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LBL-37713
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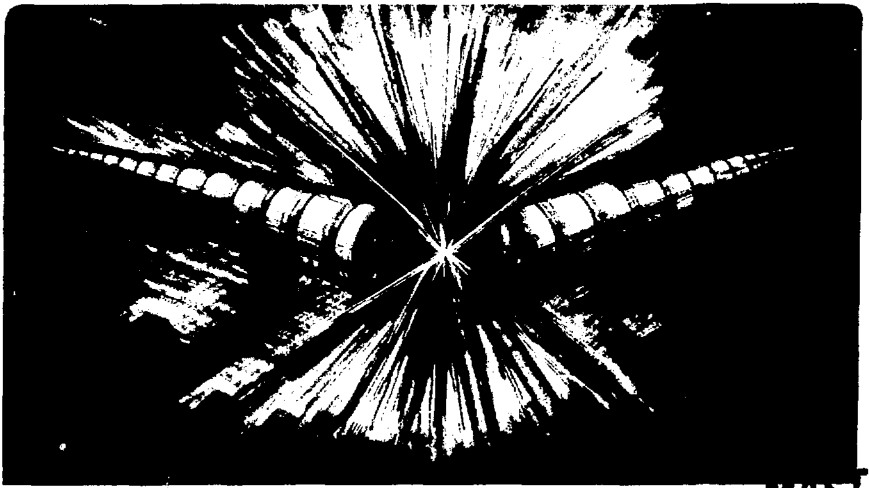
Advanced Light Source Vacuum Policy and Vacuum Guidelines for Beamlines and Experiment Endstations

Z. Hussain and the Beamline Review Committee

August 1995



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Prepared for the U.S. Department of Energy under Contract Number DE-AC03-76SF00098

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ADVANCED LIGHT SOURCE VACUUM POLICY AND VACUUM GUIDELINES FOR BEAMLINES AND EXPERIMENT ENDSTATIONS*

Beamline Review Committee
(Z. Hussain, Chairperson)

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*This work was supported by the Director, Office of Energy Research, Office of Basic Energy Sciences, Materials Sciences Division, of the U.S. Department of Energy, under Contract No. DE-AC03-76SF00098.

LSBL- 2 8 0

Light Source Note:
Author(s) Initials ZH _____ Date
Group Leader's initials _____ 9/28/95 Date

Advanced Light Source
Vacuum Policy and Vacuum Guidelines for Beamlines and Experiment Endstations
Revision 2

Beamline Review Committee
August 22, 1995
(Supersedes LSBL #116)

Contents:

Abbreviations:

BRC	Beamline Review Committee
CDR	Conceptual Design Review
EPS	Equipment Protection System
LCW	Low Conductivity Water
PRT	Participating Research Team
PSS	Personnel Safety Shutter
RGA	Residual Gas Analyzer
RSS	Radiation Safety System
UHV	Ultra High Vacuum

Front end Front end components serve to define a beam aperture for synchrotron radiation and provide necessary beam on/off, radiation safety, and vacuum-isolation systems for each beamline for both insertion device and bending magnet sources. The front end components generally reside inside the storage ring shielding and physically connect the ring vacuum chamber to the first valve of the beamline.

1. Introduction

The purpose of this document is to:

1. Explain the ALS vacuum policy and specifications for beamlines and experiment endstations.
2. Provide guidelines related to ALS vacuum policy to assist in designing beamlines which are in accordance with ALS vacuum policy.

This document supersedes LSBL-116.

The Advanced Light Source is a third generation synchrotron radiation source whose beam lifetime depends on the quality of the vacuum in the storage ring and the connecting beamlines. The storage ring and most of the beamlines share a common vacuum and are operated under ultra-high-vacuum (UHV) conditions. All endstations and beamline equipment must be operated so as to avoid contamination of beamline components, and must include proper safeguards to protect the storage ring vacuum from an accidental break in the beamline or endstation vacuum systems.

The primary gas load during operation is due to thermal desorption and electron/photon induced desorption of contaminants from the interior of the vacuum vessel and its components. The desorption rates are considerably higher for hydrocarbon contamination, thus considerable emphasis is placed on eliminating these sources of contaminants.

All vacuum components in a beamline and endstation must meet the ALS vacuum specifications. The vacuum design of both beamlines and endstations must be approved by the ALS Beamline Review Committee (BRC) before vacuum connections to the storage ring are made. The vacuum design is first checked during the Beamline Design Review (BDR) held before construction of the beamline equipment begins. Any deviation from the ALS vacuum specifications must be approved by the BRC prior to installation of the equipment on the ALS floor. Any modification that is incorporated into a vacuum assembly without the written approval of the BRC is done at the user's risk and may lead to rejection of the whole assembly.

Note: *All pressure values described in this document are N_2 equivalent values, i.e., all pressures are measured setting the sensitivity in the ion gauge controller for N_2 gas.*

2. Policy and Requirements

2.1 Storage Ring Vacuum

The ALS storage ring vacuum system consists of all-metal, chemically cleaned, bakeable components. It generally operates at pressures of less than 2×10^{-10} mbar (2×10^{-8} Pa, 1 mbar = 0.76 torr) without beam, and at pressures of less than 1×10^{-9} mbar (1×10^{-7} Pa) with beam.

2.2 Means Used for Ensuring the Quality of the Storage Ring Vacuum

The main objective of the ALS vacuum policy is to ensure that the vacuum connection of any beamline and its associated experiment endstations will not degrade the quality of the storage ring vacuum. Generally, beamlines may be separated into two broad categories. The ALS vacuum requirements differ for each category.

Category 1: **UHV beamlines** that share the same vacuum as the storage ring.

Category 2: **Non-UHV beamlines** in which the vacuum is completely or partially separated from the front end components and storage ring vacuum by using either a window or differential pumping.

For both categories, the storage ring vacuum integrity is ensured by checking that the following three items meet the requirements described in detail in Section 2:

a. The base pressure in various parts of the beamline.
b. The contribution of high mass gases to this pressure at appropriate places as checked by the residual gas spectral analysis (RGA), if and when required.
c. The vacuum interlocks which protect the storage ring in the event of accidental vacuum failure.

For non-UHV beamlines, it may also be necessary for users to provide calculations ensuring that, in case of a vacuum failure, the vacuum interlocks will adequately protect the ALS vacuum integrity.

All beamline components are required to be manufactured according to the guidelines described in Section 5 of this document.

2.3 ALS Vacuum Requirements

This section describes the three requirements that must be met for both categories of beamlines:

2.3.1 UHV Beamlines (Category 1)

This category of beamline normally shares the same vacuum as the storage ring and operates under UHV conditions.

(a) Pressure Requirement
The base pressure in all vacuum components that will be directly exposed to the storage ring vacuum must be less than 2 x 10^{-9} mbar (2 x 10^{-7} Pa) and it is expected that this pressure requirement will be maintained during the normal operation. However, during the initial scrubbing period of the beamline components with synchrotron radiation, an increase in pressure by an order of magnitude may be allowed, with the exception that at the storage ring exit port, the pressure must be 2 x 10^{-9} mbar or less at all times.

(b) **Residual Gas Analysis (RGA) Requirement**
The beamline or the vacuum system must be checked for gas analysis, using a residual gas analyzer (RGA), before it is opened to the storage ring vacuum. For beamline qualification, the RGA check is generally done downstream of the first vacuum isolation valve outside the shielding wall. For experiment chambers, the test may be done in the chamber itself or in the first beamline chamber upstream of the experiment system. The RGA used must be sensitive to a partial pressure of 1×10^{-14} mbar (1×10^{-12} Pa) or less and be capable of scanning in a range of at least 1-200 atomic mass units (AMU). The RGA scan must indicate that the sum of the partial pressures of gases having a mass of 46-and-greater (46 AMU) does not exceed 1×10^{-11} mbar (1×10^{-9} Pa).

All new systems as well as beamlines that have been changed and brought up to air must be checked to ensure that they meet the above vacuum and RGA requirements before they are allowed to be opened to the storage ring vacuum.

However, under certain conditions as determined by the ALS vacuum group, a waiver for RGA requirements may be provided to a beamline and/or experiment endstation which normally operate under UHV condition. These conditions include opening of a beamline vacuum chamber or experiment chamber for minor changes, such as replacing a burnt ion gauge filament, and changing solid samples which have similar outgasing characteristics. In all cases, a waiver will only be granted to vacuum systems which have previously been qualified at least once for meeting RGA requirements, and have achieved a pressure below 3.0×10^{-10} mbar (3×10^{-8} Pa) after necessary pumpdown and bakeout.

In any case, it is at the discretion of the ALS Vacuum Group or BRC to make the decision regarding a waiver.

(c) **Vacuum Interlocks Requirement (Protection in the Event of Vacuum Failure)**
The storage ring vacuum is protected from accidental vacuum failures by fast sensor interlocks in case of catastrophic failure, and by ion gauge pressure interlocks in the event of a relatively slow leak.

Each beamline has one or two fast sensors. The recommended distance for the fast sensor to be from the fast valve is 10 m or more, to allow enough time for the fast valve to close before arrival of the gas wave front in the event of a vacuum break. The fast sensors are interlocked with the front-end valves and shutters. The front end contains one or more all-metal isolation valves, a fast-closing valve, and a pneumatically actuated photon shutter (which is between the storage ring and the fast valve).

If there is an accidental break in the beamline vacuum system, a fast-response vacuum sensor will detect the break, and the fast valve will close in less than 10 ms. This also requires the stored beam on insertion device beamlines to be dumped to protect the fast valve from being exposed to the large power of synchrotron radiation. The primary vacuum isolation valve between the storage ring and the beamline will pneumatically close and seal the ring vacuum in about 3.5 seconds. The photon shutter located between the storage ring and the isolation valve will also close. These components are controlled by the Equipment Protection System (EPS) for the front end and the beamline. More details related to the EPS are given in *"ALS Beamline Design Requirements,"* PUB-3114.

All vacuum interlocks on beamline components supplied by experimenters must meet ALS design specifications. The ALS will advise users about vacuum requirements and interlock procedures for monochromators and endstations. Generally, these should operate under UHV conditions similar to those of front ends and the storage ring. Electrical connections between user vacuum interlocks and front-end components will be made and tested by authorized ALS staff. Fast sensors should be installed outside of the shielding wall and downstream of the monochromators in positions approved by the BRC.

For each beamline there must be at least one fast sensor located downstream of the first isolation valve near the outside of the shield wall. Another fast sensor may be located upstream of the endstation (a suitable place would be downstream of an exit slit or any other conductance-limiting component).

The fast sensors are set as follows:
Fast Sensor Set Point: A set point of 1 x 10^{-5} mbar (1 x 10^{-3} Pa) protects against catastrophic failure. If the pressure at any sensor is above this value, the corresponding fast valve/s is triggered, which simultaneously closes the photon shutter and the isolation valve. On insertion device beamlines, the stored beam must be dumped to protect the fast valve from being exposed to the large power of synchrotron radiation, as well as to protect personnel from bremsstrahlung radiation.

In addition, ion gauges (located on either side of the isolation valve) are interlocked (using ion gauge controllers at set values) to protect the storage ring against high pressure due to excessive outgasing, a slow leak, power failure, etc.

The ion gauge controller interlock set points are such that:
Ion Gauge Controller Set Point: Set at 2 x 10^{-8} mbar (2 x 10^{-6} Pa) or lower such that, if the pressure exceeds this value, the isolation valve upstream of the ion gauge will close and seal. The fast valve may remain open. The stored electron beam will not be affected.

Please note that the above pressure values set for interlocks are higher than the normal operating pressures.

If any one of the interlocks is triggered, the isolation valves along with other shutters will close. They should not be re-opened unless:
1. The pressure in that section is below the pre-approved limit, and
2. The pressure in the front end is below 2 x 10^{-9} mbar (2 x 10^{-7} Pa).

If the fast sensor is triggered, the operations coordinator will have to be contacted before beamline can be brought back on line.

2.3.2 Non-UHV Beamlines with Vacuum Window/s or a Differential Stage (Category 2)

A beamline downstream from the front end may operate in a helium atmosphere or oil-free rough vacuum under the following conditions:

i. A window capable of withstanding at least 1 atmosphere pressure isolates the storage ring vacuum from the beamline vacuum.
ii. A thin window with appropriate interlocks isolates the storage ring vacuum from the low vacuum side of the beamline.
iii. Efficient differential pumping allows downstream components to operate at higher pressure without affecting the low vacuum requirement of the front end.

The design of these devices must be approved by the BRC.

(a) Pressure Requirement
The base pressure in all vacuum components upstream of non-UHV equipment which is directly exposed to the storage ring vacuum must be less than 2×10^{-9} mbar (less than 2×10^{-7} Pa). This pressure requirement must be met at all times during the normal operation of the beamline.

However, during the initial scrubbing period of the beamline components with synchrotron radiation, an increase in pressure by a maximum of an order of magnitude may be allowed.

The maximum pressure downstream of the vacuum window or differential stage or conductance limiting component may be of any sub-atmospheric value, as long as the above condition is always maintained.

(b) Residual Gas Analysis (RGA) Requirement
The vacuum system is to be tested using a residual gas analyzer (RGA) upstream of the vacuum window or the differential stage. The RGA used must be sensitive to a partial pressure of 1×10^{-14} mbar (1×10^{-12} Pa) or less and be capable of scanning in a range of at least 1-200 atomic mass units (AMU). The RGA scan must indicate that the sum of the partial pressures of gases having a mass of 46-and-greater (46 AMU) does not exceed 1×10^{-11} mbar (1×10^{-9} Pa). The RGA scan must be performed by the ALS Vacuum Group for each new experiment before the isolation valve is opened. For experiments involving materials of potential hazard, the RGA will be monitored either continuously or intermittently during operation (at the discretion of the ALS beamline coordinator and or vacuum group).

(c) Vacuum Interlock Requirements (Protection in the Event of Vacuum Failure)
The storage ring vacuum is protected from accidental vacuum failures by fast sensor interlocks in case of catastrophic failure, or by ion gauge pressure interlock(s) in the event of a relatively slow leak.

For non-UHV beamlines, one fast sensor must be installed and it is recommended that two be installed. The first must be downstream of the first isolation valve outside the shield wall. The second sensor should be at a place with potential vacuum break, such as just upstream of a vacuum isolating window or differential stages.

All vacuum interlocks on beamline components supplied by experimenters must meet ALS design specifications. Electrical connections between user vacuum interlocks and front end components will be made and tested by authorized ALS staff members.

Both fast sensors and ion gauge controllers are set as follows:

i. **Fast Sensor Set Point:** If the pressure at any sensor is above 1 x 10^{-5} mbar (1 x 10^{-3} Pa), the corresponding fast valve/s is triggered, which simultaneously closes the photon shutter and the isolation valve. On insertion device beamlines, the stored beam must be dumped to protect the fast valve from being exposed to the large power of synchrotron radiation, as well as to protect personnel from bremsstrahlung radiation.

ii. **Ion Gauge Controller Set Point:** Set at 2 x 10^{-8} mbar (2 x 10^{-6} Pa) or lower on all ion gauge controllers measuring the pressure upstream of the vacuum isolation window or differential stage. If the pressure exceeds this value, the isolation valve upstream of the ion gauge will close and seal. The fast valve will remain open. The storage ring will not be dumped. Ion gauges located downstream of the window or differential stage may be set at any value, provided the above conditions are met.

Please note that the above set points for interlocks are considerably higher than the normal operating pressures.

If any of the interlocks is triggered, the isolation valves and the other shutters will close and must not be opened unless:

1. The pressure in that section is below the pre-approved limit, and
2. The pressure in the front end is below 2 x 10^{-9} mbar (2 x 10^{-7} Pa).

If the fast sensor is triggered, the operations coordinator will have to be contacted before beamline can be brought back on line.

3. Performance Test

The beamline and/or front end must be checked for compliance with the three ALS vacuum requirements (Vacuum, RGA scan, and Vacuum Interlocks) by the ALS Vacuum Group, if:

i. The front end is to be opened to the storage ring for the first time.
ii. The branchline is to be opened to the front end for the first time.
iii. Any part of the beamline is changed or brought up to air and is ready for re-connection to the storage ring vacuum.

For UHV beamlines, the RGA requirement may be waived under special circumstances. (When it is decided by the ALS Vacuum Group and/or BRC that checking the RGA requirement is unnecessary and would not provide information of any practical use. See Section 2.3.)

4. Review of Vacuum Design

The vacuum design of each beamline is reviewed by the BRC during a beamline design review. The experiment group (PRT) must demonstrate that the design will not degrade the quality of the storage ring vacuum and that it follows the ALS vacuum policies outlined in this document. The PRT should submit:

i) Beamline assembly drawings or suitable sketches to scale.
ii) A list of vacuum components and materials of construction.
iii) A list of pumps, their specifications, and locations.
iv) Information related to vacuum interlock system.
v) Calculations showing that in case of a vacuum failure, the vacuum interlock will adequately protect the ALS vacuum integrity.

The PRT must obtain BRC approval before ordering any non-standard, non-UHV vacuum components and before fabricating any beamline components.

Approval of a PRT beamline design by the ALS Beamline Review Committee does not allow the PRT group to bypass the performance tests outlined in Section 3.

5. Vacuum Guidelines for Beamline and Endstation Experiment Chamber Vacuum Systems

ALS beamlines must have all-metal, hydrocarbon-free front end components. UHV design criteria must be used for the hardware downstream of the front end, if the hardware and the front end share a common vacuum. The BRC must approve any deviations from the requirements in this section.

The following is a partial list of items which will help in developing a UHV system compatible with ALS requirements. Questions or requests for additional information should be directed to the BRC or the ALS Vacuum Group.

5.1 Materials

Standard UHV-compatible materials must be used in all beamlines sharing the same vacuum as the storage ring. The following is a list of materials that are and are not acceptable for UHV. Any material not listed must be approved.

Acceptable	Not Acceptable	Marginal
Pure metals: aluminum copper (incl. Glidcop) gold silver molybdenum tungsten titanium Stainless Steel: 300 series (preferred types are: 304, 316, 321, and 347). Alloys: Ampco 18 beryllium copper inconel 600 or 718 mu-metal Kovar Ceramics: Alumina ceramics sapphire machinable glass ceramic	Zinc- and cadmium-bearing metals and alloys are not UHV-compatible. Organic materials are not permitted unless they are specifically authorized by the BRC.	Stainless Steel: SS containing excessive amounts of sulfur or selenium must be avoided. Elastomers such as viton may be allowed in the seat of a gate valve with metal bonnet seals. These valves are only allowed in the places where there is no chance for the elastomer to be exposed to radiation.

All components must be inspected and leak-tested after fabrication.

5.2 Bellows

Both welded and formed bellows are allowed, provided they are manufactured using UHV standards.

Since welded bellows are made of thin stainless steel diaphragms welded on the inside and outside diameters to form a series of convolutions, proper UHV techniques are required during manufacturing to avoid trapping of hydrocarbons or contaminants in the crevices of the convolutions. It is strongly recommended that the bellows be chemically degreased and baked in vacuum before being installed in the beamline.

Formed bellows are relatively easy to clean, but must be fabricated for UHV applications.

5.3 Feedthroughs

Ceramic-to-metal type electrical feedthroughs are allowed for making electrical connections into the vacuum system. No glass-to-metal feedthroughs are permitted. Voltages and current carried through the feedthroughs must not exceed the manufacturer's ratings. External covers and cable restraint are required to protect against the accidental breaking of ceramics (which is a major cause of vacuum failure).

Bellows-type mechanical rotary and linear feedthroughs manufactured for UHV applications are allowed. **Feedthroughs with a single elastomer seal are not permitted.** However, two-stage differentially pumped feedthroughs with elastomer seals may be allowed, with approval by BRC.

5.4 Gauges

Glass ionization gauges are not permitted in beamlines. Nude ionization gauges with two independent filaments and controllers with electron bombardment degassing capability are recommended. It is recommended that the cable connection to the gauge head be bakeable to 200° C and have an enclosed connector or cable restraint. Cold cathode, thermocouple, or Vactron gauges may be allowed, if they meet UHV requirements.

5.5 Vacuum Pumps

Any one or combination of the following primary pumps may be used:

Sputter-ion pumps: Ion pumps (either diode, triode, or differential ion) are the most reliable pumps for UHV use. Differential ion pumps which contain both titanium and tantalum filaments are recommended, due to their ability to pump inert gases.

Titanium sublimation pumps (TSP): TSP, in combination with ion pumps, are very effective in creating UHV.

Non-evaporable getter (NEG) pumps: NEG pumps are made of UHV-compatible, active metals which pump by chemisorbing gases.

Cryo pumps: May be used with appropriate isolation valves and interlocks, which must be approved by the BRC.

Turbomolecular pumps: It is strongly recommended that both the turbo and the backing pump be oil-free. They must be equipped with appropriate interlock isolation valves for protection in case of pressure and/or power failures. The use of a turbo pump as a primary pump in the beamline is discouraged and must be approved by BRC. A turbo pump system (preferably oil-free) with appropriate interlocks may be used in the endstation experimental chamber.

Diffusion pump - **These are not permitted due to their inherent risks of oil contamination.**

Roughing Pumps: **Only oil-free mechanical pumps may be used as roughing pumps.** Under extreme circumstances where no alternative exists, an exception may be given by the BRC. During the initial rough-pumping and/or bake-out of the beamline, turbo pumps, cryo pumps, sorption pumps and or any other oil-free pumps as approved by the BRC or Vacuum Group may be used. This is allowed only when the front end isolation valve is closed. They may also be used at the endstations. When used at an endstation, a pump must be equipped with appropriate interlock isolation valves for protection in case of a pressure and/or power failure.

Backing Pumps: **It is strongly recommended that only oil-free mechanical pumps be used as backing pumps.** Under extreme circumstances where no alternative exists, an exception may be given by the BRC.

The vacuum requirements as outlined in Section 2 must always be satisfied.

5.6 Valves and Flanges

All-metal, bakeable UHV valves, flanges, and seals are acceptable. Flanges with elastomer seals are not allowed in the beamline. Metal bonnet valves with elastomer seals are not allowed in beamlines where the seal may be exposed to direct synchrotron radiation. If approved by the BRC, they may be used in places where radiation exposure is not a problem.

5.7 Fabrication

Fabrication of any component which becomes part of the vacuum environment of the beamline directly exposed to storage ring vacuum must be done using UHV compatible materials and following UHV-accepted techniques, including:

Surface Preparation: No machining or polishing operation which might result in contaminants being embedded in the material should be used. All tapped holes should be vented.

Machining Lubrication: No cutting lubricant may be used which results in contamination that cannot be removed by standard cleaning methods. The use of cutting fluid containing sulfur or silicone compounds is not recommended. Refer to ALS engineering notes LSME-479 (Light Source Beamlines Vacuum System–General: Fabrication, Handling, and Cleaning Parts Before Brazing, Stress-Relief Annealing, or Preliminary Bake-Out at High Temperatures for Ultra-High Vacuum Service) and LSME-500B (Light Source Beamlines Vacuum Systems General: Fabrication, Cleaning, and Certification of Stainless Steel Vacuum Chambers for Weldments for UHV) for the recommended procedures.

Water Cooled Optics: Vacuum-to-water joints are not permitted in the ALS beamline vacuum systems, unless there is an intermediate guard vacuum. Refer to ALS technical note M7184 (Mirror Brazing Technique). Vacuum-to-water joints must be avoided as much as possible in the users' vacuum chamber systems.

Chemical Cleaning: All UHV components must be vapor degreased, electropolished, and/or chemically cleaned before installation in the beamline. Refer to ALS technical note LSME-421A (Light Source Photon Beam Lines—BNL/NSLS XI Beamline Mirror System M-Zero Mirror System: General Cleaning and Brazing Procedures for Furnace-Brazed U.H.V. Parts).

5.8 Assembly of UHV Components

It is highly recommended that assembly of UHV components take place in a clean room or in a clean laminar flow hood. There are many sources of contaminants. The single largest sources during assembly are perspiration, body oils, hair, perfume, etc. Thus, the use of clean gloves, face masks, lab coats, and head covers during assembly is recommended.

Lint-free paper or cloth wipes are recommended for use with UHV parts. Ethanol should be used as a wiping solvent, if necessary.

All UHV components which may get exposed to contaminants should be protected by clean, oil-free aluminum foil or lint-free paper.

No cadmium-plated, brass, lead, or wood tools should be used during assembly.

If a chamber is to be opened to air and cannot be moved to the clean room, it is recommended that the chamber be purged continuously with dry nitrogen gas. A liquid nitrogen source is the best choice to get the quantities of dry nitrogen required. The ALS will provide such a source.

5.9 Venting

If a UHV chamber is to be vented, dry nitrogen should be used for venting the system. A pressure relief valve is required in the venting system, especially to protect view ports from exploding. A safe recommendation for the relief pressure valve setting is 30 mbar (0.5 psi) above atmosphere (a recommendation by Varian).

5.10 Leak Checking and Bakeout

It is highly recommended that the whole system be leak-checked before going through the thorough bakeout. The recommended temperature for bakeout of a stainless steel chamber is 200° C. There may be other constraints which may limit the bakeout temperature to a lower value.

For a system which may give high outgassing loads, it is generally recommended that a nitrogen bake be done, followed by a vacuum bake. During a nitrogen bake, dry nitrogen gas from an evaporated liquid nitrogen source is pumped through the assembly while the components are heated.

References:

For further details concerning ultra-high vacuum practice, the user may consult:

1. *Practical Vacuum Techniques*, by W.F. Brunner and T.H. Batzer, published by Krieger, 1974.
2. *A User's Guide to Vacuum Technology*, by J.F. O'Hanlon, published by John Wiley & Sons, 1980.
3. *High Vacuum Technology: A Practical Guide*, by Marsbed H. Hablanian, published by Marcel Dekker, Inc., New York, 1990.
4. *Basic Vacuum Practice*, Third Edition, Varian Vacuum Products Training Department, Varian Associates, 1992.
5. *Vacuum Policy for ALS Beamlines and Experimental Systems*, by R.C.C. Perera, K.D. Kennedy, J.R. Meneghetti, LSBL-116
6. *Light Source Beamlines Vacuum System–General: Fabrication, Handling, and Cleaning Parts Before Brazing, Stress-Relief Annealing, or Preliminary Bake-Out at High Temperatures for Ultra-High Vacuum Service*, by D. DiGennaro, LSME-479.
7. *Light Source Beamlines Vacuum Systems General: Fabrication, Cleaning, and Certification of Stainless Steel Vacuum Chambers for Weldments for UHV*, by D. DiGennaro, LSME-500B.
8. *Mirror Brazing Technique*, by D. DiGennaro, M7184.
9. *Light Source Photon Beam Lines—BNL/NSLS XI Beamline Mirror System M-Zero Mirror System: General Cleaning and Brazing Procedures for Furnace-Brazed U.H.V. Parts*, by D. DiGennaro, LSME-421A.
10. *ALS Beamline Design Requirements*, PUB-3114.