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ITER Vacuum Handbook

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ITER Vacuum Handbook

Acronyms

AOD	Argon-Oxygen Decarburization
CFC	Carbon Fibre Composites
DNB	Diagnostic Neutral Beam
ESR	Electro-Slag Remelted
HIP	Hot Isostatic Pressing
IO	ITER Organization
JET	Joint European Torus
LDP	Liquid Dye Penetrant
LPT	Liquid Penetrant Testing
LR	Leak Rate
MIP	Manufacturing Inspection Plan
NB	Neutral Beam
NDT	Non-Destructive Testing
PA	Procurement Arrangement
PF	Poloidal Field
PTFE	Polytetrafluoroethylene
QA	Quality Assurance
RF	Radio Frequency
RO	Responsible Officer
SVS	Service Vacuum System
TF	Toroidal Field
TIG	Tungsten Inert Gas
UHV	Ultra-High Vacuum
UKAEA	United Kingdom Atomic Energy Authority
VAR	Vacuum Arc Remelted
VOD	Vacuum Arc decarburization
VQC	Vacuum Classification System

1 Background

ITER will include one of the largest and the most complex high vacuum systems ever built. Reliable vacuum is key to the success of the ITER project. A characteristic of high vacuum is that the functionally of a whole system can be lost by not appreciating and paying attention to the effect of small details. Due to the pervasive nature of vacuum in the ITER machine, there are very few ITER systems which will not have an important vacuum interface. Orders of magnitude improvements in vacuum reliability are required compared to existing and past fusion devices to achieve the ITER goals because of the scaling in the number of components and the physical size of ITER.

There are two main vacuum systems on ITER, the Torus primary vacuum which requires ultra-high vacuum (UHV) conditions, and the cryostat primary vacuum which requires clean insulation vacuum conditions with permissible operating pressures typically 2 orders of magnitude higher than the torus. In addition, there are secondary vacuums and a cryogenic guard vacuum system. Details are given in Appendix 1.

2 Scope of this Handbook

This Vacuum Handbook outlines the mandatory requirements for the design, manufacturing, testing, assembly and handling of vacuum items to realise and subsequently to maintain the various different ITER vacuum systems. In addition, this Handbook provides significant guides and helpful information which can be used in the production of procurement specifications for ITER components.

The ITER Vacuum Handbook is issued as a high level project requirements document since it is imperative that the requirements contained in this Handbook are followed by the International Organisation, the Domestic Agencies and Industries to ensure that ITER operations are ultimately successful.

This Handbook is supported by a set of Attachments and Appendices. The Attachments are subject to the same approval process as the main handbook and contain detailed mandatory requirements. With the exception of Appendices 3 & 4 the Appendices are for guidance and provide detailed information, guides, specifications, relevant processes and lists of standard and approved components, vacuum materials, etc. Appendices 3 & 4 contain lists of materials (and associated processes) which have been approved for use on, or in, the ITER vacuum systems. Only materials (or associated processes) listed in Appendices 3 & 4 shall be used in, or on ITER vacuum systems. All Appendices are working documents subject to regular update.

The Appendices can be used by *suppliers* to aid the production of vacuum components, specifications and procedures which satisfy the mandatory requirements of the ITER Vacuum Handbook.

2.1 Communications and *Acceptance*

To satisfy the requirements of this handbook *acceptance* or *accepted* is called for in various places, this *acceptance* is to be given by the ITER Vacuum Responsible Officer (RO) or his or her nominated representative. *Acceptance* is to be a positive and recorded action, either by signature or by electronic means. The ITER Vacuum RO will respond in the shortest possible time from receipt of the request, normally within two weeks. An explanation will be provided if the proposal is rejected or if modification is required.

Requests for *Acceptance* shall be sought through the submission of the Request for *Acceptance* (ITER_D_9AY4HD).

Where the Interface compliance check list of an ITER Procurement Arrangement is signed by the ITER Vacuum Responsible officer this shall be taken as *acceptance* of these items which are detailed in the Procurement Arrangement. Where an ITER Procurement Arrangement does not provide adequate details required for *acceptance* of these items, then the PA can define the processes to be followed leading to *acceptance* in which case these processes shall be followed rather than processes of the ITER Vacuum Handbook.

Iterations with both the Domestic Agencies and industry are expected to be necessary to meet the requirements of this Handbook.

Normal communication and approval channels set up in any specific contract for supply should not be bypassed - rather that they should be the normal route by which *acceptance* requests are made and received.

A possible route of communication and acceptance would therefore be:-

Supplier (Contractor) ↔ Domestic Agency Contract Responsible Officer ↔ ITER Technical Responsible Officer ↔ ITER Vacuum Responsible Officer.

A definition of terms can be found in Appendix 21.

3 Vacuum Classification System (VQC)

3.1 Definition

Every vacuum component is given a Vacuum Classification to denote its area of service on ITER. These are defined as:

> **VQC 1X:** Torus primary vacuum components or components which become connected to the torus high vacuum through the opening of a valve during normal operations.
>
> **VQC 2X:** Cryostat primary vacuum components or components which become connected to the cryostat vacuum through the opening of a valve during normal operations.
>
> **VQC 3X:** Interspaces and auxiliary vacuum systems connected to the service vacuum system or roughing lines.
>
> **VQC 4X:** Cryogenic guard vacuum systems or items connected to the cryogenic guard vacuum system.
>
> **VQC N/A:** Components not exposed to vacuum.

Where:

> **X = A** denotes boundary components.
>
> **X = B** denotes components within vacuum but which do not form part of the vacuum boundary.

Where a component is part of the boundary between two different vacuum classes, it shall normally meet the more demanding requirements of the higher class unless the division between classes is shown on the drawings. Joints which separate classes shall always be classified according to the requirements of the more demanding class. The surface finish requirements appropriate to each class are to be applied. Surface cleaning of the less highly classified surface may be in accordance with the reduced requirements of that classification provided that the more highly classified surface is not degraded in the process.

Some examples of classification are:

- In vessel divertor cassette water cooling pipe - VQC 1A.
- In-vessel remote handling rail - VQC 1B.
- Cryogenic lines within the cryostat - VQC 2A.
- Support within the cryostat - VQC 2B.
- Cryogenic transfer-line between cryo-plant and tokamak complex - VQC 4A.

Typical base pressures and pumping speeds for the various vacuum systems are given in Appendix 1.

3.2 Notification of the Vacuum Classification

The VQC for a particular component shall be marked on any drawing related to and stated in any specification for that component. If this is not the case, the classification can be provided by the ITER Vacuum Responsible Officer (RO) upon request.

3.3 Components without a Vacuum Classification

3.3.1 Supply

In order ensure vacuum components which are intended for service on ITER and are not classified under section 3 (such as, for e.g., mechanical displacement pumps), meet the requirements for safety and performance the IO shall approve Technical Specifications for the supply of such equipment. Technical Specifications shall be submitted to the ITER Vacuum RO for review and subsequent approval prior to the commencement of the procurement process.

3.3.2 Connections Between Systems

An item of vacuum equipment which is not classified under section 3 may be connected to an item with a VQC, e.g. a leak detector may be connected to a valve on the cryostat or a roughing pump may be connected to the torus vacuum system. In all such cases, the use of such items and the operations for which they are required shall be under administrative control. A written scheme of work shall be submitted on the appropriate form to the ITER Vacuum RO. The main criterion for approval of such a scheme of work (other than the necessity of the work being carried out) shall be an assessment by the ITER Vacuum RO of the possibility of contamination of the system bearing the VQC.

4 Deviations and Non-Conformances

Requests for deviations from, and non-conformance with, the requirements of the ITER Vacuum Handbook shall be made to the ITER IO in writing following the procedures detailed in the ITER Quality Assurance Program (IDM Ref: ITER_D_22K4QX) and ITER Deviations and Non-Conformances (IDM Ref: ITER_D_22F53X) documents. Recommendations on the approval of the non-conformance report will be made by the ITER Vacuum RO.

5 Materials for Use in Vacuum

5.1 Materials Accepted for Use in Vacuum

Only materials *accepted* for the relevant Vacuum Classification shall be used on ITER vacuum systems. All material for use in vacuum shall be clearly specified at the design stage and certified in accordance with EN 10204 3.1 or 3.2 before being used in manufacturing.

Materials which may be used without prior agreement on vacuum systems with the Vacuum Classifications stated in the table are listed in Appendix 3. Materials listed in this Appendix which are shown as being subject to restricted use for a particular Vacuum Classification are subject to either an overall quota or to particular restrictions on their position of use. *Acceptance* for any particular vacuum application of such a material shall be obtained by submitting the Material Acceptance Request Form (ITER_D_2MGWR4) to the ITER Vacuum RO. An example of this completed form is to be found in Appendix 3.

5.2 Adding Materials to the Accepted List for Vacuum

Materials which are not on the accepted list may be proposed for use in vacuum. If the vacuum properties of the material are not sufficiently well documented for an assessment to be carried out, a programme of measurement of the relevant properties shall be agreed between the proposer and the designated ITER Vacuum RO.

Details of materials to be considered for acceptance shall be submitted to the ITER Vacuum RO using the Material Acceptance Request Form (ITER_D_2MGWR4). The proposer shall agree in advance with the ITER Vacuum RO a plan detailing the type and method of testing to be used to qualify the material for use. The Materials Acceptance Request Form along with the test data, report and supporting documentation, including any *supplier's* data (Certificates of Conformity, etc.), shall be submitted for consideration. These shall be assessed by the ITER Vacuum RO who will communicate the acceptance, refusal or restrictions on usage of the material to the originator of the request.

Materials qualified in this way may be added to Appendix 3.

5.3 Metallic Machined Components and Fittings

5.3.1 Final Thickness < 5 mm

All VQC 1A components which are machined from steel, austenitic steel or superalloys and which are of final thickness less than 5 mm and VQC 2A components which are machined from steel, austenitic steel or superalloys and which are of final thickness less than 2 mm and are designed to contain cryogenic helium[1], shall be made from cross-forged material which is Electro-Slag Remelted (ESR) or Vacuum Arc Remelted (VAR).

The rate of inclusions in such steels shall be checked in accordance with ASTM E-45 Method D (or equivalent) to be within the following inclusion limits:

- Inclusion Type A ≤ 1.0.
- Inclusion Type B ≤ 1.0.
- Inclusion Type C ≤ 1.0.
- Inclusion Type D ≤ 1.5.

These requirements are synopsised in Table 5-2.

5.3.2 Final Thickness between 5 mm and 25 mm

VQC 1A components which are machined and are of final thickness between 5 mm and 25 mm shall be manufactured from approved steel (listed in Appendix 3), in the form of stock which has been cross-forged (upset forged).

These requirements are synopsised in Table 5-2.

5.3.3 Manufacture of Vacuum Flanges

Both halves of demountable flanges using metal seals are to be manufactured from cross or upset forged material.

Stainless steel used for the manufacture of knife-edge sealed flanges of any thickness for all vacuum classifications shall be from cross-forged ESR grade material blanks.

5.4 Outgassing

The outgassing rates of materials used on ITER vacuum systems shall be consistent with the values in Table 5-1. Appendix 17 gives details on how outgassing requirements are derived, how they can be achieved and how they may be measured.

[1] At the time of writing this requirement is under approval and shall be included to the next version of this Handbook.

		Maximum Steady State Outgassing rate $Pa.m^3.s^{-1}.m^{-2}$		
VQC[+]	**Outgas temperature °C**	**Hydrogen isotopes**	**Impurities**	**Testing Guidelines**
1	100[‡]	1 x 10^{-7}	1 x 10^{-9}	Appendix 17
2	20	1 x 10^{-7}[*]		Appendix 17
3	20	1 x 10^{-8}		Appendix 17
4	20	1 x 10^{-7}		Published data and conformity to clean work plan.

For VQC 2, 3 and 4, the outgassing rate excludes the partial outgassing rates for water and hydrogen.

‡ The outgas test temperature can be reduced to 20 °C for components which normally operate at cryogenic temperatures.

+ For CFC refer to section 26.7

* In the case of resins for magnets it is considered that this target outgassing rate will be achievable. However, a factor of 10 increase will be permitted as an acceptance criterion.

Table 5-1 - Outgassing rates pertaining to VQC

These limits have been produced by taking into account the total surface area expected, the available pumping speed, the desired pressure and post assembly conditioning time, with due consideration of what is reasonably achievable. The addition of novel high surface area components to the design requires specific *acceptance* and appropriate limits to be assessed.

Published data and/or experimental trials shall be used to show design and process consistency with the limits.

An outgassing rate acceptance test shall be performed for all VQC 1 components to an *accepted* procedure such as those described in Appendix 17. Exceptions will be *accepted* for components which normally operate at a pressure above 1 Pa. Outgassing acceptance tests may, with prior *acceptance*, be performed using representative samples which follow, and are subjected to, the complete manufacturing process.

Where it is agreed that a specific vacuum component should not be subjected to a specific outgassing rate acceptance test, compliance shall be demonstrated by conformity to a clean work and quality plan.

5.5 Hot Isostatic Pressing

Hot Isostatic Pressing (HIP) of sintered material is allowable for use on all VQC components, provided that it is demonstrated that the components meet the mechanical and leak rate requirements for the proposed application and the vacuum boundary thickness is greater than 5mm. It must be demonstrated that HIP formed components comply with the outgassing rates in Table 5-1. Proposals for the use of HIP formed components, and the procedure for qualification of the components for use as vacuum containment, shall be subject to prior *acceptance* at the design stage.

These requirements are synopsised in Table 5-2.

5.6 Castings

For VQC 1, 2A & 3, metallic castings shall not normally be used. Where it is considered that a casting technology could provide acceptable porosity and meet the outgassing and leak rate requirements in the final application, then a vacuum properties validation program shall be proposed for *acceptance*.

These requirements are synopsised inTable 5-2..

5.7 Plate Material

Where hot or cold rolled plate material is used, it is recommended for all vacuum classes, that a surface parallel to the direction of rolling forms the vacuum boundary. This is due to the possibility of long leak paths caused by the stratification of inclusions.

For VQC1A applications which have been assigned Remote Handling Class 3 or are Non-RH classified (ITER_D_2FMAJY) where the component becomes embedded in ITER and could not in future be changed, hot or cold rolled plate material (approved steels from Appendix 3) produced with conventional smelting and refining processes such as Argon-Oxygen Decarburization (AOD), Vacuum Arc decarburization (VOD)) shall not be used where the transverse cross section across the vacuum boundary (wall thickness) is less than 25mm.

Where for VQC1A hot or cold rolled plate material (approved Steel – Appendix 3) is used with the transverse cross section crossing the vacuum boundary (wall thickness less than 25 mm), ESR or VAR low inclusion rate material shall be used which meets the inclusion limits as specified in Section 5.3.1 The component shall also be proven by leak testing in an environment which conforms as closely as possible to the operating conditions (See Section 25) with due consideration taken of the effects of possible leaks along laminations on the response time for the test method.

These requirements are synopsised in Table 5-2.

<table>
<tr><th rowspan="3">Nominal thickness (of vacuum boundary)</th><th></th><th colspan="3">Plate / Bar[1]</th><th rowspan="2">Forging[4]</th><th rowspan="2">Pipe[4]</th><th rowspan="2">Pipe, [4,5] (He, ≤ 2 mm)</th><th rowspan="3">HIP[3]</th><th rowspan="3">Casting[4]</th></tr>
<tr><th>Direction</th><th colspan="2">Crosses[2]</th><th>Parallel[2]</th></tr>
<tr><th>RH Class</th><th>3, N/A</th><th>1, 2</th><th>1, 2, 3, N/A</th><th>1, 2, 3, NA</th><th>1, 2, 3, NA</th><th>1, 2, 3, NA</th></tr>
<tr><td colspan="2">≤ 5 mm</td><td>X</td><td>L</td><td>NR</td><td>F + L</td><td>NR</td><td>L</td><td>X</td><td>A</td></tr>
<tr><td colspan="2">>5 mm ≤ 25 mm</td><td>X</td><td>L</td><td>NR</td><td>F</td><td>NR</td><td>NR</td><td>A</td><td>A</td></tr>
<tr><td colspan="2">> 25 mm</td><td>L</td><td>NR</td><td>NR</td><td>NR</td><td>NR</td><td>NR</td><td>A</td><td>A</td></tr>
<tr><td colspan="10">[1]VQC 1A, VQC 2A cryogenic helium pipework (pipe & fittings) < 2 mm
[2]Transverse cross section w.r.t. vacuum boundary or parallel w.r.t vacuum boundary
[3]All VQC
[4] VQC 1A,2A &3A
[5] Helium coolant, thickness less than 2 mm.</td></tr>
</table>

X=Not Allowed
F=Cross or Upset Forged
L= Low inclusion in compliance with 5.3.1 and ESR/VAR remelting
A=requires *acceptance*
NR = No requirement
N/A – not applicable

Table 5-2 Synopsised requirements pertaining to metallic components

6 Cutting and Machining

6.1 Use of Cutting Fluids

6.1.1 General

Care must be taken in manufacturing processes so as not to introduce contaminants into surfaces which may be difficult to remove later and which might result in degraded vacuum performance.

6.1.2 VQC 1 and 3 Cutting Fluids

Cutting fluids for use on VQC 1 and 3 systems shall be water soluble, non-halogenated and phosphorus and sulphur Free. The maximum allowable content of halogens, phosphorus, and sulphur is 200 ppm (each)

Accepted cutting fluids for use in VQC 1 and 3 vacuum applications are listed in Appendix 4. The use of other cutting fluids requires prior *acceptance*.

Acceptance for the use of any particular non-approved cutting fluid shall be obtained by submitting the Fluid Acceptance Request Form (ITER_D_48XLVJ) to the ITER Vacuum RO. An example of this form is to be found in Appendix 4.

6.1.3 VQC 2 and 4 Cutting Fluids

For VQC 2 & 4 vacuum applications it is recommended that cutting fluids be water soluble, non-halogenated and phosphorus and sulphur free (< 200 ppm for each). They should be chosen from those listed in Appendix 4. Where this recommendation is not followed particular care shall be taken to ensure the appropriateness of the cleaning procedures (See section 24).

6.2 Cleaning Prior to Joining

To minimise the risk of trapped contamination which can subsequently cause leaks or enhanced outgassing, parts and sub-components shall be degreased using solvents or alkaline detergents, rinsed with demineralised water, and dried prior to joining in accordance with Section 24 below. The use of halogenated solvents is forbidden at any stage for systems of class VQC 1 and 3. Accepted fluids are listed in Appendix 4.

7 Permanent Joining Processes

Permitted joining techniques for vacuum applications and their applicability to each VQC are shown in Table 7-1. Proposals for joining techniques not listed here shall be submitted for prior *acceptance*.

7.1 Welded Joints

Lack of attention to the details of vacuum sealing weld design, qualification and testing has proved to be a significant cause of vacuum leaks on vacuum systems.

All vacuum welds, except those excluded below, shall be qualified, produced and inspected in accordance with Attachment 1. The requirements of Attachment 1 are mandatory until superseded by the ITER baseline Welding Handbook.

Where there is regulatory requirement to design and subsequently build a vacuum system to RCC-MR or ASME VIII, the requirements of these codes shall take precedence over the requirements of Attachment 1, while remaining in compliance with Section 7.1.6. In other cases where vacuum sealing welds are to be qualified, produced and inspected to meet a code, and there is variation between the requirements of the code and Attachment 1, the more extensive or stringent requirements shall be applied.

	VQC 1		VQC 2		VQC 3		VQC 4	
	A	B	A	B	A	B	A	B
Welded joints	✓	✓	✓	✓	✓	✓	✓	✓
Brazed/soldered joints	✝	✝	✝	✝‡	✓	✓	✗	✓
Diffusion bonding	✓	✓	✓	✓	✓	✓	✓	✓
HIP	✓	✓	✓	✓	✓	✓	✓	✓
Compression joints	✗	✗	✝	✝	✓	✓	✓	✓
Adhesive bonding	✗	✝	✝	✝	✝	✝	✝	✝
Explosion bonding	✓	✓	✓	✓	✓	✓	✓	✓

✓ - indicates an acceptable technique ✗ - indicates an unacceptable technique

✝ - application specific *acceptance* required

‡- For soldering of super conducting joints see Section 7.2

Table 7-1 Joining methods applicable to VQC

7.1.1 Joint Configuration

The use of welds from both sides makes leak testing difficult and enhances the risk of trapped volumes forming virtual leaks or contaminant traps that are to be avoided. Thus, for all vacuum classes, vacuum sealing welds shall be either internal (i.e. facing the vacuum) or external. In VQC 2, double sided welding may be used where unavoidable, but an NDT inspection schedule giving 100% volumetric examination must be used to ensure that a full-thickness melt zone has been achieved.

The use of stitch welds on the vacuum facing side is prohibited.

For VQC 1A, VQC 2A and VQC 3A on the boundary to air or water, full penetration welds are required.

For VQC 4A (process to insulation vacuum) welds full penetration welds are required.

It is good engineering practice to design joints to be accessible for repair if necessary.

Butt welded joints are preferred to fillet or lap joints, since testability is improved. Fillet, corner, lap and cross joints should be avoided wherever possible on VQC 1 systems.

Welds shall normally be made in such a way that they can be leak tested at the time of completion. Welds that cannot be inspected (see Sections 7.1.4 & 7.1.6) are not permitted for use on VQC 1 and VQC 3 and should be minimised for use on VQC 2 and VQC 4. Where leak detection is not practical at the time of completion, a test plan including provision for repair of the weld must be *accepted* at the design stage.

7.1.2 Qualification of Welding Processes

Qualification of welding processes for use on vacuum sealing welds shall follow the requirements of Attachment 1 and section 7.1.

A welding and inspection plan shall always be submitted to the ITER IO.

7.1.3 Selection of the Welding Process

The selected welding technique for vacuum applications (e.g. electron beam, laser or TIG welding) should produce a clean, pore free weld with minimal oxidation. Autogenous welding shall be used where practical.

7.1.4 Inspection and Testing of Production Welded Joints

All such inspection and testing shall be carried out using approved procedures in accordance with Attachment 1.

For all VQC 1A, VQC 2A water boundaries, vacuum boundary welds which become inaccessible and VQC2A cryogenic pipework connections, 100% volumetric examination of production welds shall be performed, unless a method of pre-production proof sampling is approved.

For VQC 4A (process to insulation vacuum) 100% volumetric examination of production welds shall be performed, unless a method of pre-production proof sampling is approved.

The range of thickness and preferred volumetric examination method to be applied is given in Table 7-2.

Wall Thickness (wt) (mm)	Preferred Volumetric Examination Method
wt < 8	Radiography
8 < wt < 19	Radiography & Ultrasonic
wt > 19	Ultrasonic or radiography
Note: For wt > 19 mm ultrasonic examination of welds is preferred only in cases where radiographic examination would require excessive exposure times.	

Table 7-2 Range of wall thickness and preferred volumetric examination method to be applied

For all other vacuum boundaries, volumetric examination of 10% of production welds shall be performed with the wall thickness limits specified in Table 7-2, unless a method of pre-production proof sampling is agreed by the ITER IO.

On welds forming the vacuum boundary the use of liquid penetrant testing (LPT) or magnetic particle techniques shall not in general be permitted for the inspection of welds or in the inspection of weld preparations. This is because such substances may block leaks temporarily and can be difficult to remove satisfactorily.

Where there is a mandatory requirement to build a component to a code then the flexibility of the code to avoid the use of LPT on welds forming the vacuum boundary shall be a key factor in the assessment of that code for selection. The selection process shall be recorded and *accepted*.

Where a code selected for building a component requires the use of a qualified surface examination method, and LPT cannot be avoided, only the ITER vacuum qualified liquid dye penetrant (see Appendix 4) may be used. If the use of LDP is permitted, then cleaning must be performed to procedures qualified and subsequently *accepted* by the ITER Vacuum RO.

For VQC 1B welds which are subject to high cyclic stresses, the use of ITER qualified LDP for detection of surface defects is permitted subject to notification of this application to the ITER Vacuum RO.

For VQC 2B and 4B the use of ITER qualified LDP is permitted. The method of application and subsequent removal of LDP shall be performed to procedures qualified and *accepted* by the ITER Vacuum RO.

7.1.5 Weld Finish & Repair

Production welds used on all vacuum systems shall be left clean and bright but there is no vacuum requirement to machine the weld zone to match the surface finish of the parent material.

All weld regions shall be free from scale, voids, blowholes, etc., and there shall be no visible evidence of inclusions.

The size and magnitude of weld leaks found shall be reported to the ITER Vacuum RO and no weld repairs shall be carried out without prior agreement.

All weld repairs shall be qualified in accordance with the relevant design and construction codes where applicable, and with Section 7.1.2 above. Where RCCMR or ASME VIII is not applied, if a weld leak is found, the repair procedure shall be subject to specific *acceptance* by the ITER vacuum RO as well any other relevant approvals.

7.1.6 Helium Leak Testing of Production Welds

All vacuum sealing welds in each VQC shall be subject to helium leak testing in accordance with the procedures of Section 25.

Where multi-pass welding is required in the production of components of VQC 1A and VQC 2A, it is recommended that leak testing of the root weld pass shall be performed with only this pass completed. However, for multi-pass welding that takes place on the ITER site, this requirement is mandatory.

If it has been agreed that liquid dye penetrant may be used for testing such a weld (see Section 7.1.4), the root weld leak test shall be performed before the application of this liquid.

Any leak which is found in the root weld to be above the minimum detectable leak rate of the equipment which has been *accepted* for use in the *accepted* procedures for such tests, must be repaired and re-tested before proceeding with further weld passes.

In all cases, a further leak test shall be carried out (see Section 25).

7.1.7 Helium Leak Testing after Repair of Welds

All repaired vacuum boundary welds shall be subject to full vacuum leak testing in accordance with the procedures of Section 25.

7.2 Brazed and Soldered Joints

Brazing shall be carried out in a vacuum, hydrogen or inert gas atmosphere. Torch brazing is not permitted except where unavoidable for VQC 2B. Where the use of brazing flux is unavoidable a cleaning procedure shall be qualified and submitted for *acceptance* to the ITER vacuum RO.

Brazing materials which contain silver are subject to specific quotas for components for VQC 1, 2 or 3 in systems where the irradiation environment may lead to significant silver transmutation to cadmium. The use of such materials is subject to prior *acceptance*.

Brazing is not permitted for any water to vacuum joint in VQC 1, 2 or 3.

Brazing is not permitted for VQC 4A where there is contact with cryogenic fluid.

All brazing techniques shall be to an *accepted* standard or to a procedure *accepted* prior to manufacture.

On account of the relatively high vapour pressure of the solder, soft soldering (< 400°C with Sn, Zn, alloys of Pb, Cd, etc) shall not be permitted for VQC 1 or VQC 2A, or VQC 3A and is only allowable on VQC 2B for applications which operate at a temperature < 60 K.

7.2.1 Design of Brazed Joints

The design of brazed joints shall be such as to minimise the risk of trapped volumes.

7.2.2 Qualification of Brazed joints

All brazing techniques shall be qualified to an *accepted* standard or to an *accepted* qualification programme. Tests on pre-production samples of brazed joints shall be performed to *accepted* procedures or to an *accepted* standard. Brazing procedure qualification shall be compliant with EN 13134:2000 (or equivalent).

7.2.3 Inspection and Testing of Brazed Joints

Brazed joints shall be subject to qualification to ensure the vacuum integrity of the joint.

All brazed joints shall be inspected visually to ensure that the vacuum exposed braze regions are clean, flush and free from voids, blowholes, etc., that there is no visible evidence of inclusions and that the braze material has filled the joint without excessive over-run.

Where practicable, radiography of an agreed percentage sample of brazed joints shall be carried out. Where this is not practicable, then samples shall be produced for sectioning and microscopic examination.

The use of liquid dye penetrant or magnetic particle techniques shall not be permitted for the inspection of brazed joints or in the inspection of joint preparations.

All brazed joints which form part of a vacuum boundary shall be subject to 100% helium leak testing.

No braze shall be re-run for rectification of any sort without prior agreement.

7.3 Diffusion Bonding

Diffusion bonding of joints is acceptable for all VQC. If it is used, diffusion bonded inter-layers shall comprise materials listed in Appendix 3. Diffusion bonded joints shall be subject to the same vacuum qualification procedures as brazed joints to ensure the integrity of the joint and compliance with the requirements of this Handbook.

7.4 Explosion Bonding

Explosion bonding of metals is acceptable for all VQC. Explosion bonded joints shall be subject to the same vacuum qualification process as brazed joints to ensure the integrity of the joint and compliance with the requirements of this Handbook. Existing qualifications of the process may be used for VQC2 applications if compliant with the requirements of this Handbook.

7.5 Adhesive Bonding

Adhesive bonding may only be used in limited circumstances (see Table 7-1) and using materials listed in Appendix 3.

8 Surface Finish

8.1 Surface Roughness

Metallic components for different VQC shall be supplied with the maximum average surface roughness listed in Table 8-1. Surface roughness is defined in accordance with ISO 4287: 2000.

Classification	Maximum average Surface Roughness Ra (μm)	Measurement Technique
VQC 1	6.3	Electric stylus
VQC 2	12.5†	Electric stylus
VQC 3	12.5	Electric stylus
VQC 4	12.5	Electric stylus
† Where to satisfy this surface roughness requirement additional machining would be required a rougher surface is accepted provided the surface is easily cleanable and can be shown not to catch fibres when wiped with a lint free cloth.		

Table 8-1 - Maximum permissible average surface roughness for metals

Generally, where the base material is not produced with an acceptable surface finish, such surface finishes may be achieved using techniques including:

- Machining.
- Electropolishing.
- Bead Blasting in a slurry in a water jet with alumina or glass beads.
- Surface Passivation / Pickling (see Section 24.4).

All processes on vacuum surfaces shall be followed by appropriate cleaning of the surface (see Section 24 below).

8.2 Coatings

Only materials accepted by ITER for the relevant Vacuum Classification shall be used for coatings on ITER vacuum systems (see Section 5).

Surface coatings for VQC1 shall be subject to qualification and *acceptance* at the design stage. The assessment of the coating shall include consideration of :-

- The risk of the coating producing trapped volumes and temporary leak blocking.
- The method of applying the surface coating (e.g. painting, chemical, plasma spray, etc.).
- The chemical composition, morphology, cleaning and outgassing of the surface coating.
- Conformance of the coating with the ITER outgassing requirements as detailed in Section 5.4.

- The method for testing the adhesion of the surface coating to the substrate.

9 Confinement and Vacuum Containment

Confinement is the term used for the physical enclosure of hazardous substances (e.g. tritium).

“Vacuum containment” is a term used for vacuum tight boundaries which cope with differential pressure in either direction. Vacuum containment may also provide a confinement function.

Vulnerable components are generally considered to be those components which have been shown to exhibit a failure rate higher than 10^{-5} per year in an experimental environment and typically include windows, bellows, lip seals, flexible hoses, metallic to non-metallic joints, feedthroughs, electrical breaks, thin walled material (<1.5 mm), and demountable seals. Reliability data and references can be found in Appendix 18.

VQC 2 high voltage electrical breaks and high voltage feedthroughs are considered vulnerable only if they have a specified failure rate greater than 10^{-5} per year or have been shown, in the specific design proposed, to exhibit a failure rate greater than 10^{-5} per year.

VQC 1A components that are considered to be vulnerable shall be doubly vacuum contained with a monitored interspace connected to the Service Vacuum System (see Section 11). This requirement is necessary to achieve overall machine reliability. Lip seals which are accessible for repair in port cells are excluded from this requirement but shall have provision for remote leak identification. If a vulnerable component is accessible for maintenance and fitted behind an approved, interlocked, isolating valve then *acceptance* may be sought for single vacuum containment.

Demountable joints on VQC 1A shall use double seals with the interspace monitored and connected to the Service Vacuum System.

Demountable joints shall not be used for water to vacuum boundaries for any vacuum class.

Boundaries between VQC 1A and VQC 2A components that are considered to be vulnerable shall be doubly vacuum contained with a monitored interspace connected to the Service Vacuum System. This is a requirement to avoid an undetected leak of tritium into the cryostat vacuum.

VQC 2A components that are considered to be vulnerable are recommended to be doubly vacuum contained with a monitored interspace connected to the Service Vacuum System. Where it is considered that double vacuum containment increases the failure risk or failure consequences, then an alternative method to provide leak localisation and mitigation shall be proposed for *acceptance*.

An analysis of the probability of air ingress is required for safety and investment protection for any vacuum system which contains hydrogen and can reach a deflagration pressure above the design pressure. (For a 200 KPa design pressure the hydrogen isotope concentration limit is 1.5 mole/m^3 for volumes or 0.8 mole/m^3 for pipes). If the probability of air ingress is greater than 10^{-6} per year, then the probability shall be reduced by design. For example, measures such as double vacuum containment with a monitored interspace may be applied.

The requirements of this Handbook for VQC 1A will generally satisfy the requirements for primary tritium confinement (also see ITER Tritium Handbook ITER_D_2LAJTW).

The requirements of this Handbook for VQC 3A will generally satisfy the requirements for the temporary confinement of tritium in off-normal events and of levels expected to be permeated (also see ITER Tritium Handbook ITER_D_2LAJTW).

On ITER, the secondary tritium confinement function is generally performed by buildings, ventilation and detritation systems, and hence is not part of this Handbook.

Further information on requirements for the confinement of tritium can be found in the ITER Tritium Handbook (ITER_D_2LAJTW).

10 Trapped Volumes

For VQC 1 and VQC 2A, 3A and 4A, the design of any vacuum component shall avoid trapped volumes in vacuum spaces which could result in virtual leaks.

For VQC 2B, 3B and 4B, care in the design of any vacuum component shall minimise trapped volumes in vacuum spaces which could result in virtual leaks.

Communicating passages should be made between any potential trapped volume and the pumped volume. The design of welded and brazed joints shall be such as to avoid the risk of trapped volumes.

Care should be taken to avoid large areas of surface contact which, through imperfect flatness, can provide a trap for gas and impurities. Such surfaces, if required, should be channelled.

Where relief holes are necessary, these should preferably be in the “fixed” part of the work piece, rather than relying on, for example, the use of a vented screw which may be missed on assembly.

11 Connections to the Service Vacuum System

Interspaces, e.g. between double windows, double bellows, double-sealed valves, etc., should be designed to be connected to the Service Vacuum System (SVS) with a minimum of two independent connections in every case meeting the following requirements:

- Interspaces which have a total volume less than 50 L shall utilise 6 mm tube welded to 6 mm (1/4 inch) VCR male fittings.
- Where the interspace volume is between 50 L and 500 L, the connections to the SVS shall utilise 12 mm tube welded to 12 mm (1/2 inch) VCR male fittings.
- Interspaces with volume greater than 500 L shall be fitted with 40 mm tubes with flanges selected from those listed in Appendix 8 welded to the tubes.

This requirement is valid for all interspaces except where the interspace is to be pumped to less than 5×10^{-1} Pa, in which case connections to the SVS shall be *accepted* by the ITER Vacuum RO.

12 Pipework (Pipe & Fittings)

12.1 General

In all applications in VQC 1A and VQC 2A and VQC 4A (process to insulation vacuum), pipe and fittings shall be seamless. Where this is not possible, specific *acceptance* is required to use seamed components which shall conform to the testing requirements of Section 7.1.4.

To mitigate risk of the loss of availability associated with water leaks in the cryostat, it is recommended that single contained water pipes do not pass through the cryostat.

Where practical, for components classified as VQC 2A, water pipework forming part of the cryostat vacuum boundary shall be doubly contained. Where it is not practical to doubly contain the pipework, all welded joints shall be full penetration butt welds subject to 100% Non-Destructive Testing (NDT).

Interspaces on VQC 2A water pipework shall be brought out to the port cells or pipe chase area and provision made for water detection, draining and temporary vacuum connection for vacuum leak testing the interspaces.

Where interspaces are not used as a method of water leak localization for water pipes passing through the cryostat, an alternative *accepted* method shall be integrated with the water pipe design.

For VQC 1A and VQC 2A, & VQC 4A (process to insulation vacuum) pipework of wall thickness less than 2.0 mm designed to contain helium, Electro-Slag Remelted (ESR) or Vacuum Arc Remelted (VAR) material shall be used for the pre-extruded material and the inclusion limits of Section 5.3 adhered to.

In the case of VQC 4 (atmosphere to insulation vacuum), there is no restriction on the use of seamed pipe provided that it conforms to the testing requirements of Section 7.1.4.

12.2 Pipework Sizes

To comply with the ITER standard vacuum flange dimensions as specified in Appendix 8, standard pipework sizes shall be used where practical. Standard pipe sizes are listed in Appendix 11.

13 Demountable Joints

Demountable vacuum joints i.e. quick release couplings, compression joints, transition couplings, flange pairs, etc. for use on ITER vacuum systems shall be *accepted* prior to use. Lists of standard joints are given in Appendix 8.

For VQC 1 and 2 there shall be no demountable vacuum joints within the vacuum.

Vacuum joints for use on VQC 1, 2 and 3 systems shall use all-metal seals. In addition, vacuum joints for use on VQC 1A shall utilise a double seal arrangement, with the interspace connected to the Service Vacuum System consistent with Section 9 (Confinement and Vacuum Containment).

All demountable joints must be accessible for maintenance/testing.

In all cases the fixed sealing face of the vacuum joint shall be accessible for manned inspection and repair during periods of ITER maintenance.

Seal faces must have the requisite surface finish and cutting lay or lap direction for the seal design. Seal faces shall not be electropolished.

For VQC 4, demountable vacuum joints shall normally use all-metal seals, although the use of other types of seals is permitted subject to prior *acceptance*.

For all VQC, the reuse of metal seals is permitted for system testing only. However, the final mating of demountable vacuum joints shall be made using previously unused metal seals.

Where demountable vacuum joints are mated for testing purposes, the applied sealing bolt loading on the test flanges shall be consistent with the final sealing option utilised. Once the sealing flange is proven, temporary use of other sealing options can be permitted. When the item is in its operational position and a temporary seal is used this must be recorded using a non-conformance.

All demountable vacuum joints shall be subject to 100% helium leak testing to installation procedures following the guidelines specified in Appendix 12. Installation procedures shall be approved by the ITER Vacuum RO. A design guide for the manufacture of demountable joints and sealing options for use on ITER vacuum systems is given in Appendix 8.

14 Fasteners and Fixings

14.1 Tapped Holes

Blind tapped holes shall be avoided as far as possible, since in addition to being a source of virtual leaks (see Section 10), they provide a potential trap for contaminants. Where the use of blind holes is unavoidable, holes shall be tapped with flat bottoms and vented screws or bolts shall be used.

Tapped holes shall be cut using only the approved cutting fluids listed in Appendix 4. Cutting fluids not listed in Appendix 4 may be *accepted* in advance by the ITER Vacuum RO and submitted for inclusion in Appendix 4 using the procedure in Section 5.2. Where an insertion is used to provide a screw thread in a plain hole (e.g. Helicoil™ inserts), the material used shall be consistent with those listed in Appendix 3.

14.2 Bolts

14.2.1 Bolts for use on the Vacuum Boundary (P < 0.15 MPa)

It shall be demonstrable that bolts for use in the formation of a vacuum boundary are of satisfactory mechanical properties to provide the relevant seal force requirements of Appendix 8. Bolts should be of rolled thread and supplied with certification in accordance with EN 1024, 3.1.

14.2.2 Prevention of Bolt Seizing

For all VQC, threaded fixings (e.g. bolts), shall be treated to prevent seizing. Approved solid (dry) lubricants, aluminium bronze inserts or coatings are preferred.

Lubricants for each class are listed in Appendix 3. The use of any other lubricant is subject to prior *acceptance*. Bolts for use on ITER vacuum systems but not exposed to vacuum (i.e. VQC N/A), shall be lubricated to prevent seizing with a hard coating or, where appropriate, Molykote®.

14.2.3 Bolt Locking

It is recommended that bolts in vacuum for use on VQC 1 and VQC 2 systems shall be locked after loading to prevent them becoming free and causing damage to other parts of the vacuum system. Bolts may, for example, be locked using resistance spot welded stainless steel tangs. Other suitable materials may be selected from those listed in Appendix 3.

14.3 Riveting

Riveting is an approved technique for the joining of components in VQC 2B and 3B. Rivets shall only be formed from the materials listed in Appendix 3.

Trapped volumes formed by riveting shall be eliminated at the design stage in accordance with Section 10 above.

14.4 Bearings and Sliding Joints

Designs for in-vacuum bearings and sliding joints for VQC 1 to 3 shall be subject to prior *acceptance* at the design stage. These should be eliminated by design wherever practical, for example by the use of flexure pivots. Solid (dry) lubricants or coatings are preferred, but other permitted lubricating materials are listed in Appendix 3.

In VQC 2 and 4 applications, polytetrafluoroethylene (PTFE) bearings are approved for positions where the predicted radiation fluence over the full operational life of ITER is less than 10^3 Gray (up to 10^6 Gray for *accepted* cross-linked PTFE) (Gamma or Neutron dose equivalents).

15 Windows and Window Assemblies

15.1 General

Window assemblies for VQC 1 and VQC 2 shall be double, with no ’design basis’ common mode failure between the two windows, or shall be fitted behind a UHV isolation valve and have direct connection through the window to a VQC 3 vacuum system.

For windows transmitting high power (e.g. RF heating systems) the interspace pressure shall be continuously monitored and suitably interlocked with the power system.

Window assemblies accessible from outside the vacuum systems should incorporate mechanical protection against accidental impact.

For VQC 1A double window assemblies to air, the maximum diameter permitted is 160 mm.

An example of a specification for the design, qualification, manufacture and acceptance testing of window assemblies for use on ITER vacuum systems can be found in Appendix 6.

15.2 Qualification of Window Assemblies

Prior to manufacture, the design of window assemblies shall be qualified by performing type tests on pre-manufacture window assemblies. The *supplier* shall submit for *acceptance* a qualification test plan detailing the qualification tests to be performed in order to qualify the window for a particular application.

The qualification of the window assemblies for use on a vacuum boundary shall include the following tests:

- Pressure testing of window assemblies.
- Mechanical shock testing.
- Thermal shock testing.
- Helium leak testing.

15.3 Testing of Window Assemblies

Prior to the manufacture of window assemblies the *supplier* shall supply for *acceptance* a test plan and test procedures detailing the tests to be performed on window assemblies before delivery to the ITER site. After the completion of all manufacturing processes the window assemblies shall be subject to a thermal cycle test, pressure test, and helium leak test.

Acceptance testing of window assemblies which operate at elevated temperatures requires a minimum of three thermal cycles to be performed to their maximum operating temperature consistent with Section 25.5.

16 Vacuum Valves and Valve Assemblies

For VQC 1, 2 & 3, valves shall be of all-metal construction with the exception of the valve closure seal, for which polyimide is also permitted.

For VQC 2 valves, elastomers may be used on the valve closure seal only with the prior *acceptance* of the ITER Vacuum RO.

For VQC 4, valves need not be all-metal except where they may be in contact with cryogenic fluids.

For VQC 1A all actuating and actuator bellows and seals shall be of double construction with the interspaces connected to the Service Vacuum System (see Section 11). Valves requiring compressed gas to maintain a seal shall be avoided where practical and any use requires prior *acceptance.*

Valve assemblies shall normally be installed such that the internal actuating system for the valve is on the side exposed to lower vacuum quality or to atmosphere and the seal face to the higher vacuum quality side. To facilitate this, all valve assemblies shall be permanently marked on the outside with an arrow pointing towards the seal face end of the assembly.

The valve position shall be positively identified by means of “open” and “closed” limit switches and a visual position indicator shall be provided on the valve or actuator body.

16.1 Acceptance Testing of Vacuum Valves and Valve Assemblies

Prior to shipping, valves shall be subject to an acceptance vacuum leak test. Detailed leak testing procedures shall be submitted for prior *acceptance*. Guidance can be found in Appendix 12.

Valve testing shall include the following helium leak tests:

- Valve body (global).
- Across the valve seat.
- Valve actuator bellows.
- Internal pressure element.
- Valve double bellows interspace.

Valves for use on VQC1 systems at elevated temperature shall be baked and hot leak tested at 200 °C.

An example specification for the design, manufacture and testing of valves for use on ITER vacuum systems is given in Appendix 7.

17 Bellows and Flexibles

17.1 General

In general, bellows and flexibles are considered to be inherently vulnerable components (see section 9) due to their method of construction and because their application is typically to facilitate movement.

The use of bellows or flexibles in water circuits inside vacuum systems with any VQC shall be avoided by design wherever possible, and shall only be only permitted with prior *acceptance* for VQC 1A and VQC 2A when the surrounding vacuum is behind an isolation valve. For such usage, consideration must be made at the design stage to proven reliable performance in similar applications. Double bellows are not recommended for use in water circuits in vacuum.

In all test situations and after installation, the bellows shall be protected against all abnormal load conditions. This may include the design of physical constraints.

An example of a specification for the design, qualification, manufacture and acceptance testing of bellows assemblies for use on ITER vacuum systems can be found in Appendix 9.

17.2 Bellows Protection

Bellows shall be protected against damage from falling objects. The bellows protection shall be equivalent too, or better than, that provided by a cover of schedule 20 pipe.

17.3 Design of Bellows

Circular bellows are to be designed to the EJMA or EN14917 or equivalent. The use of other design codes is subject to *acceptance*. Where design codes are not applicable, design shall be by analysis and shall be proven by qualification.

Care shall be taken to ensure that the operational loading parameters are fully considered. Precautions need to be taken against rupture and other failure modes where there is a pressure difference in either direction between the inner and outer surfaces of the unit.

Bellows for use on VQC 1 systems shall be of double construction (or *accepted* multilayer design) with a monitored interspace, unless they are accessible for maintenance and fitted behind an approved interlocked isolating valve.

Where bellows are be used on VQC 2 systems it is recommended that they be of double construction (or *accepted* multilayer design) with a monitored interspace.

Multiple ply bellows are not permitted for VQC 1A components unless they are accessible for maintenance and fitted behind an approved isolating valve.

For VQC 1A and VQC 2A, where regular and significant movement is to be taken up by a double bellows, the norm shall be to design the double arrangement such that one bellows is in compression whilst the other is in expansion so as to reduce the chances of a common mode failure.

The interspace between the two bellows of an assembly shall normally be filled with a suitable tracer gas and the pressure in the interspace shall be continuously monitored. The interspace shall be connected to the Service Vacuum System (see Section 11).

Normally accessible bellows assemblies and bellows assemblies which become accessible during machine maintenance shall be supplied with mechanical protection (such as the use of metal braiding or removable cover plates) to prevent accidental damage and ingress of matter to the bellows edge-welds or convolutions.

Non-circular bellows of non edge-welded construction are to be welded and then formed, rather than formed in parts then joined. This does not apply to the post-forming welding of bellows sections to collars. Cross welds are to be avoided where possible.

Hydrostatic, rolling or elastomeric formation is approved for all vacuum classes.

Bellows which are of edge-welded construction shall be acceptable provided that they comply with Section 7.1.

Cleaning of bellows shall be in accordance with the requirements of Section 24.

17.4 Qualification of Bellows

Bellows designed by analysis shall be subject to a qualification procedure prior to manufacture. The design of bellows shall be qualified by performing type tests on pre-manufacture bellows assemblies. The *supplier* shall submit for *acceptance* a qualification test plan detailing the qualification tests to be performed.

The qualification of the bellows assemblies shall include the following:

- Pressure test.

- Fatigue life test.
- Mechanical shock testing.
- Helium leak test.

17.5 Testing & Inspection of Bellows

Prior to the manufacture of bellows assemblies the *supplier* shall supply for *acceptance* a test plan and test procedure detailing the tests to be performed on bellows assemblies before delivery to the ITER site. After the completion of all manufacturing processes the bellows assemblies shall undergo a vacuum baking cycle to the operating temperature and a helium leak test. The *supplier* shall perform a survey of the bellows convolutions to confirm compliance with the bellows technical specification. The survey results shall be supplied to ITER and any non-conformance may lead to rejection of the bellows.

17.6 Bellows Protection

Bellows shall be protected against damage from falling objects. The bellows protection shall be equivalent too, or better than, that provided by a cover of schedule 20 pipe.

18 Feedthroughs

18.1 General

Where for VQC 1A and 2A a feedthrough penetrating the air boundary is considered vulnerable (see Section 9) a doubly vacuum contained electrical feedthrough with interspace connected to the Service Vacuum System shall be used. Where necessary, alternative arrangements shown to ensure sufficient integrity of the feedthrough may be *accepted*.

The sheaths of mineral insulated cable shall not pass directly through a VQC 1A and 2A feedthrough, but shall be discontinuous and sealed within feedthrough interspaces.

Where applied or induced voltages may be present on such feedthroughs, then protection against arcing or Paschen breakdown shall be provided.

18.2 Paschen Breakdown

Where there is a risk that Paschen breakdown may occur in an interspace of a feedthrough, it must either be continually pumped or be backfilled with a gas of *accepted* composition to a pressure appropriate to mitigate the risk of Paschen breakdown.

In both cases, the interspace pressure must be continuously monitored and interlocked with the system controls to prevent power being applied in the event of single barrier failure.

19 Electrical Breaks

Where for VQC 1A and 2A, an electrical break (i.e. providing electrical isolation between systems) is considered vulnerable (see Section 9), a doubly vacuum contained electrical break with interspace connected to the Service Vacuum System shall be used, unless it is accessible for maintenance and fitted behind an approved interlocked isolating valve.

If an electrical break is at risk of Paschen breakdown in an external or internal rough vacuum, suitable precautions shall be taken to ensure that the risk of breakdown is eliminated.

20 Cables for use in Vacuum

20.1 General

Up to 80 km of cables are anticipated in the ITER vacuum vessel. Many kilometres are also required in the cryostat. Special care shall be taken in the choice and quality control of such cables. In-vacuum cabling shall comply with all the general vacuum requirements for its VQC.

In particular:

- Materials shall be selected to be in accordance with Appendix 3.
- Outgassing shall be consistent with Table 20-1.

VQC	**Outgassing temperature (°C)**	**Maximum steady state outgassing rate per unit length+ [$Pa.m^3.s^{-1}.m^{-1}$]**		**Testing guidelines**
		Hydrogen Isotopes	**Impurities**	
1	100	1×10^{-9}	1×10^{-11}	Appendix 17
2‡	20	1×10^{-9}		Appendix 17
3	20	1×10^{-10}		Appendix 17
4	20	1×10^{-9}		Published data and conformity to clean work plan.

For VQC 2, 3 & 4 the total outgassing rate excludes water and hydrogen.

+Valid for cables up to Ø 5mm outer sleeve. Pro-rata values can be applied for larger cables.

‡ The requirements for high voltage cables in the cryostat are still being studied and hence requirements will be specified in future.

Table 20-1 – In vacuum cabling outgassing rates

Approved cable types pertaining to each VQC are listed in Appendix 10. The use of other cables is subject to prior *acceptance*.

All mineral insulated cables shall be sealed at both ends, and the void volume shall be less than 5%. The cable shall be proven to be leak tight, consistent with the levels for VQC 1 and VQC 2 given in Table 25-1, by helium bombing (see Appendix 12).

Specification for the manufacture and qualification of in-vacuum cables shall be *accepted* by the ITER Vacuum RO prior to production. A guide for the supply of in-vacuum cables can be found in Appendix 10.

20.2 Connectors and Terminations

In-vacuum connectors shall comply with the general vacuum requirements for the relevant VQC.

21 Interconnection between VQC 1 systems

Any system which can be directly connected to the main ITER tokamak vacuum by opening a valve shall have, as a minimum, full range pressure monitoring. Residual gas analysis capability is also required for systems with volume > 1 m^3.

The control of the isolating valve shall be via the ITER vacuum control system. Signals for all vacuum monitoring shall be made available to the ITER vacuum control system.

Any necessary inhibits on valve movements required to protect the sub-system, shall be made available to the ITER vacuum control system.

22 Proprietary Components

In the context of this Handbook, proprietary components are standard products which are listed in *supplier's* catalogues and are sufficiently well documented for their specification to be checked for fitness for purpose.

Proprietary components fully meeting the ITER specification of the item and the requirements of each VQC are permissible for use.

For VQC 1, 2 and 3, proprietary components meeting the requirements of this Handbook shall be supplied with an individual certificate of conformity, stating that the item conforms to the specification provided by the *supplier*.

For VQC 4, proprietary components shall be supplied with a certificate of conformity as above, but this may be in the form of generic or type conformance certificates to the catalogue specification.

A list of standard proprietary components which are known to conform to the requirements of this Handbook and so can be recommended for use on ITER vacuum systems is to be found in the Appendix 20.

Other proprietary components will be added to Appendix 20 when they are shown to meet the requirements of this Vacuum Handbook. Proposed additions should be submitted to the ITER Vacuum RO for consideration using the form in Appendix 20.

23 Vacuum Instrumentation

The requirements stated below shall be applicable to any instrumentation that directly interfaces with ITER vacuum spaces, and is applicable to all Vacuum Classifications.

In all cases instrumentation shall be compatible with ITER operational requirements and the ITER physical environment. This shall include among other matters:

- Being compatible with the relevant VQC.

- Being compatible with operation in a hydrogen environment.
- Exhibiting an outgassing rate consistent with those given in Section 5.4.
- Being leak tight consistent with Table 25-1.
- Being resistant to neutron and gamma radiation at the instrument location. The radiation map to define these levels is defined in the ITER Room Book. See also Appendix 3.
- Being able to survive any pressure within the full operational and off-normal range (from 10^{-9} Pa to 0.15 MPa for VQC 1 and 2).

Instrumentation shall be servicing free to the maximum extent.

Generally on VQC 4, wherever the operational environment permits, active sensors may be used.

VQC 1 and 2 Instrumentation for use in the control of vacuum shall be fitted behind a UHV isolation valve or have agreed redundancy, and shall be accessible for maintenance.

24 Cleaning and Handling

24.1 Cleaning

Cleanliness is required during the whole manufacturing process and the preservation of cleanliness is good practice for any component to achieve the necessary vacuum standards and to minimise the time required to recover from any contamination incident. All components shall be subjected to a rigorous cleaning procedure, consistent with the Vacuum Classification of that particular component. A guide to cleaning and handling of components for use on ITER vacuum systems can be found in Appendix 13.

A detailed Clean Work Plan shall be submitted for prior *acceptance* to the ITER Vacuum RO before any cleaning operations are undertaken at the *supplier's* site. The plan shall specify how cleanliness will be maintained throughout the manufacturing process. It shall state when specific cleaning procedures will be applied and all of the controls which will be in place to maintain cleanliness, including handling.

Parts and sub-components shall be degreased using solvents or alkaline detergents, rinsed with demineralised water, and dried in hot gas or an oven to *accepted* procedures. The use of halogenated solvents is forbidden at any stage.

Lists of accepted cleaning fluids can be found in Appendix 4.

VQC 2 components incorporating cryostat vacuum-facing resins give a risk from volatile surface compounds which, if sticking to the reflective coatings of the tokamak thermal shields, could degrade the emissivity of the shields. As no acceptable procedure is foreseen for cleaning volatiles from a resin surface, care shall be taken not to introduce them to the surface.

24.2 Design Rules for Cleanability

At the design stage for a vacuum component, careful consideration shall be given to how the item is to be cleaned. In particular, crevices, blind holes, cracks, trapped volumes, etc., shall be avoided as these will act as dirt and solvent traps and it can be very difficult to remove contaminants from such areas. Fortunately, good vacuum practice regarding trapped volumes will also usually result in a component which is cleanable.

24.3 Mechanical Processes on Vacuum Surfaces

Abrasive techniques to clean or to attempt to improve the appearance of the surfaces of vacuum components must be kept to an absolute minimum and are preferably avoided. For all VQC the use of files, harsh abrasives, sand, shot or dry bead blasting, polishing pastes and the like is prohibited under normal circumstances and may not be used without prior agreement. However, for VQC 2, shot or dry bead blasting is permitted. Stainless steel wire brushes, cleaned to the standards of this handbook, may be used only when it is considered essential to do so.

If grinding is essential on VQC 1 systems, the grinding wheel shall be free of organic components and shall have been manufactured in an oil-free, clean environment. The material and manufacturing process of the grinding wheel shall be *accepted* by the ITER Vacuum RO before use.

24.4 Pickling/passivation of Steels and Copper

If an assembly is pickled, then final machining of vacuum sealing surfaces must be left until after the pickling/passivation process.

Pickling should always be followed by passivation. This is best carried out chemically, although native oxide layers can reform on exposure to atmosphere. Pickling and passivation must always be followed immediately by an appropriate cleaning process relevant to the VQC of the component.

It should be noted that thermal outgassing from surfaces which have been pickled/passivated may well be greater than that from a native metal surface and baking may be required to reduce outgassing rates to acceptable levels prior to installation.

A guide to the pickling/passivation of steels and copper can be found in Appendix 14.

24.5 Post-Cleaning Handling of Vacuum Equipment

After final cleaning, the handling of vacuum equipment shall be strictly controlled to preserve cleanliness. General area cleanliness requirements pertaining to Vacuum Classifications are summarised in Table 24-1. The continuing suitability of any given area used for handling vacuum equipment should be checked on a regular basis by monitoring the airborne particulate count, which should not exceed 5×10^6 particles of size > 0.5 µm per m^3 for VQC 1.

VQC	Cleanliness requirements	Personnel	Area Cleanliness	Monitoring
1	Segregated clean area. Limited Access to authorised personnel. Authorised equipment operated to approved	Trained personnel. Protective hair nets. Clean powder free latex or nitrile outer gloves.	Daily Cleaning of area including floors and surfaces. Sticky mats at area entry.	Daily air quality checks. Results stored in component document package.

	procedures. Management of equipment (e.g. no vacuum pumps or other machinery exhausting into clean area).	Clean white overalls. Overshoes. Clean job specific footwear.		Weekly cleanliness test of area with results stored in component document package.
2	Authorised equipment operated to approved procedures. Management of equipment (e.g. no vacuum pumps or other machinery exhausting into clean area).	Trained personnel. Clean outer protective gloves for the handling of clean equipment.	Daily Cleaning of work area including floors and surfaces.	
3&4	House Keeping.	Trained personnel. Clean powder free latex or nitrile outer gloves for the handling of clean equipment.	Daily cleaning of area.	

Table 24-1 – Environmental cleanliness pertaining to VQC

Additional cleanliness requirements shall be defined in the component installation procedures.

Handling cleanliness guidelines for each VQC are detailed in Appendix 2.

24.6 Cleanliness during the Assembly of Vacuum Equipment

The mandatory requirements relating to cleanliness during assembly of vacuum equipment are detailed in Attachment 2 (ITER_D_MBXPP3).

25 Leak Testing

25.1 General

Generally, leak tests shall be performed:-

- During manufacturing to confirm the soundness of joining processes and sub-components and to reduce the risk of Incorporating leaks in a system that are subsequently difficult to locate or to repair.
- As an acceptance test at the *supplier's* site to show that completed assemblies meet the acceptance leak criteria.
- When a component arrives at the ITER site, to confirm that there has been no damage during packaging and transport. This test, which is under the control and at the discretion of ITER, will be designed to be as simple and fast as possible.
- During installation, under the control of ITER, when testing is implemented to reduce the risk of newly made joint leaks only being detected at the completion of the total installation.

- On pumping down of the completed installation as part of the final commissioning.

Leak testing shall be carried out by suitably trained and experienced personnel. Acceptance test methods require prior *acceptance*. Guidance can be found in Appendix 12.

Leak testing shall be performed after pressure testing (if applicable). Before leak testing, components shall be cleaned, dried or baked in accordance with Section 27 of this Handbook.

Unless otherwise specified in the relevant contract or Procurement Arrangement the supply of any vacuum component shall include all testing jigs, flange closure plates (welded or otherwise) and fittings to allow helium leak testing at the ITER site. These may be the same items that were used for tests prior to delivery. Methodologies for the subsequent removal of such features shall also be supplied.

The requirement to leak test proprietary components delivered to the ITER site with a *supplier's* Certificate of Compliance may be waived by ITER at the discretion of the ITER Vacuum RO.

25.2 Maximum Acceptance Leak Rates

Maximum acceptance leak rates for several of the ITER vacuum systems are given in Table 25-1.

Any concession to permit leak rates greater than those specified in Table 25-1 can only be by prior *acceptance*.

25.3 Design Considerations for Leak Testing

All components and systems forming a vacuum boundary shall be designed so as to facilitate leak testing using tracer gas leak detection methods during the building of ITER.

Components shall also be designed to facilitate the timely localization of leaks occurring during ITER operations. Different techniques can be considered which may include the provision of small-bore tubing to allow the introduction of helium to the vicinity of potential leaks.

The design of vacuum systems shall be such that leak tightness can to be proven across all vacuum boundaries.

25.4 Scheduling of Leak Tests

Prior to manufacture the *supplier* shall have an *accepted* leak test plan detailing the timing and type of tests to be performed during manufacture. The plan shall include which tests are to be witnessed by the ITER or Domestic Agency Vacuum Specialist.

The ITER Vacuum RO shall be informed a minimum of two weeks in advance of a test requiring witnessing by ITER.

Scheduling of leak testing shall be in compliance with the ITER Leak Testing Policy (ITER_D_L5P5P2).

System/ Component	Maximum Leak Rate (Pa.m^3/s air equivalent†)
VQC 1 *	1×10^{-10}
VQC 2*	1×10^{-9}
VQC 3*	1×10^{-9}
VQC 4* (Atmosphere to insulation Vacuum)	1×10^{-7}
VQC 4* (Process line to insulation Vacuum)	1×10^{-10}
Tokamak primary vacuum (including all in-vessel components and attachments)	2×10^{-7}
Vacuum vessel (Including ports but excluding attachments) (Total allocation of leakage into main chamber vacuum)	1×10^{-7}
Individual vessel sector (Total allocation to a sector main chamber vacuum assuming enclosed)	1×10^{-8}
Individual field joints (covers port and sector field joints)	1×10^{-8}
Individual port plugs (complete)	5×10^{-10}
Each NB/DNB injector enclosure	1×10^{-8}
Cryostat vessel (excluding contents)	5×10^{-5}
Completed Cryostat (including all in-cryostat components and attachments) ‡	1×10^{-4}
Central solenoid assembly‡	1×10^{-7}
Individual PF-coil assembly‡	1×10^{-7}
Individual TF-coil assembly‡	1×10^{-7}
Complete thermal shield assembly‡	1×10^{-5}

*Individual system or component not otherwise mentioned.

† Helium equivalent Leak Rate (LR) = Air equivalent x 2.69 at the same temperature.

$$\frac{LR_{Helium}}{LR_{Air}} = \frac{\sqrt{M_{Air}}}{\sqrt{M_{Helium}}} = 2.69\,(\mathrm{M} = \text{atomic mass})$$

‡ Values quoted refer to systems under normal operational pressures and temperatures. Conversion to room temperature and atmospheric pressure tests can be supplied on request.

Table 25-1 Maximum acceptance leak rates for various vacuum systems

Generally it is advised that component parts should be tested before assembly, but final assemblies must be tested before shipping to ITER. For VQC2A in the case of a construction with many joints which become embedded and inaccessible in an assembly, then individual leak tests may be *accepted* as an acceptance test to replace final assembly acceptance leak testing prior to shipping.

Leak testing may be performed at the ITER site following transportation of vacuum components prior to it being accepted by ITER for installation.

Installation leak testing will be carried out to *accepted* procedures as part of the ITER assembly. All ITER vacuum systems will undergo final leak testing as part of the integrated commissioning of the ITER machine.

25.5 Methods and Procedures

The leak test procedure for acceptance tests shall be *accepted* in advance by the ITER vacuum RO. The procedure shall describe how the leak test will be performed, and include configuration diagrams and full details of the equipment to be used. Guidance on acceptable methods of carrying out leak testing is given in Appendix 12.

The acceptance leak test method shall ensure leak tightness is proven across all vacuum boundaries.

Test conditions (pressure, temperature) for the acceptance leak test shall be as close as practical to the design conditions. Testing shall be carried out with the component at ambient temperature and as close as practical to both its maximum and minimum design temperatures. The direction of the pressure differential shall normally be in the same direction as during operation exhibited by the components. Exceptions will be considered for the larger ITER components for tests prior to the final commissioning tests.

Where acceptance leak tests are not to be performed on cryogenic systems at cryogenic temperatures, a method of cold leak testing any welded connections shall be *accepted* in advance.

For an acceptance helium leak test, the helium concentration around the test piece shall be at a minimum of 50% for the duration of the test. The helium concentration shall be measured and recorded. The helium shall be maintained for a period calculated to be sufficient to identify leaks at the acceptance level.

Acceptance leak tests on VQC 1A or VQC 3A components which include joints of dissimilar materials[2] shall be subject to a minimum of three thermal cycles from ambient to the maximum possible operating temperature prior to leak testing. The time taken for any component to reach the specified bake temperature from ambient shall be less than 100 hours.

A representative of the ITER Organisation may inspect the *supplier's* leak testing equipment and witness a proof of procedure prior to the acceptance leak test.

Acceptance leak tests shall be witnessed or, where there are many tests agreed to form the acceptance leak testing, a representative sample of the test shall be

[2] Metallic joints shall be considered to be of dissimilar materials if the difference in linear thermal expansion coefficients over the operating temperature range of the materials comprising the joint is greater than or equal to 20%. Joints between non-metallic materials shall be considered as dissimilar.

witnessed. The ITER Vacuum RO shall nominate or approve the Vacuum Specialist to witness the acceptance leak tests. ITER may require that other key (ITER_D_L5P5P2) leak tests to be implemented as part of a manufacturing process be witnessed. Those tests to be witnessed by ITER, including the acceptance tests, shall be defined in the Manufacturing Inspection Plan (MIP).

25.6 Acceptance Leak Testing at the *Supplier's* Premises

The *supplier* is responsible for the supply of all testing equipment, vacuum components, all testing jigs, flange closure plates (welded or otherwise) and fittings to allow an acceptance helium leak test to be carried out.

No repair or re-work of the components (with the exception of simple tightening of flange joints or replacement of gaskets) shall be undertaken without prior agreement. Any repair or rework will require the leak test procedure to be repeated and may include a repeat leak test at the operating temperature.

No vacuum component which fails to meet the specified acceptance leak rate at the *supplier's* site shall be accepted for delivery to the ITER site without prior *acceptance*.

25.7 Acceptance Criteria for Leak Testing

On successful completion of the specified leak tests, the item under test may be accepted provided the following conditions have been met:

- The leak detector in the test configuration has been calibrated and its calibration value is within the limits of ±5% of the nominal value of the standard leak rate value, taking into account the ambient temperature and the age of the standard leak.
- The background level of the leak test was below the acceptance leak rate without electronic correction prior to the test.
- The reading from the leak detector has not increased in value above the measured background by more than the specified leak rate as defined for the item under test throughout the entire duration of the leak test procedure.
- The test has been performed to the agreed procedure and, where specified in the Quality Plan, has been witnessed by the ITER Vacuum Specialist.

25.8 Acceptance Leak Testing at the ITER site

Normally, vacuum components shall be subject to a leak test at the ITER site following transportation. The purpose of such a test is to reduce the risk of installing a leaking component and is of particular importance for components which would have a high impact to replace or repair. This test will normally be performed by ITER but a *supplier* may witness this test. This test may be a more limited test than that performed at the *supplier's* site and may be performed at ambient temperature at the discretion of the ITER Vacuum RO.

25.9 Reporting of Leak Tests

Full records of the tests carried out shall be compiled in order to maintain traceability of the leak test history of a particular item. The records shall become part of the final document package for the component concerned. Records shall include the following:

- Data records of the output of the leak detector for all the global tests specified including the standard leak calibration and response time determination. These data records shall include the date and time of all the tests as well as any other data necessary to allow a full analysis of the results, such as the start and finish of helium gas application to the item under test.
- A record of the helium concentration during the leak test.
- A record of the system total pressure and temperature during a temperature cycle as it may pinpoint the time when a leak opened up and be instrumental in the subsequent diagnosis of the leak.
- The make and model of the helium mass spectrometer leak detector used in the test.
- The nominal value of all standard leaks used, their date of calibration, ageing and temperature characteristics, and the ambient temperature(s) experienced during the tests.
- Results of all tests showing whether it was a pass or fail and if a failure, the measured leak rate and the location of the leak plus the steps taken for repair or elimination.
- The magnitude and location (if applicable) of all leaks identified during testing. This includes leaks of size lower than the acceptance criteria for which no remedial action may have been taken.
- A full record of any residual gas scans taken with appropriate time markers to identify the scans to the position in the component leak test cycle.

An example template for the reporting of leak tests is provided as part of Appendix 12

26 Baking

26.1 General

Vacuum components for the various classifications may require to be baked to ensure satisfactory vacuum performance. Raw materials may also require baking before being used in manufacture if a higher temperature is required to achieve satisfactory vacuum properties than will be possible later.

Baking can be included in the component leak testing procedure (see Section 25) and/or the component cleaning procedure (see Section 24). A bake temperature and duration will normally be specified in the specification documents and/or drawings for individual components or assemblies. If this is not the case, then the standard temperatures listed in Table 26-1 shall be used. Normally, the time taken for any component to reach the specified bake temperature from ambient shall be less than

100 hours and the component shall normally be held at the baking temperature for a minimum of 24 hours.

Where the *supplier* is unable to carry out a bake procedure, either to the standard conditions in Table 26-1 or as otherwise specified, then any variation shall be agreed with ITER before proceeding.

For all vacuum components that require baking, a detailed procedure describing the baking process shall be submitted for *acceptance* before any baking is started. The acceptable leak rate and vacuum conditions of any baking chamber shall be agreed as part of this procedure.

Vacuum ovens containing heating filaments within the vacuum are not permitted for VQC 1 baking operations without full qualification of the baking process.

Post bake handling of vacuum components shall be in accordance with Section 24.5.

A guide to the vacuum baking of components, including baking temperatures, is to be found in Appendix 15.

26.2 VQC 1 Components (non plasma-facing)

After manufacture, VQC 1 non plasma-facing components which operate at elevated temperature shall be baked using the guidance of Appendix 15. Baking shall be for a minimum of 24 hours at the maximum operating temperature. The bake cycle may be performed as part of the cleaning process or, if applicable, the hot leak test. There is no vacuum requirement to bake at temperatures in excess of the design temperature.

26.3 VQC 1 Components (plasma-facing)

To ensure vacuum cleanliness and to reduce impurity outgassing, components which are plasma facing or operate within 0.25 m of plasma shall be conditioned after manufacture by vacuum baking following the guidance of the ITER Vacuum Handbook Appendix 15. For VQC 1 component materials in proximity to the plasma, the normal vacuum baking temperature is given in Table 26-1. Where the temperature is too high for a composite assembly, the component part requiring higher temperature baking shall be baked at that temperature prior to assembly and then the complete assembly baked at the lowest listed temperature of the component parts. Temperature requirements for baking materials not listed shall be agreed in advance of baking operations.

For any individual component, the point in the manufacturing schedule or testing procedure at which such bake or bakes is carried out and the maximum temperature used shall be agreed with the ITER Vacuum RO. Post baking handling shall be minimised to preserve cleanliness and shall be in accordance with Section 24.

Component Material	Baking temperature (°C)[1]
Beryllium	350[2]
Stainless Steel (all grades)	250
Carbon Composites	450 or 2000[3]
Precipitation-hardened copper alloys	250
Tungsten	350

[1] Maximum temperature for baking complete systems may be limited by the system components

[2] A 250 °C baking cycle for a substantially increased duration at may be permitted on approval.

[3] Section 26.7 and Appendix 16

Table 26-1 Baking temperature VQC 1 materials in proximity to the plasma

26.4 VQC 2 Components

There is normally no vacuum requirement to bake VQC 2 components, but baking may be used as part of the cleaning and surface conditioning process to achieve the outgassing requirements of Table 5-1.

26.5 VQC 3 Components

There is normally no vacuum requirement to bake VQC 3 components, but baking may be used as part of the cleaning and surface conditioning process to achieve the outgassing requirements of Table 5-1.

26.6 VQC 4 Components

There is no vacuum requirement to bake VQC 4 components.

26.7 Vacuum Conditioning of Carbon Composites

In order to remove impurities from graphite or carbon fibre composite components (CFC), it is necessary to bake components in a suitable furnace. Due to the high temperature requirements of CFC, subcomponents shall be baked prior to system assembly.

Conditioning of CFC is dependent on the manufacturing processes involved; hence baking procedures must be qualified and *accepted* prior to manufacture.

After baking the total outgassing rate for Carbon Fibre Composites shall be $< 1 \times 10^{-6}$ $Pa.m^3.s^{-1}.m^{-3}$ at 200 °C (excluding the partial outgassing rates for H_2, CO and CO_2)

The *supplier* shall perform a degassing cycle of components after machining to a procedure approved by the ITER Vacuum RO in accordance with Section 26.

Guidance for the conditioning of CFC can be found in Appendix 16.

26.8 Documentation to be Supplied for Vacuum Baking

For each vacuum item, the following records shall be supplied:

- Record of the pre-baking conditioning cycle for the vacuum baking chamber.
- The initial leak rate of the vacuum baking chamber.
- The final leak rate of the vacuum baking chamber.
- A record of the temperature distribution for the item and the pressure within the vacuum item against time for the full duration of the bakeout process.
- A full record of any residual gas scans taken with appropriate time markers to identify the scans to the position in the component bakeout cycle.
- Full documentation regarding any leaks or any other problems which occurred during the baking and any remedial action taken.

27 Draining and Drying

27.1 Design Considerations for Draining and Drying

In order to perform effective vacuum leak testing systems under test must be dry.

VQC 1 in-vessel systems which contain water shall be designed in such away as to facilitate draining and drying. Systems shall be designed to be drained and dried so that after drying for <100 hours purge gas passing through the component has a water content <4000 ppm at ambient temperature and pressure.

Consideration shall be given to the position of inlet and outlet water feeds to minimise the volume of trapped water which cannot be removed without drying.

27.2 Components Delivered to ITER

Vacuum components delivered to the ITER site shall be dry internally and externally. Any internal volumes wetted during acceptance testing shall be drained completely and dried by purging with dry air until the purge gas has a water content of <4000 ppm (alternatively the system may be dried by baking using the guidance of Appendix 15 and backfilled with dry air). The volumes will then be left at atmospheric pressure of dry air for a minimum period of 24 hours at ambient temperature. If after that time, the water content of the enclosed gas has risen to >4000 ppm, the drying process shall be repeated until this condition is met.

28 Marking of Vacuum Equipment

Surfaces which are to be exposed to vacuum shall only be marked or identified if necessary and shall be marked by scribing with a clean sharp point, laser scribing or electromagnetic dot peen method. Seal faces shall not be marked in any way. For VQC1, chemical etching shall not be used unless *accepted* by the ITER Vacuum RO.

Only approved (appendix 4) dyes, marker pens, paints, etc. shall be used on surfaces which will be exposed to vacuum.

29 Packaging and Handling of Vacuum Equipment

Components shall be packed with adequate protection from thermal or mechanical stresses which may adversely affect the operation of the component. All packing shall be sealed and marked externally with the component VQC. Handling instructions shall also be clearly marked on the outside of the packaging. Chemical or radiological hazards, etc., shall be identified on the packaging. All such marking shall be in English and French.

All vacuum components shall be shipped dry internally and externally, irrespective of final acceptance testing at the *supplier's* site.

Aluminium foil is recommended for sealing pipe openings, and protective caps shall be fitted to flanges before packaging and sealing. Where it is not practical to enclose the components, e.g. due to size, all apertures must be sealed to prevent the ingress of contaminants during transit. Sealing surfaces shall be protected to prevent damage by scratching, impact, etc.

The use of adhesive tape for the protection and packaging of vacuum components shall be restricted to prevent the risk of contamination from the tape. In particular, tape used on austenitic stainless steel shall meet leachable chloride and fluoride limits of 15 ppm and 10 ppm, respectively. Where used, tape shall be fully removable leaving no residue, using isopropyl alcohol or acetone as the solvent to remove all traces of the adhesive.

To prevent damage and possible contamination during transit, the packaging of components shall be done as soon as possible after acceptance testing and final cleaning at the *supplier's* premises. Cleaning and packaging operations may be witnessed by ITER.

Vacuum components shall be handled as little as possible after final cleaning. All subsequent operations shall be carried out in clean conditions consistent with Section 24.5.

In particular persons handling VQC 1 components shall wear clean powder-free latex or nitrile gloves (over cotton or linen gloves if desired) and, as a minimum, be dressed in clean white overalls. In the cases where the component is large (e.g. a vessel sector) and internal access is required, hair nets and clean overshoes over footwear specifically provided for use in the vacuum component shall be worn.

Volumes which have been pumped for leak testing shall be backfilled with dry nitrogen or air (<4000 ppm H_2O) at a positive pressure of 0.12 MPa and valved off. Where the equipment allows manned access, air shall always be used. Where this is not practical, alternative conditions shall be *accepted* by the vacuum RO.

Cryogenic volumes which have been previously filled with helium for testing shall also follow the above or may be backfilled with dry helium (<4000 ppm H_2O) at a positive pressure of 0.12 MPa and valved off.

Where practical, vacuum components shall be entirely enclosed in heat sealed polyethylene for shipping. The polyethylene enclosure shall be purged and backfilled with dry air (<4000 ppm H_2O). Where this is not practical, alternative conditions shall be *accepted* by the vacuum RO.

30 Incoming Inspection at ITER of Vacuum Equipment

Before acceptance by ITER all components delivered to the ITER site will be subject to incoming inspection.

The following inspections will normally be carried out on vacuum equipment delivered to ITER:

- Checking of backfilled volumes (see Section 29).
- Seal face inspection.
- Checking the integrity of packing and status of accelerometers (if fitted).
- Cleanliness check.
- Leak test.

On completion of the incoming inspection any non-conformance with, or deviation from, the vacuum specification or this Handbook shall be raised in accordance with Section 4.

31 Long Term Storage of Vacuum Equipment

In many cases vacuum components will be delivered to the ITER site in advance of installation to the ITER vacuum system. Vacuum components shall be stored in such a state as not to degrade the vacuum performance.

In the case of VQC 1 components, after incoming inspection and acceptance, the components, where practical, shall be entirely enclosed in heat sealed polyethylene. The polyethylene enclosure shall be purged and backfilled with dry air (<4000 ppm water). Volumes which have been pumped for leak testing shall be backfilled with dry nitrogen (<4000 ppm water) at a positive pressure of 0.12 MPa and valved off. The component shall then be re-packed into its transportation case and stored at a suitable location.

After incoming inspection and acceptance VQC 2, 3 and 4 components shall be stored in clean, dry packing cases in a suitable location.

32 QA and Documentation

All vacuum components supplied to ITER shall be subject to the ITER Quality Assurance System detailed in the ITER Procurement Quality documentation (IDM Ref; ITER_D_22MFG4).

Specific guidance on satisfying the vacuum requirement of such a system is outlined in Appendix 19.

33 Acknowledgements

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Disclaimer

34 List of Attachments

1. Inspection and Qualification of Welded Vacuum Joints
2. Cleanliness Requirements Relating to the Assembly of Vacuum Equipment (ITER_D_MBXPP3)

35 List of Appendices

1. Base Pressures and Expected Pumping Speeds (ITER_D_2ELEJT).
2. Environmental Cleanliness Requirements pertaining to Vacuum Classification (ITER_D_2EL9Y6)
3. Accepted Materials (ITER_D_27Y4QC)
4. Accepted Fluids (ITER_D_2ELN8N)
5. *Acceptance* Checklist (ITER_D_2N4NDK)
6. Guide to the Supply of Windows (ITER_D_2DXZZ3)
7. Guide to the Supply of Valves (ITER_D_2EPFG4)
8. Supply and Manufacture of Vacuum Flanges (ITER_D_2DJYQA)
9. Guide to the Supply of Bellows (ITER_D_2E5LJA)
10. Supply and Manufacture of Cables for use in Vacuum (ITER_D_2ETNLM)
11. Standard Pipe Sizes (ITER_D_2E5PJK)
12. Guide to Leak Testing (ITER_D_2EYZ5F)
13. Guide to Cleaning and Cleanliness (ITER_D_2ELUQH)
14. Guide to Passivation and Pickling (ITER_D_2F547S)
15. Guide for Vacuum Baking (ITER_D_2DU65F)
16. Guide for the Conditioning of Graphite and Carbon Composites (ITER_D_27YH3U)
17. Guide to Outgassing Rates and their Measurement (ITER_D_2EXDST)
18. Vacuum Component Reliability Data (ITER_D_2F2PYS)
19. Guide Documentation and QA (ITER_D_2DMNNR)
20. Standard Components (ITER_D_2F9QWX)
21. Glossary of Vacuum Terms Relevant to ITER (ITER_D_2F94QX)

References

This ITER Technical Report may contain references to internal technical documents. These are accessible to ITER staff and External Collaborators included in the corresponding ITER Document Management (IDM) lists. If you are not included in these lists and need to access a specific technical document referenced in this report, please contact us at ITR.support@iter.org and your request will be considered, on a case by case basis, and in light of applicable ITER regulations.