleaning procedure

4.5.2.1 Preparation for cleaning

Fix the bellows in an extended position, if possible, and remove any visible traces of contamination with a jet of clean, dry air or nitrogen.

4.5.2.2 Removal of loose scale and dirt

Immerse in an ultrasonically agitated bath containing isopropyl alcohol (IPA) or ethyl alcohol (Ethanol) for typically 1 hour. NOTE: Due to low flash points, the ultrasonic bath should not be filled with IPA or Ethanol. A beaker kit can be used to fill with just enough IPA or Ethanol to clean the part safely. The beaker should be loosely covered to prevent evaporation of the IPA or Ethanol but not tight where it can allow the buildup pressure. The beaker should be hung in the ultrasonic bath. Only 1 inch of the beaker needs to be in the ultrasonic bath to be effective. Any applications with parts that do not fit in a standard 1000ml beaker kit should be reviewed for safe use prior to cleaning. Parts requiring large volumes of IPA should be cleaned using an explosion proof ultrasonic cleaner designed for use with flammable solvents.

4.5.2.3 Degrease using suitable solvent

Vapor wash immediately in IPA or other suitable solvent.

4.5.2.4 Drying

Thoroughly dry the bellows, inside and out, using a jet of clean, dry air or nitrogen.

4.5.2.5 Rinse

Rinse in acetone or ethanol and thoroughly dry with air or nitrogen.

4.5.2.6 Vacuum bake

Vacuum bake at 200°C for 24 hours.

4.5.2.7 Handling and packing

When removing the component from the oven, observe the procedures laid out in Section 3.7.1 to avoid any contamination.

4.5.2.8 Use of gloves

Do not use nylon gloves on hot parts or surfaces as they can melt causing injury.

4.6 CLEANING OF ASSEMBLIES AND SUB-ASSEMBLIES

4.6.1 General guidance

4.6.1.1 Cleaning prior to assembly

Many assemblies and sub-assemblies will contain components for which, as individual items, more than one of the above cleaning procedures would be applicable. Individual components should be cleaned according to the most appropriate procedure for that item. Assembly should then take place under clean conditions.

4.6.1.2 Trial assembly

Once fabricated a trial assembly should be undertaken to ensure all components fit together correctly. Any machining, filing, or welding operations should take place before cleaning. Only when cleaning is complete should the final assembly take place.

4.6.1.3 Fastener assembly

All fasteners must be clean before assembly can begin. The assembly procedure must be carried out in clean conditions using clean tools. Refer to Section 3.7.3 for advice on handling and packing. All fasteners must have either a dry lube coating or vacuum grease applied to them to prevent galling and seizing of fasteners in assemblies. Refer to section 2.12 for guidance.

4.6.1.4 Work area conditions

All work bench surfaces and tools shall be thoroughly cleaned with detergent, rinsed with water, and then wiped with alcohol before used in the assembly area. The work top surfaces shall be hard and non-absorbent. Wood bench tops or similar materials are not acceptable.

4.6.1.5 Clean work attire

As a minimum, once components have been cleaned, lint free lab coats, gloves, and hairnets shall be worn while working on vacuum vessels and assemblies to avoid contaminating the equipment with lint, dust, hair, pet hair, or other household contamination. No wool sweaters should be worn while working on vacuum assemblies. If working in a clean room, the clean room attire for that area will supersede this requirement.

4.7 STORAGE OF ASSEMBLIES AND SUB-ASSEMBLIES

4.7.1 General guidance

Once cleaned, components should be protected from contamination using the guidelines in section 3.7. Components that are intended to be changed out of the vacuum system on a frequent basis should be cleaned, vacuum baked, and stored in a manner that minimizes the vacuum system pump down time.

[VH.038] Components and assemblies shall be stored in a nitrogen purged bag, nitrogen or helium purged storage cabinet or dry box after vacuum bake out to avoid buildup of surface water.

5 VACUUM ACCEPTANCE TESTING AND CRITERIA

5.1 PREPARATION FOR TESTING

[VH.039] Vessels, components, and assemblies shall be cleaned by applicable MPEX methods prior to testing. Where applicable, all connections for leak testing shall be made with metal or elastomer seals as intended for final design and operation. Whilst connecting the vessel and carrying out these tests take care to observe procedures in Section 3.10.1 in order to maintain cleanliness of the vessel.

It is preferred for the manufacturer to provide their own gaskets, blanks, flanges, hardware, and other equipment for leak testing. However, if required and negotiated in writing, MPEX may provide certain pieces of hardware upon request.

5.2 LEAK TESTING

[VH.040] All leak testing shall be performed at the appropriate vacuum level for the component being tested and follow all the guidelines of section 5.2.

The roughing pump utilized should preferably be a dry pump capable of pumping the vessel down in an acceptable time period to conduct the vacuum tests. If using a non-dry roughing pump (oil sealed pump) whilst testing, the turbomolecular pump must be started at or before the pressure reaches 1 Torr. This will help prevent any oil back-streaming through the pump into the chamber. Alternatively, if using a dry roughing pump, the turbo pump may be started at pressures lower than 1 Torr.

The chamber under test must be fitted with a NIST-traceable calibrated leak at or near the acceptable test leak rate and the leak detector should be calibrated before and after the test to confirm correct operation and calibration. When carrying out the leak test the backing pump should be isolated and the helium leak detector should be used to back the turbomolecular pump, giving maximum sensitivity whilst conducting the vacuum acceptance tests. The following standard: "ASTM E498-95 Standard Test Methods for Leak Detection" [3] shall be used. The test method selected should take into consideration the operating conditions of the item being tested with regards to pressurization versus evacuation. Pressurizing and "sniffing" a part meant for vacuum service or vice versa could result in an ineffective test.

Vessels or components that will be in cryogenic service shall be leak tested at room temperature and not have a total leak rate above the acceptable leak rate criteria. The vessel or component under test shall then be cooled to liquid nitrogen temperature and leak tested again with and not have a total leak rate above the acceptable leak rate criteria. The vessel or component shall then be allowed to warm up to room temperature naturally and shall be leak checked a final time and not have a total leak rate above the acceptable leak rate criteria. If any rework is required, the entire leak testing process shall be repeated.

5.2.1 Use of Dry Pump

It is recommended that a dry pump be used for evacuating any vessel or assembly for leak testing. If the manufacturer does not have a capable dry pump, MPEX may provide one to the manufacturer provided that the manufacturer:

1) pays for return shipping from the manufacturer's site to ORNL.
2) pays for appropriate shipping insurance.
3) returns the pumps and components in the original shipping containers.
4) operates the pump in accordance with the manual provided.
5) provides in writing, the request to use the pump.

5.2.2 Record of leak test

The manufacturer is required to provide proof of leak test results. A printout from the leak test equipment is acceptable. Such printout should include date, a plot of the leak test or highest background reading during testing, leak detector operator, part or serial number, and indication of "Pass" or "Fail," based upon criteria from this specification. The leak detection criteria from this specification can only be superseded by a more detailed "Statement of Work" or in writing from the MPEX Vacuum Team.

5.3 OUT-GASSING AND RESIDUAL GAS ANALYSIS

If a residual gas analyzer (RGA) scan is specified by MPEX, the residual gas analyzer must be capable of recording and providing a printout of the vacuum spectrum from 1 to 100 AMU. The high vacuum gauge used should be fitted between the turbomolecular pump and the chamber under test, with an isolation valve for isolating the pumping test rig from the chamber. Preferably all connections between the chamber and the turbomolecular pump must be made with metal seals. Sealing of the chamber flanges must be made using the same sealing system used during installation to ensure sealing system works and is acceptable at the manufacturer's facility. The Manufacturer is required to provide a printout from the RGA.

5.4 RESERVED RIGHTS

5.4.1 Witnessing for acceptance

MPEX reserves the right to witness residual gas analysis and leak tests on large vessels or assemblies prior to shipping. The manufacture shall give MPEX at least 2 weeks notification for witness testing on-site.

5.4.2 Additional rights

MPEX reserves the rights to check material records, dimensional inspections, test reports and other documentation required by the technical specifications in this handbook.

6 MPEX VACUUM SYSTEMS TEAM

The MPEX Vacuum Systems Team shall consist of at least the MPEX Vacuum Subject Matter Expert and the MPEX Project Engineer.

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7 REFERENCES

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[2] Vacuum Systems Consensus Guideline for Department of Energy Accelerator Laboratories – BNL-81715-2008-IR, https://www.bnl.gov/isd/documents/43659.pdf

[3] ASTM E498-95 Standard Test Methods for Leak Detection

[4] Magnetic Properties of Stainless Steels, Carpenter Steel White Paper https://www.carpentertechnology.com/blog/magnetic-properties-of-stainless-steels