ITER ダイバータ高熱負荷試験範囲検知に関する

X 線計測用ビームダンプの製作設計作業

仕 様 書

国立研究開発法人量子科学技術研究開発機構

那珂フュージョン科学技術研究所

ITER プロジェクト部 プラズマ対向機器開発グループ

1. 一般仕様

1.1. 件名

ITER ダイバータ高熱負荷試験範囲検知に関する X 線計測用ビームダンプの製作設計作業

1.2. 目的

量子科学技術研究開発機構（以下「QST」という。）は、ITER ダイバータ外側垂直ターゲットのプラズマ対向ユニットの除熱性能の品質確認試験として高熱負荷試験を実施している。QST が製作・運転する高熱負荷試験装置においては、熱負荷範囲を同定するため電子ビームが照射されている範囲を精度よく検知する必要がある。電子ビームがビームダンプに照射されると X 線が発生するため、この X 線を計測することで電子ビームの照射範囲を同定することができる。本件では高熱負荷試験時照射範囲検知に関する X 線計測用ビームダンプの製作設計作業を行う。

受注者は本作業の目的を十分に理解し、受注者の責任と負担において取扱方法、関係法令、規格等の下に計画を立案し、本作業を実施するものとする。

1.3. 業務内容（詳細は 2 章の技術仕様による。）

(1) ビームダンプの製作設計作業

(2) 提出図書作成

1.4. 履行場所

受注者事業所

1.5. 納入物及び納期

1.5.1. 納入物

図書（1.8 項及び表 1-1 参照）　1 式

1.5.2. 納期

令和 9 年 2 月 26 日

1.6. 納入場所

茨城県那珂市向山 801-1

QST　那珂フュージョン科学技術研究所（以下「当研究所」という。）

第 1 工学試験棟居室棟

1.7. 検査条件

1.5 項に定める納入物の納入及び本仕様書に定める作業が完了し、仕様の要求を満足すると QST が認めたことをもって合格とする。

1.8. 提出図書

1.8.1. 提出図書の要求事項

提出図書の要求を以下に記す。

(1) 提出図書は電子版（CD-ROM）で提出すること。

(2) 提出図書は和文とすること。

(3) 本契約に基づいて提出する図書は表 1-1 のとおり。なお、表紙には表題、契約件名、契約管理番号、契約年月日、契約者名を明記すること。

(4) 提出図書内で使用する単位は、国際単位系（SI 単位系）で記すこと。

1.8.2. 提出図書の確認方法

提出図書の確認方法を以下に記す。

(1) 受注者から QST へ提出図書の事前提出

(2) 表 1-1 に示す提出図書の電子版（1 部）を受注者から QST へ電子メール等で提出。

(3) 再委託承諾願以外の提出図書は、10 暦日以内までに QST の確認を完了し、修正が必要な場合には修正を指示する。QST の確認後、期限日を記載した確認印を押印して QST から受注者へ電子メール等で返却する。再委託承諾願は QST が確認後、書面にて回答する。

(4) 全ての作業の完了後、QST の確認印が押された全ての図書（電子版）を受注者から QST に提出。

表 1-1　提出図書

図書名	提出時期
ビームダンプの製作設計要領書	作業開始前
ビームダンプの製作設計報告書	納入時
打合せ議事録	打合せ後、1 週間以内
再委託承諾願（下請負等がある場合のみ提出）（QST 指定様式）	作業開始 2 週間前まで

1.9. 支給品

本件における支給品に関する詳細は下記のとおりとする。

支給物：XM-19 ステンレス鋼ブロック　505mm×630mm×400mm

ただし、支給物のサイズ及び員数(1 体または 2 体)は本契約を実施できる範囲で変更する可能性がある。

支給場所：茨城県那珂市向山 801-1　QST 当研究所の指定場所

支給方法：車上渡し。支給品の輸送・保管等にかかる費用は受注者負担とする。

支給時期：契約締結後、別途協議

1.10. 貸与品

特になし。

1.11. 適用法規・規格基準

本件に関しては原則として、以下の法令、規格・基準に準拠すること。なお、詳細は QST 側担当者と協議の上、決定すること。

(1) 労働基準法

(2) 労働安全衛生法

(3) QST 内諸規程等

(4) その他関係する諸法令、諸規格、基準

なお、技術仕様に適用される規格については、2 章に記載する。

1.12. 知的財産権等

1.12.1. 知的財産権等の取扱い

知的財産権等の取扱いについては、別紙－1「知的財産権特約条項」に定められたとおりとする。

1.12.2. 技術情報の取扱い

受注者は本契約を実施することによって得た技術情報を第三者に開示しようとするときは、あらかじめ書面による QST の承認を得なければならないものとする。

QST が本契約に関し、その目的を達成するため受注者の保有する技術情報を了知する必要が生じた場合は、QST 側担当者と受注者の協議の上、受注者は当該技術情報を無償で QST に提供するものとする。

1.13. グリーン購入法の促進

(1) 本契約において、グリーン購入法（国等による環境物品等の調達の推進等に関する法律）に適用する環境物品（事務用品、ＯＡ機器等）が発生する場合は、これを採用するものとする。

(2) 本仕様に定める提出図書（納入印刷物）については、グリーン購入法の基本方針に定める「紙類」の基準を満たしたものであること。

1.14. 打合せ

(1) QST と受注者は、常に緊密な連絡を保ち、本仕様の解釈及び作業に万全を期すものとする。また、必要に応じて適宜打合せを行うものとし、QST 又は受注者の施設等において打合せを実施する。なお、日時については協議の上決定する。打合せの形態は、テレビ会議、電話会議も含めるとする。

(2) 受注者は、必要に応じて、機器製作者及び作業実施者（下請など本仕様一部などを再発注した場合の契約先）の技術者を打合せに出席させることができるものとする。

(3) 打合せをした場合は、受注者は直ちに打合せ議事録を作成し、QST、受注者双方の責任者の署名又は押印をする。

(4) 受注者は QST からの質問事項に対しては速やかに回答すること。回答は打合せ議事録によることを原則とし、急を要する場合についてはあらかじめ口頭で了承を得て、後日（7 暦日以内を原則とする。）正式版を提出し、確認を得ること。

(5) 回答文書の提出がない場合には、QST の解釈を優先するものとする。

1.15. 一般責任事項

(1) 本件に係わる全ての工程に関して、充分な品質管理を行うこととする。

(2) 受注者は、QST が量子科学技術の研究・開発を行う機関であるため、高い技術力及び高い信頼性を社会的に求められていることを認識し、試験検査等で当研究所の施設を使用する場合、当研究所の規程等を遵守し安全性に配慮して業務を遂行し得る能力を有する者を従事させること。

1.16. 協議

本仕様書に記載されている事項及び本仕様書に記載のない事項について疑義が生じた場合は、QST と協議の上、その決定に従うものとする。

2.　技術仕様

2.1.　　ビームダンプ構造体の製作設計概要

本件で設計検討を行う高熱負荷試験時照射範囲検知用ビームダンプの概略及び要求事項を別紙－2 に示す。同ビームダンプは高出力ビームを止める役割を担うため、高熱負荷入射体をビームダンプ構造体に取り付け、冷却水を循環させるための接続配管を接合した構造である。ビームダンプ構造体の製造方法には、内部を機械加工によりくり抜き、蓋を溶接する方法(蓋溶接方式)と、複数のセグメントに分割し、それぞれを溶接する方法(セグメント溶接方式)がある。近年、蓋溶接方式の優位性が見直されてきたが、実際のビームダンプ構造体製作、すなわち製作設計を行うには解決すべき課題がある。代表的なものとしては、１．くり抜き加工の加工性確認、２．蓋溶接方式における変形量の確認、３．溶接後機械加工による変形量の確認、４．検査性確認の4 点である。これらについて設計検討の妥当性確認を行うこと(2.2 項)。また、ビームダンプ構造体は接続配管や冷却システムの取り合いとなる配管を複数持ち、高い溶接品質が必要である。そのため自動溶接を適用することが有効であると考えられている。製作設計を行うために、溶接性の確認を行うこと(2.3 項)。これらの結果を統合し、ビームダンプ構造体の製作設計としてまとめること(2.4 項)。

2.2.　　ビームダンプ構造体製作の確認試験

ビームダンプ構造体製作の製作設計のため、以下の妥当性確認試験を実施すること。各項目の要領はビームダンプの製作設計要領書にまとめ、QST の確認を得ること。また、得られた結果はビームダンプの製作設計報告書にまとめること。

2.2.1 くり抜き加工の加工性確認

以下のくり抜き加工の加工性確認を実施すること。

⑴ 支給品である XM-19 ステンレス鋼ブロックから図 1 に示す試験材を切り出し、ビームダンプ構造体の内部構造を模擬したくり抜き加工を実施すること。蓋部の試験材も切り出すこと。

⑵ 試験材の切り出し、くり抜き加工、開先加工に必要な加工条件をそれぞれ検討し、ビームダンプの製作設計要領書に記載すること。ビームダンプの製作設計要領書には加工図面を含むこと。

⑶ 上記要領に従って加工を実施すること。詳細な加工条件やマシンタイムなどをビームダンプの製作設計報告書に記載すること。合理的な条件で加工が出来なかった場合は、加工条件の見直し案をビームダンプの製作設計報告書に記載すること。

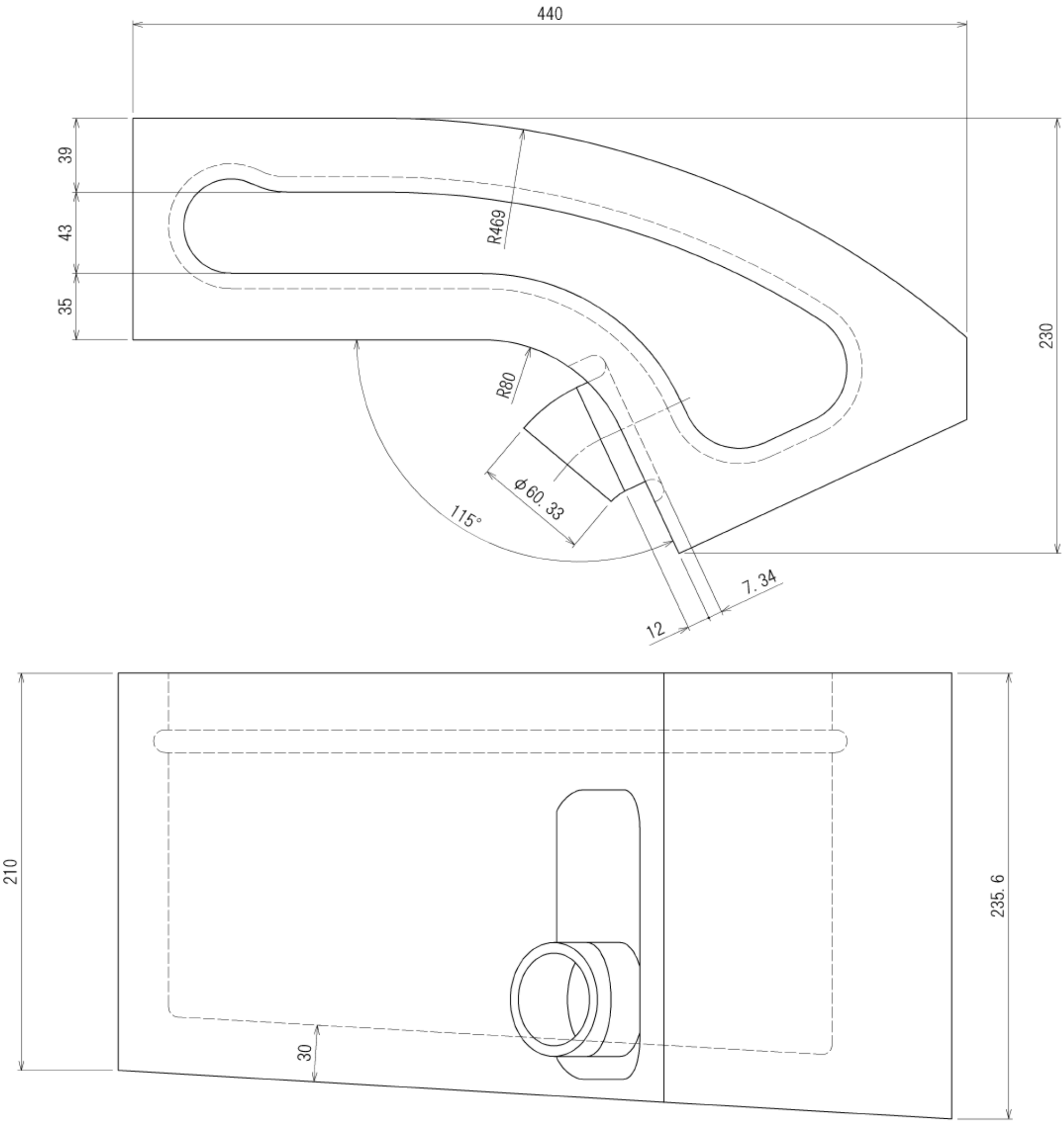


図 1 試験材の概形

2.2.2 蓋溶接方式における変形量の確認

以下の蓋溶接方式における変形量の確認を実施すること。

(1)溶接条件を検討し、ビームダンプの製作設計要領書に記載すること。溶接には品質と再現性に優れ、要素試験でも良好な結果を得られている自動溶接または手動溶接とのハイブリッド溶接を採用すること。その条件に基づき、2.2.1 項で製作した各試験材を使用し、蓋溶接を実施すること。

(2) 詳細な溶接の記録をビームダンプの製作設計報告書に記載すること。

(3) 溶接した試験体の変形量を測定すること。溶接前に基準点を設け、溶接による収縮量や面外変形量を把握すること。

(4) 溶接した試験体に対して、以下の検査を行うこと。詳細はビームダンプの製作設計要領書に記載すること。適用規格等は別紙－2 に示すビームダンプ要求事項を参照すること。

（ア）目視検査(VT)：EN ISO 17637:2016 に準拠すること。

（イ）浸透探傷検査(PT)：EN ISO 3452-1:2013 準拠すること。使用試験剤の制限に留意すること。現像液を塗布し、現像液が乾いたらすぐに最初の検査を行うこと。

(5) 溶接した試験体または同一条件で溶接した試験体の溶接部に対して、金属組織観察(マクロ及びミクロ)を行うこと。方法については ISO 17639:2013 を準用すること。

(6) 溶接した試験体または同一条件で溶接した試験体の溶接部に対して、シャルピー衝撃試験（ISO 9016: 2012, ISO 148-1: 2016 に準拠すること）を行うこと。試験詳細並びに機械試験片の採取図についてはビームダンプの製作設計要領書に記載すること。

2.2.3 溶接後機械加工による変形量の確認

2.2.2 項で製作した試験体に、ビームダンプ製作において実施される溶接後機械加工を行い、変形量を把握すること。寸法測定方法及び測定位置をビームダンプの製作設計要領書に記載すること。なお、2.2.2 項(5)以降では、試験体を加工する必要があるため、本項目はそれより前に実施すること。

2.2.4 検査性確認

ビームダンプ構造体を蓋溶接方式で製作した場合も、形状を工夫することで放射性透過試験(RT)や超音波探傷試験(UT)といった体積検査が可能である見通しを得ている。本項目では、2.2.2 項で製作した試験体に対して、RT 又は、UT を実施すること。EN ISO 17636-1:2013 又は EN ISO 17640：2010 に準拠すること。合否判定基準等は別紙－2 に示すビームダンプ要求事項を参照すること。ビームダンプの製作設計要領書には、各溶接線に対して、照射条件及び検査対象物やフィルムなどの配置等を記載した照射計画(Exposure Plan)を含めること。なお、2.2.2 項(5)以降では、試験体を加工する必要があるため、本項目はそれより前に実施すること。

2.3.　ビームダンプ構造体冷却配管の溶接性確認試験

以下のビームダンプ構造体冷却配管溶接性確認試験を実施すること。

(1) ビームダンプ構造体の冷却配管の溶接を模擬した試験体形状及び配置を検討し、ビームダンプの製作設計要領書に記載すること。

(2) 溶接条件を検討し、ビームダンプの製作設計要領書に記載すること。溶接には品質と再現性に優れる自動溶接または手動溶接とのハイブリッド溶接を採用すること。加えて取り合い位置とのずれを最小にするため、変形を抑制した溶接順序にすること。これらの条件に基づき試験体の加工及び溶接を実施すること。

(3) 詳細な溶接の記録をビームダンプの製作設計報告書に記載すること。

(4) 溶接した試験体の変形量を測定すること。溶接前に基準点を設け、溶接による収縮量や角変形量（倒れ量）を把握すること。

(5) 溶接した試験体に対して、以下の検査を行うこと。詳細はビームダンプの製作設計要領書に記載すること。適用規格等は別紙－2 に示すビームダンプ要求事項を参照すること。

(ア) 目視検査(VT)：EN ISO 17637:2016 に準拠すること。

(イ) 浸透探傷検査(PT)：EN ISO 3452-1:2013 準拠すること。使用試験剤の制限に留意すること。現像液

を塗布し、現像液が乾いたらすぐに最初の検査を行うこと。

(ウ) RT 又は UT: EN ISO 17636-1:2013 又は EN ISO 17640：2010 に準拠すること。ビームダンプの製作設計要領書には、各溶接線に対して、照射条件及び検査対象物やフィルムなどの配置等を記載した照射計画(Exposure Plan)を含めること。

2.4. ビームダンプ構造体の製作設計

2.2 項及び 2.3 項で得られた結果から、ビームダンプ構造体の製作設計を行うこと。別紙－2 に示すビームダンプ要求事項を参照すること。製作設計の結果は、以下の項目を含むこととし、ビームダンプの製作設計報告書にまとめること。

(1) ビームダンプ構造体を蓋溶接方式で製作する場合の加工、溶接及び検査条件。加工及び溶接図面を含むこと。

(2) 溶接及び熱処理等による変形を加味したビームダンプ構造体の余肉量。

(3) 蓋溶接方式とセグメント溶接方式のハイブリッド方式の適用性。

(4) ビームダンプ構造体冷却配管の溶接条件。自動溶接の適用性。

以上

別紙－1

知的財産権特約条項

（知的財産権等の定義）

第１条　この特約条項において「知的財産権」とは、次の各号に掲げるものをいう。

一　特許法（昭和34年法律第121号）に規定する特許権、実用新案法（昭和34年法律第123号）に規定する実用新案権、意匠法（昭和34年法律第125号）に規定する意匠権、半導体集積回路の回路配置に関する法律（昭和60年法律第43号）に規定する回路配置利用権、種苗法（平成10年法律第83号）に規定する育成者権及び外国における上記各権利に相当する権利（以下総称して「産業財産権等」という。）

二　特許法に規定する特許を受ける権利、実用新案法に規定する実用新案登録を受ける権利、意匠法に規定する意匠登録を受ける権利、半導体集積回路の回路配置に関する法律に規定する回路配置利用権の設定の登録を受ける権利、種苗法に規定する品種登録を受ける地位及び外国における上記各権利に相当する権利

三　著作権法（昭和45年法律第48号）に規定する著作権（著作権法第21条から第28条までに規定する全ての権利を含む。）及び外国における著作権に相当する権利（以下総称して「著作権」という。）

四　前各号に掲げる権利の対象とならない技術情報のうち、秘匿することが可能なものであって、かつ、財産的価値のあるものの中から、甲乙協議の上、特に指定するもの（以下「ノウハウ」という。）を使用する権利

２　この特約条項において「発明等」とは、次の各号に掲げるものをいう。

一　特許権の対象となるものについてはその発明

二　実用新案権の対象となるものについてはその考案

三　意匠権、回路配置利用権及び著作権の対象となるものについてはその創作、　育成者権の対象となるものについてはその育成並びにノウハウを使用する権利の対象となるものについてはその案出

３　この契約書において知的財産権の「実施」とは、特許法第２条第３項に定める行為、実用新案法第２条第３項に定める行為、意匠法第２条第２項に定める行為、半導体集積回路の回路配置に関する法律第２条第３項に定める行為、種苗法第２条第５項に定める行為、著作権法第21条から第28条までに規定する全ての権利に基づき著作物を利用する行為、種苗法第２条第５項に定める行為及びノウハウを使用する行為をいう。

（乙が単独で行った発明等の知的財産権の帰属）

第２条　甲は、本契約に関して、乙が単独で発明等行ったときは、乙が次の各号のいずれの規定も遵守することを書面にて甲に届け出た場合、当該発明等に係る知的財産権を乙から譲り受けないものとする。

一　乙は、本契約に係る発明等を行った場合には、次条の規定に基づいて遅滞なくその旨を甲に報告する。

二　乙は、甲が国の要請に基づき公共の利益のために特に必要があるとしてその理由を明らかにして求める場合には、無償で当該知的財産権を実施する権利を国に許諾する。

三　乙は、当該知的財産権を相当期間活用していないと認められ、かつ、当該知的財産権を相当期間活用していないことについて正当な理由が認められない場合において、甲が国の要請に基づき当該知的財産権の活用を促進するために特に必要があるとしてその理由を明らかにして求めるときは、当該知的財産権を実施する権利を第三者に許諾する。

四　乙は、第三者に当該知的財産権の移転又は当該知的財産権についての専用実施権（仮専用実施権を含む。）若しくは専用利用権の設定その他日本国内において排他的に実施する権利の設定若しくは移転の承諾（以下「専用実施権等の設定等」という。）をするときは、合併又は分割により移転する場合及び次のイからハまでに規定する場合を除き、あらかじめ甲に届け出、甲の承認を受けなければならない。

イ　子会社（会社法（平成17年法律第86号）第２条第３号に規定する子会社をいう。以下同じ。）又は親会社（会社法第２条第４号に規定する親会社をいう。以下同じ。）に当該知的財産権の移転又は専用実施権等の設定等をする場合

ロ　承認ＴＬＯ（大学等における技術に関する研究成果の民間事業者への移転の促進に関する法律（平成10年法律第52号）第４条第１項の承認を受けた者（同法第５条第１項の変更の承認を受けた者を含む。））又は認定ＴＬＯ（同法第11条第１項の認定を受けた者）に当該知的財産権の移転又は専用実施権等の設定等をする場合

ハ　乙が技術研究組合である場合、乙がその組合員に当該知的財産権を移転又は専用実施権等の設定等をする場合

２　乙は、前項に規定する書面を提出しない場合、甲から請求を受けたときは当該知的財産権を甲に譲り渡さなければならない。

３　乙は、第１項に規定する書面を提出したにもかかわらず、同項各号の規定のいずれかを満たしておらず、かつ、満たしていないことについて正当な理由がないと甲が認める場合において、甲から請求を受けたときは当該知的財産権を無償で甲に譲り渡さなければならない。

（知的財産権の報告）

第３条　前条に関して、乙は、本契約に係る産業財産権等の出願又は申請を行うときは、出願又は申請に際して提出すべき書類の写しを添えて、あらかじめ甲にその旨を通知しなければならない。

２　乙は、産業技術力強化法（平成12年法律第44号）第17条第１項に規定する特定研究開発等成果に該当するもので、かつ、前項に係る国内の特許出願、実用新案登録出願、意匠登録出願を行う場合は、特許法施行規則（昭和35年通商産業省令第10号）、実用新案法施行規則（昭和35年通商産業省令第11号）及び意匠法施行規則（昭和35年通商産業省令第12号）等を参考にし、当該出願書類に国の委託事業に係る研究の成果による出願である旨を表示しなければならない 。

３　乙は、第１項に係る産業財産権等の出願又は申請に関して設定の登録等を受けた場合には、設定の登録等の日から60日以内（ただし、外国にて設定の登録等を受けた場合は90日以内）に、甲に

その旨書面により通知しなければならない。

4　乙は、本契約に係る産業財産権等を自ら実施したとき及び第三者にその実施を許諾したとき（ただし、第５条第４項に規定する場合を除く。）は、実施等した日から60日以内（ただし、外国にて実施等をした場合は90日以内）に、甲にその旨書面により通知しなければならない。

5　乙は、本契約に係る産業財産権等以外の知的財産権について、甲の求めに応じて、自己による実施及び第三者への実施許諾の状況を書面により甲に報告しなければならない。

（乙が単独で行った発明等の知的財産権の移転）

第４条　乙は、本契約に関して乙が単独で行った発明等に係る知的財産権を第三者に移転する場合（本契約の成果を刊行物として発表するために、当該刊行物を出版する者に著作権を移転する場合を除く。）には、第２条から第６条まで及び第12条の規定の適用に支障を与えないよう当該第三者に約させなければならない。

2　乙は、前項の移転を行う場合には、当該移転を行う前に、甲にその旨書面により通知し、あらかじめ甲の承認を受けなければならない。ただし、乙の合併又は分割により移転する場合及び第２条第１項第４号イからハまでに定める場合には、この限りでない。

3　乙は、第１項に規定する第三者が乙の子会社又は親会社（これらの会社が日本国外に存する場合に限る。）である場合には、同項の移転を行う前に、甲に事前連絡の上、必要に応じて甲乙間で調整を行うものとする。

4　乙は、第１項の移転を行ったときは、移転を行った日から60日以内（ただし、外国にて移転を行った場合は90日以内）に、甲にその旨書面により通知しなければならない。

5　乙が第１項の移転を行ったときは、当該知的財産権の移転を受けた者は、当該知的財産権について、第２条第１項各号及び第３項並びに第３条から第６条まで及び第12条の規定を遵守するものとする。

（乙が単独で行った発明等の知的財産権の実施許諾）

第５条　乙は、本契約に関して乙が単独で行った発明等に係る知的財産権について第三者に実施を許諾する場合には、第２条、本条及び第12条の規定の適用に支障を与えないよう当該第三者に約させなければならない。

2　乙は、本契約に関して乙が単独で行った発明等に係る知的財産権に関し、第三者に専用実施権等の設定等を行う場合には、当該設定等を行う前に、甲にその旨書面により通知し、あらかじめ甲の書面による承認を受けなければならない。ただし、乙の合併又は分割により移転する場合及び第２条第１項第４号イからハまでに定める場合は、この限りではない。

3　乙は、前項の第三者が乙の子会社又は親会社（これらの会社が日本国外に存する場合に限る。）である場合には、同項の専用実施権等の設定等を行う前に、甲に事前連絡のうえ、必要に応じて甲乙間で調整を行うものとする。

4　乙は、第２項の専用実施権等の設定等を行ったときは、設定等を行った日から60日以内（ただし、外国にて設定等を行った場合は90日以内）に、甲にその旨書面により通知しなければならない。

５　甲は、本契約に関して乙が単独で行った発明等に係る知的財産権を無償で自ら試験又は研究のために実施することができる。甲が　甲のために第三者に製作させ、又は業務を代行する第三者に再実施権を許諾する場合は、乙の承諾を得た上で許諾するものとし、その実施条件等は甲乙協議のうえ決定する。

（乙が単独で行った発明等の知的財産権の放棄）

第６条　乙は、本契約に関して乙が単独で行った発明等に係る知的財産権を放棄する場合は、当該放棄を行う前に、甲にその旨書面により通知しなければならない。

（甲及び乙が共同で行った発明等の知的財産権の帰属）

第７条　甲及び乙は、本契約に関して甲乙共同で発明等を行ったときは、当該発明等に係る知的財産権について共同出願契約を締結し、甲乙共同で出願又は申請するものとし、当該知的財産権は甲及び乙の共有とする。ただし、乙は、次の各号のいずれの規定も遵守することを書面にて甲に届け出なければならない。

一　乙は、甲が国の要請に基づき公共の利益のために特に必要があるとしてその理由を明らかにして求める場合には、無償で当該知的財産権を実施する権利を国に許諾する。

二　乙は、当該知的財産権を相当期間活用していないと認められ、かつ、当該知的財産権を相当期間活用していないことについて正当な理由が認められない場合において、甲が国の要請に基づき当該知的財産権の活用を促進するために特に必要があるとしてその理由を明らかにして求めるときは、当該知的財産権を実施する権利を甲が指定する 第三者に許諾する。

２　前項の場合、出願又は申請のための費用は原則として、甲、乙の持分に比例して負担するものとする。

３　乙は、第１項に規定する書面を提出したにもかかわらず、同項各号の規定のいずれかを満たしておらず、さらに満たしていないことについて正当な理由がないと甲が認める場合において、甲から請求を受けたときは当該知的財産権のうち乙が所有する部分を無償で甲に譲り渡さなければならない。

（甲及び乙が共同で行った発明等の知的財産権の移転）

第８条　甲及び乙は、本契約に関して甲乙共同で行った発明等に係る共有の知的財産権のうち、自らが所有する部分を相手方以外の第三者に移転する場合には、当該移転を行う前に、その旨を相手方に書面により通知し、あらかじめ相手方の書面による同意を得なければならない。

（甲及び乙が共同で行った発明等の知的財産権の実施許諾）

第９条　甲及び乙は、本契約に関して甲乙共同で行った発明等に係る共有の知的財産権について第三者に実施を許諾する場合には、その許諾の前に相手方に書面によりその旨通知し、あらかじめ相手方の書面による同意を得なければならない。

（甲及び乙が共同で行った発明等の知的財産権の実施）

第10条　甲は、本契約に関して乙と共同で行った発明等に係る共有の知的財産権を試験又は研究以外の目的に実施しないものとする。ただし、甲は甲のために第三者に製作させ、又は業務を代行する第三者に実施許諾する場合は、無償にて当該第三者に実施許諾することができるものとする。

２　乙が本契約に関して甲と共同で行った発明等に係る共有の知的財産権について自ら商業的実施をするときは、甲が自ら商業的実施をしないことに鑑み、乙の商業的実施の計画を勘案し、事前に実施料等について甲乙協議の上、別途実施契約を締結するものとする。

（甲及び乙が共同で行った発明等の知的財産権の放棄）

第11条　甲及び乙は、本契約に関して甲乙共同で行った発明等に係る共有の知的財産権を放棄する場合は、当該放棄を行う前に、その旨を相手方に書面により通知し、あらかじめ相手方の書面による同意を得なければならない。

（著作権の帰属）

第12条　第２条第１項及び第７条第１項の規定にかかわらず、本契約の目的として作成され納入される著作物に係る著作権については、全て甲に帰属する。

２　乙は、前項に基づく甲及び甲が指定する 第三者による実施について、著作者人格権を行使しないものとする。また、乙は、当該著作物の著作者が乙以外の者であるときは、当該著作者が著作者人格権を行使しないように必要な措置を執るものとする。

３　乙は、本契約によって生じた著作物及びその二次的著作物の公表に際し、本契約による成果である旨を明示するものとする。

（合併等又は買収の場合の報告等）

第13条　乙は、合併若しくは分割し、又は第三者の子会社となった場合（乙の親会社が変更した場合を含む。第３項第１号において同じ。）は、甲に対しその旨速やかに報告しなければならない。

２　前項の場合において、国の要請に基づき、国民経済の健全な発展に資する観点に照らし、本契約の成果が事業活動において効率的に活用されないおそれがあると甲が判断したときは、乙は、本契約に係る知的財産権を実施する権利を甲が指定する者に許諾しなければならない。

３　乙は、本契約に係る知的財産権を第三者に移転する場合、次の各号のいずれの規定も遵守することを当該移転先に約させなければならない。

一　合併若しくは分割し、又は第三者の子会社となった場合は、甲に対しその旨速やかに報告する。

二　前号の場合において、国の要請に基づき、国民経済の健全な発展に資する観点に照らし本業務の成果が事業活動において効率的に活用されないおそれがあると甲が判断したときは、本契約に係る知的財産権を実施する権利を甲が指定する者に許諾する。

三　移転を受けた知的財産権をさらに第三者に移転するときは、本項各号のいずれの規定も遵守することを当該移転先に約させる。

（秘密の保持）

第14条　甲及び乙は、第２条及び第７条の発明等の内容を出願公開等により内容が公開される日まで他に漏えいしてはならない。ただし、あらかじめ書面により出願又は申請を行った者の了解を得た場合はこの限りではない。

（委任・下請負）

第15条　乙は、本契約の全部又は一部を第三者に委任し、又は請け負わせた場合においては、当該第三者に対して、本特約条項の各規定を準用するものとし、乙はこのために必要な措置を講じなければならない。

２　乙は、前項の当該第三者が本特約条項に定める事項に違反した場合には、甲に対し全ての責任を負うものとする。

（協議）

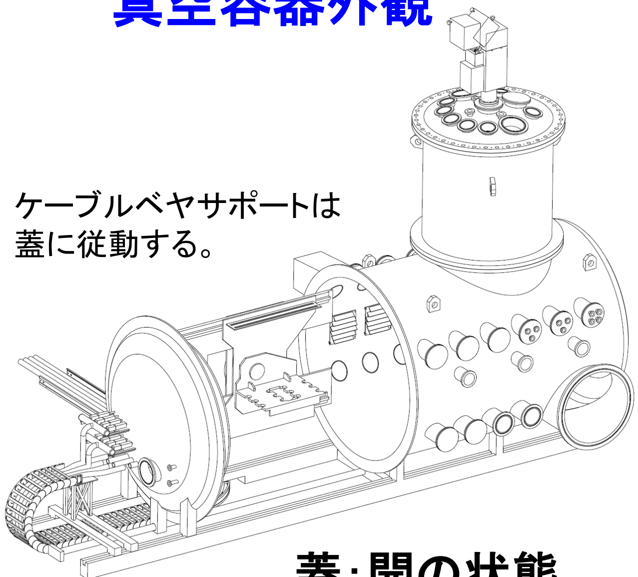
第16条　第２条及び第７条の場合において、単独若しくは共同の区別又は共同の範囲等について疑義が生じたときは、甲乙協議して定めるものとする。

（有効期間）

第17条　本特約条項の有効期限は、本契約の締結の日から当該知的財産権の消滅する日までとする。

以上

図1 高熱負荷試験装置 真空容器外観



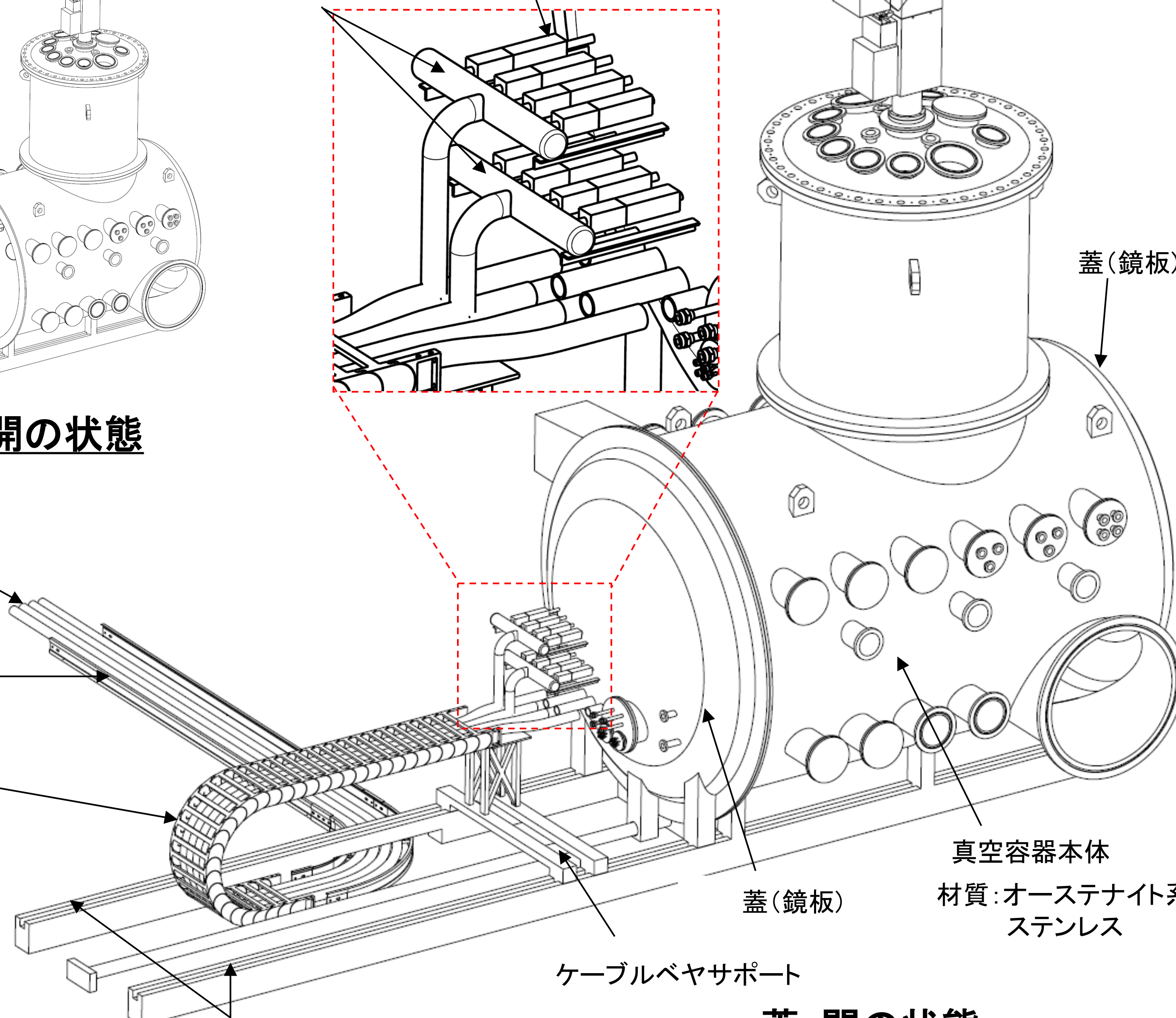


図2　真空容器内機器

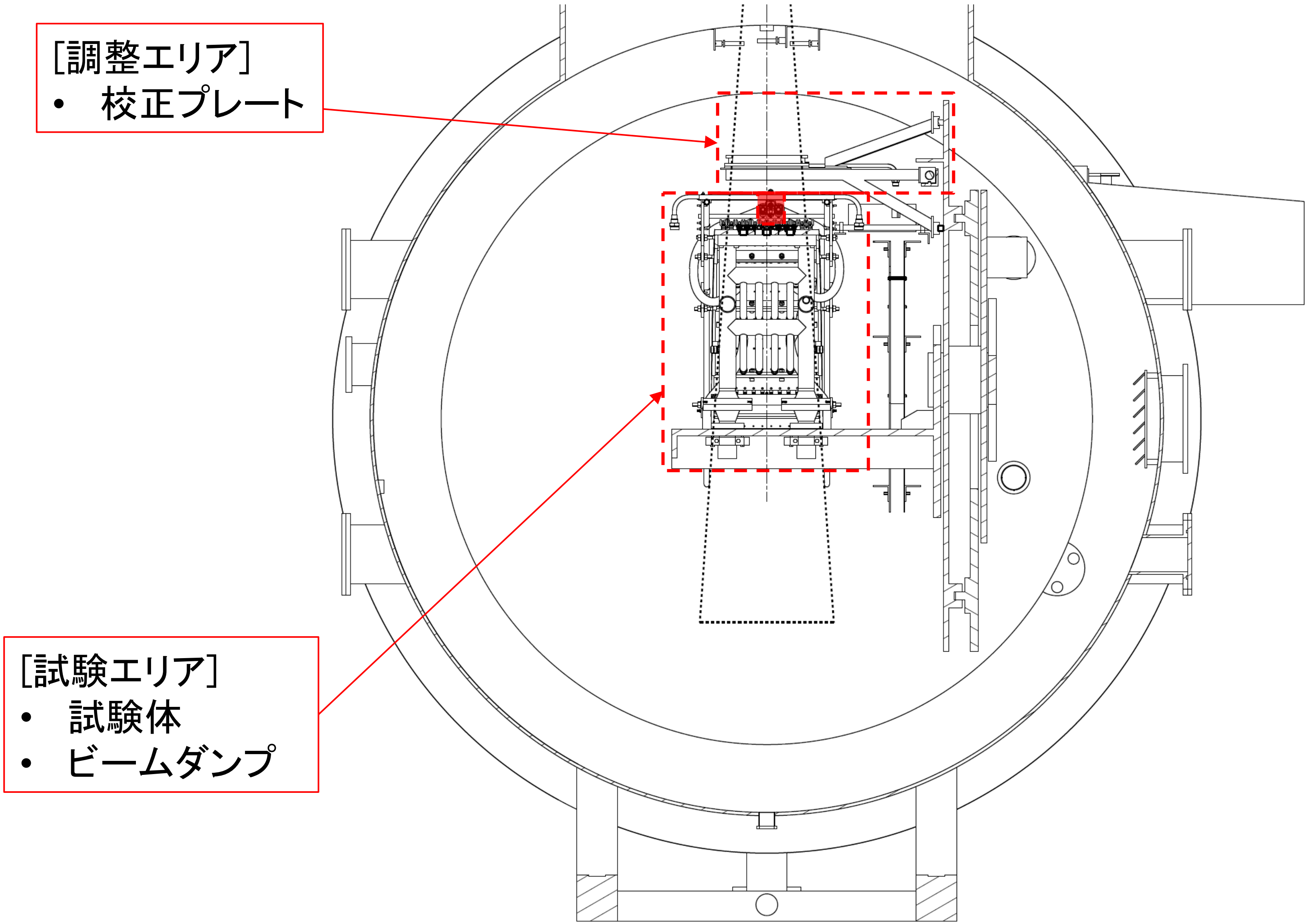


図3　電子ビーム照射範囲

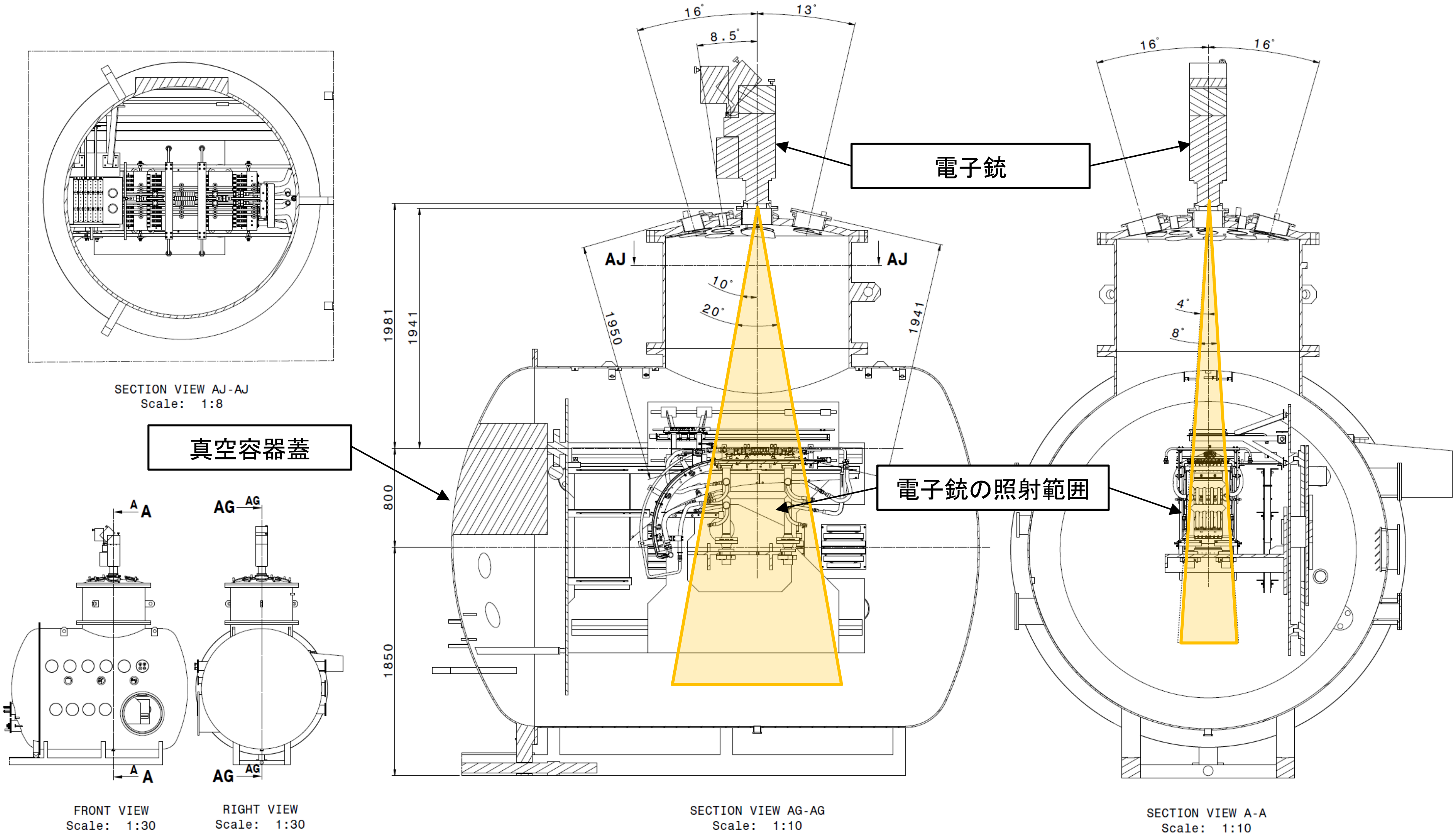


図4 ビームダンプ要求事項

[冷却水仕様]
- 公称運転圧力: 4.0 MPa
- 入口温度: 100℃
- 設計圧力: 5.0 MPa

[要求クラス]
- 真空分類: VQC-1A(別紙-3参照)
- 寸法測定分類: ～Class 1(別紙-4参照)
- 品質レベル: QC1(別紙-5参照)

[適用規格]
- 放射線透過試験:EN 1435
- 浸透探傷試験:EN ISO 3452-1
- 溶接部合否判定基準:レベルB EN ISO 5817/EN ISO 13919-1
- 溶接施工法認証:EN ISO 15614

IDM UID
2EZ9UM

VERSION CREATED ON / VERSION / STATUS
28 May 2019 / 2.5 / Approved

EXTERNAL REFERENCE / VERSION

Guideline

ITER Vacuum Handbook

ITER Vacuum Handbook.
Updated to include changes reviewed under scope of mPCR 260 Change Notice "PCR-M260 - Application of ITER Vacuum Handbook to standard products, clarification of requirements and minimal update to reflect the phase of the ITER project" for "ITER Vacuum Handbook (2EZ9UM v2.3)": review and approval (SK47R3 v1.0).

v2.5 is v2.3+ changes introduced through mPCR260. there is no change between v2.4 and v2.5.

Approval Process			
	Name	*Action*	*Affiliation*
Author	**Worth L.**	**28 May 2019:signed**	**IO/DG/COO/PED/FCED/VS**
Co-Authors			
Reviewers	**Pearce R.**	**28 May 2019:recommended**	**IO/DG/COO/PED/FCED/VS**
Approver	**Lee G.- S.**	**28 May 2019:approved**	**IO/DG/COO**
Document Security: Internal Use *RO: Chiocchio Stefano*			
Read Access	**GG: MAC Members and Experts, GG: STAC Members & Experts, AD: ITER, AD: External Collaborators, AD: IO_Director-General, AD: EMAB, AD: EUROfusion-DEMO, AD: Auditors, AD: ITER Management Assessor, project administrator, RO, LG: Section Scheduling, AD: OBS - Vacuum Section (VS) - EXT, AD: OBS - Vacuum ...**		

Change Log			
ITER Vacuum Handbook (2EZ9UM)			
Version	***Latest Status***	***Issue Date***	***Description of Change***
v1.0	Signed	27 Aug 2008	
v1.1	Signed	28 Aug 2008	
v1.2	Signed	22 Oct 2008	
v1.3	Signed	27 Oct 2008	
v1.4	Signed	17 Dec 2008	
v2.0	Signed	10 Apr 2009	
v2.1	In Work	27 May 2009	
v2.2	Signed	28 May 2009	
v2.3	Approved	12 Jun 2009	VH ref. Original sentence V2.2 Modified sentence V2.3 7.1.5 Weld Finish & Repair 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. The size and magnitude of all leaks found on welds forming a vacuum boundary shall be reported to the ITER Vacuum RO. All repair welds forming part of a vacuum boundary 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. 9 Confinement and Vacuum Containment VQC 2A components that are considered to be vulnerable shall

			normally be doubly vacuum contained with a monitored interspace connected to the Service Vacuum System. 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. 12 Pipework Where practical, for components classified as VQC 2A, water pipes 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). It is recommended that pipework classified as VQC 2A, water pipes forming part of the cryostat vacuum boundary, be doubly contained. Where the pipework is not doubly contained, all welded joints shall be full penetration butt welds subject to 100% Non-Destructive Testing (NDT). 17.2 Design of Bellows All vulnerable bellows for use on VQC 1 and 2 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 vulnerable 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.
v2.4	Revision Required	10 Dec 2018	Updated to include changes reviewed under scope of mPCR 260 Change Notice "PCR-M260 - Application of ITER Vacuum Handbook to standard products, clarification of requirements and minimal update to reflect the phase of the ITER project" for "ITER Vacuum Handbook (2EZ9UM v2.3)": review and approval (SK47R3 v1.0)
v2.5	Approved	28 May 2019	No change from V 2.4. v2.5 is v2.3 plus changes introduced by mPCR 260. V2.5 is to be applied for future contracts/PAs.

ITER Vacuum Handbook		
Revision: Issue 2.5	Date:28th May 2019	Page 1 of 48

ITER Vacuum Handbook

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.

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

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.

		Maximum Steady State Outgassing rate **$Pa.m^3.s^{-1}.m^{-2}$**		
VQC+	**Outgas temperature °C**	**Hydrogen isotopes**	**Impurities**	**Testing Guidelines**
1	100‡	1×10^{-7}	1×10^{-9}	Appendix 17
2	20	1×10^{-7}*		Appendix 17
3	20	1×10^{-8}		Appendix 17
4	20	1×10^{-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 in Table 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.

Nominal thickness (of vacuum boundary)		Plate / Bar[1]			Forging[4]	Pipe[4]	Pipe, [4,5] (He, ≤ 2 mm)	HIP[3]	Casting [4]
	Direction	Crosses[2]		Parallel[2]					
	RH Class	3, N/A	1, 2	1, 2, 3, N/A	1, 2, 3, NA	1, 2, 3, NA	1, 2, 3, NA		
≤ 5 mm		X	L	NR	F + L	NR	L	X	A
>5 mm ≤ 25 mm		X	L	NR	F	NR	NR	A	A
> 25 mm		L	NR	NR	NR	NR	NR	A	A

[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.
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))5

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 $5x10^{-1}$ 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.	Trained personnel. Protective hair nets. Clean powder free	Daily Cleaning of area including floors	Daily air quality checks. Results stored

	Authorised equipment operated to approved procedures. Management of equipment (e.g. no vacuum pumps or other machinery exhausting into clean area).	latex or nitrile outer gloves. Clean white overalls. Overshoes. Clean job specific footwear.	and surfaces. Sticky mats at area entry.	in component document package. 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.

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

‡ 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 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

[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.

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 < 1×10^{-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

The ITER Vacuum Group acknowledges the following in the preparation of the ITER Vacuum Handbook:

UKAEA and JET, Culham Science Centre, Oxfordshire, UK

Accelerator Science and Technology Centre (ASTeC), Daresbury, UK

Dr. R J Reid, Dr. M Wykes and Dr. A Kaye

In addition the efforts of many in extensively reviewing the Handbook are acknowledged.

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)

IDM UID
2ELEJT

VERSION CREATED ON / VERSION / STATUS
23 Sep 2013 / 1.6 / Approved

EXTERNAL REFERENCE / VERSION

Guideline (not under Configuration Control)

Appendix 1 Base Pressures and Expected Pumping Speeds

Approval Process			
	Name	*Action*	*Affiliation*
Author	**Worth L.**	**23 Sep 2013:signed**	**IO/DG/COO/PED/FCED/VS**
Co-Authors			
Reviewers			
Approver	**Pearce R.**	**25 Oct 2013:approved**	**IO/DG/COO/PED/FCED/VS**
Document Security: Internal Use *RO: Chiocchio Stefano*			
Read Access	**GG: MAC Members and Experts, GG: STAC Members & Experts, AD: ITER, AD: External Collaborators, AD: IO_Director-General, AD: EMAB, AD: Auditors, AD: ITER Management Assessor, project administrator, RO, LG: [CCS] CCS-All for Ext AM, LG: [CCS] CCS-Section Leaders, LG: [CCS] JACOBS, LG: [CCS] CCS-Doc Co...**		

Change Log			
Appendix 1 Base Pressures and Expected Pumping Speeds (2ELEJT)			
Version	***Latest Status***	***Issue Date***	***Description of Change***
v1.0	In Work	27 Aug 2008	
v1.1	In Work	22 Sep 2008	
v1.2	In Work	13 Jan 2009	
v1.3	Signed	24 Mar 2009	
v1.4	Disapproved	02 Sep 2009	Minor changes to text for consistency with Vacuum Handbook
v1.5	Approved	09 Sep 2009	Minor changes to text to clarify pumping speed(s)
v1.6	Approved	23 Sep 2013	Number of TCPs updated to reflect current design (from 8 to 6)

ITER Vacuum Handbook
Appendix 1

Base Pressures pertaining to Vacuum Classification and Expected Vacuum System Pumping Speed

	Name	Affiliation
Author/Editor	Liam Worth	Vacuum Group - CEP
Vacuum Responsible Officer	Robert Pearce	Vacuum Group - CEP
Reviewed by		
Approved by		

1 Scope

This appendix relates gives base pressures that it is expected systems with a Vacuum Classification will operate. The appendix also gives the expected pumping speeds of ITER vacuum systems. This appendix is intended as a guide and figures will be updated as the system design matures.

2 Base Pressures

Base pressures pertaining to VQC are given in Table 2-1.

	VQC1[1]	VQC2[2]	VQC3[3]	VQC4[3]
Base Pressure (Pa)	10^{-7} - 10^{-4}	<10^{-4}	10^{-6} -10^{2}	10^{-4}

[1] Before operations, the base pressure in the ITER vacuum vessel will be required to be 10^{-5} Pa or less for hydrogen isotopes and 10^{-7} Pa or less for any other individual species at 100 ℃ after bake-out and conditioning.
[2]Pressures at ambient (with magnets cold). Lower values expected if total pressure is not helium dominated.
[3]Total pressure when pump down, some system may operate at higher pressures.

Table 2-1 Base pressure pertaining to VQC

3 Pumping speeds for Cryopumps

The expected pumping speeds various large ITER cryopumps are given in Table 3-1. Pumping speeds are given at the pump inlet with inlet valves fully open.

Cryopumping System	VQC	Pumping Speed ($m^3 \cdot s^{-1}$)				
		H_2	D_2	DT	He	N_2
Torus Vacuum Cryopump[1]	**1A**	78	55	49	52	21
Cryostat Vacuum Cryopump[2]	**2A**	>78	>55	>49	>52	>21
Heating Neutral Beam Cryopump	**1A**	4700	3600	3255	TBD[3]	1380
Diagnostic Neutral Beam Cryopump	**1A**	2900	2270	2035	TBD[3]	860

[1] The torus cryopumping system consists of 6 cryosorption pumps for which the individual pumping speed is given. The total pumping speed is dependent on the operating cycle of the pumps. The conductance of the divertor duct restricts the total pumping speed available. Modelling of the 2001 divertor duct configuration gave a maximum molecular flow pumping speed for Deuterium of 20 m^3/s when using 4 ducts for the pumping. The current more open divertor duct configuration is estimated to give a molecular flow pumping speed for Deuterium of 100 m^3/s when using 4 ducts and 4 pumps for the pumping.

[2] One cryopump only, not including the cold surfaces of the magnets or the thermal shield. Pumping speed of the torus cryopump is used, but the gas conductance to the pump housing will be higher than for the torus pump. Two pumps are available to pump, but at times one will have to be offline for regeneration.

[3] Pending Monte Carlo simulations.

Table 3-1 Expected pumping speeds of large cryopumps

4 Pumping speeds for roughing pumps.

The design of the roughing system and the roughing lines is at an early stage and hence pumping speed cannot yet be accurately provided. The figures below outline the required provisional roughing pump(s) performance.

- Torus ~1330 m^3 ,10^5 Pa to 10 Pa in 24 Hours.
- 1 torus cryopump, ~18 m^3, max 30 KPa$m^{3\dagger}$ (Hydrogen isotopes), to 10 Pa in 150 sec.
- Cryostat ~8500 m^3 ,10^5 Pa to 10 Pa in 24 Hours.
- 1 cryostat cryopump, ~18 m^3, max 30 KPam^3 (Helium + Hydrogen), to 10 Pa in 150 sec.
- NIBs ~ 171 m^3 + 171 m^3 + 170 m^3 + 93 m^3, 10^5 Pa to 10 Pa in 24 Hours.
- 1 NIB cryo-pump, ~170 m^3, max 300 KPam^3 (Hydrogen isotopes), to 20 Pa in 650 sec.
- PI – overnight gas transfer to TEP.
- Adequate pumping for Auxiliaries.

†May double

IDM UID
2EL9Y6
VERSION CREATED ON / VERSION / STATUS
02 Sep 2009 / 1.4 / Approved
EXTERNAL REFERENCE / VERSION

Baseline Report (not under Configuration Control)

Appendix 2 Environmental Cleanliness

This Appendix provides guidelines relating to the cleanliness requirements for the post cleaning handling of vacuum components for installation in the various ITER Vacuum systems. It only refers to the post final cleaning cleanliness requirements to maintain the achieved cleanliness.

Approval Process			
	Name	*Action*	*Affiliation*
Author	**Worth L.**	**02 Sep 2009:signed**	**IO/DG/COO/PED/FCED/VS**
Co-Authors			
Reviewers			
Approver	**Pearce R.**	**14 Sep 2009:approved**	**IO/DG/COO/PED/FCED/VS**
Document Security: Internal Use *RO: Chiocchio Stefano*			
Read Access	**GG: MAC Members and Experts, GG: STAC Members & Experts, AD: ITER, AD: External Collaborators, AD: IO_Director-General, AD: EMAB, AD: Auditors, AD: ITER Management Assessor, project administrator, RO, LG: [CCS] CCS-All for Ext AM, LG: [CCS] CCS-Section Leaders, LG: [CCS] JACOBS, LG: [CCS] CCS-Doc Co...**		

Change Log			
Appendix 2 Environmental Cleanliness (2EL9Y6)			
Version	***Latest Status***	***Issue Date***	***Description of Change***
v1.0	In Work	27 Aug 2008	
v1.1	In Work	12 Jan 2009	
v1.2	In Work	13 Jan 2009	
v1.3	Signed	18 Jun 2009	Updated to include new figures for airbourne contamination and minor textual changes
v1.4	Approved	02 Sep 2009	Minor changes to text for consistency with Vacuum Handbook

ITER Vacuum Handbook
Appendix 2

Environmental Cleanliness

	Name	Affiliation
Author/Editor	Liam Worth	Vacuum Group - CEP
Vacuum Responsible Officer	Robert Pearce	Vacuum Group - CEP

2 Environmental Cleanliness requirements pertaining to Vacuum Quality Classification

2.1 Scope

This Appendix provides guidelines relating to the cleanliness requirements for the post cleaning handling of vacuum components for installation in the various ITER Vacuum systems. It only refers to the post final cleaning cleanliness requirements to maintain the achieved cleanliness.

It is anticipated that further guidance which will not be mandatory may be provided in the future.

2.2 Post Cleaning Handling of Vacuum Components

The following details are reproduced from the ITER Vacuum Handbook (Issue 2.3), Section 24.5 and Table 24.1and are therefore mandatory.

"After final cleaning, the handling of vacuum equipment shall be controlled to preserve cleanliness. General area cleanliness requirements pertaining to Vacuum Classification are summarised in Table 2-1. The suitability of any given area used for handling vacuum equipment should be assessed on a regular basis by monitoring the airborne particulate count and should not exceed 5.0×10^6 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 procedures. Management of equipment (e.g. no vacuum pumps exhausting into clean area)	Trained personnel. Protective hair nets. Powder free latex or nitrile outer gloves. Clean white overalls. Overshoes. Clean job specific footwear	Daily Cleaning of area including floors and surfaces. Sticky mats at area entry	Daily air quality checks. Results stored in component document package. 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	Trained personnel Powder free latex or nitrile outer gloves for the handling of clean equipment	Daily Cleaning of work area including floors and surfaces.	

	exhausting into clean area)			
3&4	House Keeping	Trained personnel. Powder free latex or nitrile outer gloves for the handling of clean equipment	Daily cleaning of area.	

Table 2-1 Environmental cleanliness pertaining to VQC

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

IDM UID
27Y4QC

VERSION CREATED ON / VERSION / STATUS
17 Jul 2017 / 1.20 / Approved

EXTERNAL REFERENCE / VERSION

Guideline (not under Configuration Control)

Appendix 3 Materials

Approval Process			
	Name	*Action*	*Affiliation*
Author	**Vine G.**	**17 Jul 2017:signed**	**IO/DG/COO/PED/FCED/VS**
Co-Authors			
Reviewers	**Pearce R.** **Worth L.**	**31 Aug 2017:recommended** **17 Jul 2017:recommended**	**IO/DG/COO/PED/FCED/VS** **IO/DG/COO/PED/FCED/VS**
Approver	**Lee G.- S.**	**08 Sep 2017:approved**	**IO/DG/COO**
#SecureIDM# *RO: Chiocchio Stefano*			
Read Access	**GG: MAC Members and Experts, GG: STAC Members & Experts, AD: ITER, AD: External Collaborators, AD: IO_Director-General, AD: EMAB, AD: EUROfusion-DEMO, AD: Auditors, AD: ITER Management Assessor, project administrator, RO, LG: [CCS] CCS-All for Ext AM, LG: [CCS] CCS-Section Leaders, LG: [CCS] JACOBS,...**		

Change Log			
Appendix 3 Materials (27Y4QC)			
Version	***Latest Status***	***Issue Date***	***Description of Change***
v1.0	In Work	27 Aug 2008	
v1.1	In Work	29 Aug 2008	
v1.2	In Work	12 Jan 2009	
v1.3	In Work	14 Jan 2009	
v1.4	Signed	26 Jan 2009	
v1.5	Signed	13 May 2009	
v1.6	Signed	18 Jun 2009	Changed approved to accepted throughout document
v1.7	Approved	02 Sep 2009	Minor textual changes for consistency with Vacuum Handbook
v1.8	Approved	26 Sep 2011	Reference to Material Approval Request form added. New materials added. References to requested materials added. Simplification to material groups. Changes agreed with ITER Vacuum RO prior to Up-load.
v1.9	Approved	11 Feb 2014	Added grade and standard for Alumina
v1.10	Approved	11 Feb 2014	Date correction. Affiliation modification.
v1.11	Signed	23 Jan 2015	Changes between v1.10 and v1.11 of 27Y4QC. Links added for, 304 B7 Outgassing data YDH 50 MAR XM-19 MAR Oxygen Free (OF) UNS C10200 Al-15 (Mirrors for EC Equatorial launcher) Tantalum sheet TiN Materials added:- Nitronic-60 (UNS S21800) 431 (UNS S43100) (1.4057) 431 (UNS S43100) (1.4059) Inconel 708 N-type thermocouple STEMET 1301 amorphous brazing alloy Nicuman 23 brazing alloy Nicuman 37 brazing alloy STEMET 1101 microcrystalline brazing alloy STEMET 1108 microcrystalline brazing alloy Aluminium Grade 6061 Tungsten Carbide Mechanical pump (sliding seal) Gold Thin leaf 100 micron (bonding agent) Silver-based braze BAg-8 Titanium ASTM Grade2 T2 & 5 T5 Silicon Mono-crystalline Silicon Poly –crystalline Diamond composite Sckeleton-1 Glass Ceramic MACOR (MGC) Aluminum Oxide (TS-03312) Alumina Filled Cyanate Ester (MC7885-UF) Aluminium Nitride Shapal SH-15) Aluminium Nitride Shapal M-soft Aluminium Nitride (Circuit Board Substrate)

			Quartz Filled Cyanate Ester (MC7883-UF or MC9883-LPM) Kalrez Non-vacuum application (3rd party pump) Barium Fluoride vacuum windows Molybdenum (Tracks on surface of silicon wafer sensor) ZrO2 with TiN coating Non-vacuum application (3rd party pump) ZrO2 Non-vacuum application (3rd party pump)
v1.12	Approved	23 Jan 2015	Approval corrected to restricted for:- Aluminium Nitride (Shapal SH-15, Shapal M-soft, Circuit Board Substrate) Plus previous:- Links added for, 304 B7 Outgassing data YDH 50 MAR XM-19 MAR Oxygen Free (OF) UNS C10200 Al-15 (Mirrors for EC Equatorial launcher) Tantalum sheet TiN Materials added:- Nitronic-60 (UNS S21800) 431 (UNS S43100) (1.4057) 431 (UNS S43100) (1.4059) Inconel 708 N-type thermocouple STEMET 1301 amorphous brazing alloy Nicuman 23 brazing alloy Nicuman 37 brazing alloy STEMET 1101 microcrystalline brazing alloy STEMET 1108 microcrystalline brazing alloy Aluminium Grade 6061 Tungsten Carbide Mechanical pump (sliding seal) Gold Thin leaf 100 micron (bonding agent) Silver-based braze BAg-8 Titanium ASTM Grade2 T2 & 5 T5 Silicon Mono-crystalline Silicon Poly –crystalline Diamond composite Sckeleton-1 Glass Ceramic MACOR (MGC) Aluminum Oxide (TS-03312) Alumina Filled Cyanate Ester (MC7885-UF) Aluminium Nitride Shapal SH-15) Aluminium Nitride Shapal M-soft Aluminium Nitride (Circuit Board Substrate) Quartz Filled Cyanate Ester (MC7883-UF or MC9883-LPM) Kalrez Non-vacuum application (3rd party pump) Barium Fluoride vacuum windows Molybdenum (Tracks on surface of silicon wafer sensor) ZrO2 with TiN coating Non-vacuum application (3rd party pump) ZrO2 Non-vacuum application (3rd party pump)
v1.13	Signed	23 Feb 2015	MAR ITER_D_9K3J5P for Alumimium 6061 use in VQC 2B and 4B now deleted as request is unnecessary. Use of Aluminium use in all VQC (except VQC 1A-restricted) is already indicated in Appendix 3 Table.
v1.14	Approved	25 Feb 2015	Materials:- -EPDM (Ethylene-propylene), & -Nitrile rubber (Buna – N) Added with use restricted to 2nd, outer, seal gasket only (i.e. between SVS pumped volume/Air) in VQC 2A double sealed flanges (1st, inner seal,

			being metallic) for consistency with materials noted in VH App 8, Flanges, Table 6. Aluminium "and alloys" noted in grades for clarity
v1.15	Approved	20 Aug 2015	Materials added Cu and Cu based alloys:- CuBe1.7 CuBe2 SeCu Ni and Ni based alloys:- Nilo 42 (Nickel Iron Alloy 42 material) Mineral cement:- Thermoguss 2000 Glass / Ceramic:- Zirconia ZrO2
v1.16	Approved	03 Nov 2015	Materials added:- Nicrobraz 10 Alloy BNi6 (Ni / P 11%) Molybdenum solid, pure (not powdered or compound)
v1.17	Approved	06 Jun 2016	Materials added;- PEEK shrink tubing, Brazing Filler Material (Ni 102 / BNi2 / L-Ni2 / B-Ni82CrSiBFE DuPont 951 Green Tape Shapal M-Soft NiP-11% electroless nickel braze Aluminium Nitride (W Coated) G11 / EPGC203 epoxy glass composite Magnesium Oxide, MgO, sintered
v1.18	Approved	12 Dec 2016	Materials added:- Polyimide-cable insulant Zirconia based ceramic paste (Resbond 940) Papyex: N 998 Flexible Graphite Inconel X-750 Aluminium alloy EN AW-6082-T6 Boron Carbide F4C Molybdenum alloy APT-3 TZM SA-240 316Ti Stainless steel Steel 316Ti (1.4571 according to VDEh)
v1.19	Signed	17 Jul 2017	Materials added:- Molybdenum Molykote D-321 R Anti-Friction Coating Sputtered MoS2 Brazing matrial NIORO AuNi 82/18% Araldite Rapid Ticuni Braze BrazeTec_CB10 Copper Alloy (Cu-Sn-Pb) Ertalon 66 SKTN-MED optical glue BPd-2 Braze
v1.20	Approved	17 Jul 2017	Materials added as previous version:-

			Molybdenum Molykote D-321 R Anti-Friction Coating Sputtered MoS2 Brazing matrial NIORO AuNi 82/18% Araldite Rapid Ticuni Braze BrazeTec_CB10 Copper Alloy (Cu-Sn-Pb) Ertalon 66 SKTN-MED optical glue BPd-2 Braze (& 1 correction-Nicrobraz 10 restored)

ITER Vacuum Handbook
Appendix 3

Accepted Materials

	Name	Affiliation
Author/Editor	Liam Worth	IO Vacuum Section
Vacuum Responsible Officer	Robert Pearce	IO Vacuum Section

3 ITER Approved Materials

3.1 Scope

This appendix relates to the materials *accepted* for use in ITER vacuum exposed to the ITER vacuum environments.

The ITER Vacuum Handbook (section 5.1) states that

"Only materials *accepted* by ITER 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 2.2, 3.1 or 3.2, or equivalent, before being used in manufacturing."

Pursuant to this, materials which may be used freely on vacuum systems with the Vacuum Classifications stated are listed in the tables below.

Materials listed in this Appendix and 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 Approval Request Form, stored on IDM (ITER_D_2MGWR4), to the ITER Vacuum RO. An example of this form completed is to be found at the end of this Appendix.

3.2 Materials Not on the Approved List

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 Approval Request Form. The proposer shall agree in advance with the ITER Vacuum RO a plan detailing the type and method of testing to qualify the material for use. The Materials Approval 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.

Materials qualified in this way may be added to the *accepted* list.

3.3 Material Selection / Qualification

The materials listed in the following tables have been considered in terms of usage (vapour pressure, outgassing etc) and in terms of the environment of intended use.

The properties of materials may change either permanently or temporarily when irradiated. Such changes which can affect their suitability for use in vacuum may include -

- Induced radioactivity – which might necessitate the use of remote handling techniques to disassemble or remove a component (e.g. steels may become active). Induced activity may be long-lived or short-lived.
- Mechanical degradation – which might affect the physical integrity of a component or a bond between components or which may generate particulates which could spread through a vacuum system (e.g. PTFE degenerates to a powder). Such changes are permanent.
- Transmutation – where a particular atomic species with good vacuum properties is transformed into one with poor vacuum properties (e.g. silver transmutes to cadmium). The products formed by transmutation can themselves transmute hence such changes can not be considered permanent.
- Chemical change – where the material decomposes under the influence of radiation (e.g. Viton releases hydrochloric acid, and PTFE releases fluorine, both of which are undesirable). Such changes are permanent.
- Desorption – under the influence of radiation, many materials exhibit enhanced outgassing due to induced desorption (e.g. hydrogen from steel when irradiated with X-rays). This stops when the source of radiation is switched off.

The effect of irradiation has been considered for *accepted* materials, and shall be considered in the qualification when materials not on the list are assessed for inclusion on the list.

Table 3-1 *Accepted* Materials

Material / Material Class	Grades, (or composition applicable to ITER)	Vacuum Quality Classification							
		1A	1B	2A	2B	3A	3B	4A	4B
Austenitic stainless steels	316L, 316LN 316L(N)-IG + Corresponding EN grades	✓	✓	✓	✓	✓	✓	✓	✓
	316 + Corrsponding EN grades	×	✓	✝	✓	✝	✓	✝	✓
	316Ti SA-240 (NB Bellows Convolutions) MAR: ITER_D_TT37NF			✓					

KEY: ✓ = approved for use. × = not approved for use. ✝ = restricted use

Material / Material Class	Grades, (or composition applicable to ITER)	Vacuum Quality Classification							
		1A	1B	2A	2B	3A	3B	4A	4B
	316Ti (Elektical and optical patch boxes) MAR: ITER_D_TLM3YP				✓				
	304L 304LN 304B4 + Corresponding EN grades	✓	✓	✓	✓	✓	✓	✓	✓
	304 304 B7 Outgassing data:- ITER_D_EMZ98G + Corresponding EN grades	×	✓	✝	✓	✝	✓	✝	✓
Austenitic stainless steels	YDH 50 MAR:- ITER_D_4CRYM8	✓	✓	✓	✓	✓	✓	✓	✓

KEY: ✓ = approved for use. × = not approved for use. ✝ = restricted use

Material / Material Class	Grades, (or composition applicable to ITER)	Vacuum Quality Classification							
		1A	1B	2A	2B	3A	3B	4A	4B
Austenitic Chromium-Manganese-Nickel stainless steels	XM-19 (UNS S20910), MAR:- ITER_D_DG7SKX JJ1	✓	✓	✓	✓	✓	✓	✓	✓
Austenitic Chromium-Manganese-Nickel stainless steels	Nitronic-60 (UNS S21800) MAR:- ITER_D_CA3TB6 Material data sheet ITER_D_CX9QCX Material information ITER_D_DCEREP	✓	✓	✓	✓	✓	✓	✓	✓
Precipitation Hardening Iron Base Super-alloy	Grade 660 (UNS S66286), another name A286 + Corresponding EN grades	✓	✓	✓	✓	✓	✓	✓	✓
Ferritic (martensitic) stainless steel	430 (UNS S43000) Eurofer, F82H, Rusfer,	✓	✓	✓	✓	✓	✓	✓	✓

KEY: ✓ = approved for use. ✗ = not approved for use. ✝ = restricted use

Material / Material Class	Grades, (or composition applicable to ITER)	Vacuum Quality Classification							
		1A	1B	2A	2B	3A	3B	4A	4B
Ferritic (martensitic) stainless steel	431 (UNS S43100) (1.4057) ITER roughing pump shaft MAR:- ITER_D_DCCQYE Materials cert ITER_D_DBY4WW	×	×	×	×	✝	✝	×	×
Ferritic (martensitic) stainless steel	431 (UNS S43100) (1.4059) ITER roughing pump rotor and case MAR:- ITER_D_DCHJDM Materials cert ITER_D_DCEQ7B	×	×	×	×	✝	✝	×	×
Kovar	ASTM F15 KV-1~9	✓	✓	✓	✓	✓	✓	✓	✓
Nickel		✓	✓	✓	✓	✓	✓	✓	✓
Nickel based Alloys	Nimonic 80A(UNS N070080)	✓	✓	✓	✓	✓	✓	✓	✓

KEY: ✓ = approved for use. × = not approved for use. ✝ = restricted use

Material / Material Class	Grades, (or composition applicable to ITER)	Vacuum Quality Classification							
		1A	1B	2A	2B	3A	3B	4A	4B
	Monel 400	✓	✓	✓	✓	✓	✓	✓	✓
	Alumel (95% Ni, 2% Mn, 2%Al, 1%Si)	✗	✝	✗	✓	✗	✓	✗	✓
	Chromel (90%-10% Ni – Cr)	✓	✓	✓	✓	✓	✓	✓	✓
	Alloy 718 (UNS N07718) Alloy 625 (UNS N06625)	✓	✓	✓	✓	✓	✓	✓	✓
	Inconel 708 Bellows seal MAR:- ITER_D_KTP2JW	✓	✓	✓	✓	✓	✓	✓	✓
	N-type thermocouple MAR :- ITER_D_64J7S9	✗	✗	✗	✓	✗	✗	✗	✗
	Nilo 42 (Nickel Iron Alloy 42 material) MAR:- ITER_D_QTVQ7F	✗	✓	✗	✓	✗	✓	✗	✗

KEY: ✓ = approved for use. ✗ = not approved for use. ✝ = restricted use

Material / Material Class	Grades, (or composition applicable to ITER)	Vacuum Quality Classification							
		1A	1B	2A	2B	3A	3B	4A	4B
	Inconel X-750 (UNS N07750, DIN W.-Nr. 2.4669) MAR: ITER_D_S98EXM Material datasheet ITER_D_SM54DQ	✓	✓	✓	✓	✓	✓	✓	✓
Nickel based Braze	STEMET 1301 amorphous brazing alloy Vacuum brazing of W-Cu joint in the Divertor Dome PFUs armour (only PRPs) MAR:- ITER_D_7NTH2J Outgassing data:- ITER_D_7NSWW8 Mat Cert ITER_D_7NTH2J	×	✓	×	✓	×	✓	×	✓
	Nicrobraz 10 Alloy BNi6 (Ni / P 11%) Brazing of stainless steel cable sheaths into stainless steel bulkheads. MAR:- ITER_D_QZW8DY	✓	✓	✓	✓	✓	×	×	×

KEY: ✓ = approved for use. × = not approved for use. ✝ = restricted use

Material / Material Class	Grades, (or composition applicable to ITER)	Vacuum Quality Classification							
		1A	1B	2A	2B	3A	3B	4A	4B
	Ni 102 Nickel-based high temp brazing paste For Brazing of non-vacuum boundary components DNB Beam (AKA:-Ni 102, BNi2 , L-Ni2, B-Ni82CrSiBFE-970/1000, 4777F, 9500/97) MAR ITER_D_S43LCB	✗	✓	✗	✓	✗	✓	✗	✓
Nickel based Braze	Nickel - Phosphorus 11% vacuum braze for the 6x diamagnetic coils (55.AG) under Triangular Support MAR ITER_D_S5EHB2	✗	✓	✗	✓	✗	✓	✗	✓

KEY: ✓ = approved for use. ✗ = not approved for use. ✝ = restricted use

Material / Material Class	Grades, (or composition applicable to ITER)	Vacuum Quality Classification							
		1A	1B	2A	2B	3A	3B	4A	4B
Pure Copper	Oxygen Free (OF) UNS C10200 Oxygen Free electronic (OFE) UNS C10100 EU grades: Cu-ETP (CW004A), Cu-FRTP, (CW006A), Cu-OF (CW008A), Cu-OFE (CW009A), Cu-PHCE (CW022A)	✝	✓	✓	✓	✓	✓	✓	✓
Pure Copper	Oxygen Free (OF) UNS C10200 OF (CW008A) MAR:- ITER_D_NT9JT5	✝	✓	✓	✓	✓	✓	✓	✓

KEY: ✓ = approved for use. ✗ = not approved for use. ✝ = restricted use

Material / Material Class	Grades, (or composition applicable to ITER)	Vacuum Quality Classification							
		1A	1B	2A	2B	3A	3B	4A	4B
Copper alloys	CuCrZr-IG: Cr (0.6 – 0.9 %), Zr (0.07 – 0.15 %) CuCr1Zr (CW 106C) CuCrZr (UNS C18150) БрХЦр (RF grade) YZC (JA grade)	✓	✓	✓	✓	✓	✓	✓	✓
	CuBe1.7 MAR:- ITER_D_RBENAP	×	✓	×	×	×	×	×	×
	CuBe2 MAR:- ITER_D_RB34RC	×	✓	×	×	×	×	×	×
	SeCu MAR:- ITER_D_R7NEZM	×	✓	×	×	×	×	×	×

KEY: ✓ = approved for use. × = not approved for use. ✝ = restricted use

Material / Material Class	Grades, (or composition applicable to ITER)	Vacuum Quality Classification							
		1A	1B	2A	2B	3A	3B	4A	4B
Copper alloys-Bronze	Aluminum bronze: UNS C63200,(82Cu-9Al-5Ni4Fe), CuAl10Ni5Fe4 (CW307G) CW301G (CuAl6Si2Fe)	✝	✓	✓	✓	✓	✓	✓	✓
Copper alloys-Bronze	Aluminium Bronze Casting (SO-5) (oilless bearing for in -vessel mirror motors. MAR:- ITER_D_4CT93S	×	✓	×	✝	×	✝	×	✝
Copper alloys-Bronze	Bronze (Cu-Sn-Pb) Application is VQC N/A (approved for installation use only) MAR: ITER_D_UG2K5V								
Copper alloys-Alumina Dispersion Strengthened	Glidcop Al60 Glidcop Al25-IG Al-15	✓	✓	✓	✓	✓	✓	✓	✓

KEY: ✓ = approved for use. × = not approved for use. ✝ = restricted use

Material / Material Class	Grades, (or composition applicable to ITER)	Vacuum Quality Classification							
		1A	1B	2A	2B	3A	3B	4A	4B
Copper alloys- Alumina Dispersion Strengthened	Al-15 (Mirrors for EC Equatorial launcher) MAR:-ITER_D_4CQPLA	✗	✓	✗	✓	✗	✓	✗	✓
Copper-based braze	Nicuman 23 brazing alloy as a brazing alloy for use in the divertor MAR:- ITER_D_9K83MF Outgassing data:- ITER_D_6XLFJQ	✗	✓	✗	✗	✗	✗	✗	✗
Copper-based braze	Nicuman 37 brazing alloy for use in VQC 1B as a brazing alloy for use in the divertor. MAR :- ITER_D_9K6V2C Outgassing data:- ITER_D_6XLFJQ Materials cert ITER_D_9K6V2C	✗	✓	✗	✗	✗	✗	✗	✗

KEY: ✓ = approved for use. ✗ = not approved for use. ✝ = restricted use

Material / Material Class	Grades, (or composition applicable to ITER)	Vacuum Quality Classification							
		1A	1B	2A	2B	3A	3B	4A	4B
Copper-based braze	STEMET 1101 microcrystalline brazing alloy Vacuum brazing of Cu-CuCrZr joint in the Dome PFUs armour MAR:- ITER_D_7NXAUN Outgassing data:- ITER_D_7NSWW8 Materials certificate ITER_D_7NSWW8	✗	✓	✗	✓	✗	✓	✗	✓

KEY: ✓ = approved for use. ✗ = not approved for use. ✝ = restricted use

Material / Material Class	Grades, (or composition applicable to ITER)	Vacuum Quality Classification							
		1A	1B	2A	2B	3A	3B	4A	4B
Copper-based braze	STEMET 1108 microcrystalline brazing alloy Vacuum brazing of Cu-CuCrZr joint in the Dome PFUs armour MAR:- ITER_D_7NSWW8 Outgassing data:- ITER_D_7NSWW8 Materials certificate ITER_D_7NSWW8	✗	✓	✗	✓	✗	✓	✗	✓
Beryllium	S – 65C VHP, DShG-200, TGP-56FW, CN-G01	✓	✓	✓	✓	✓	✓	✗	✗
Aluminium	Pure or alloys	✝	✓	✓	✓	✓	✓	✓	✓
	Aluminium alloy EN AW-6082-T6 MAR : ITER_D_S97FXR Deviation request also required for this VQC 1A application	✝							

KEY: ✓ = approved for use. ✗ = not approved for use. ✝ = restricted use

Material / Material Class	Grades, (or composition applicable to ITER)	Vacuum Quality Classification							
		1A	1B	2A	2B	3A	3B	4A	4B
Tungsten	Pure sintered W and rolled, cast W alloy, W-1%La_2O_3 CVD	✗	✓	✗	✓	✗	✓	✗	✓
Tungsten Carbide	WC Cemented Carbide (Bearing Ring). MAR:-ITER_D_4CSC86 Mechanical pump (sliding seal) MAR :- ITER_D_L25NLL	✗	✓	✗	✓	✗	✓	✗	✓
Caesium		✗	✓	✗	✓	✗	✓	✗	✓
Gold		✝	✝	✝	✓	✓	✓	✓	✓
Gold	Thin leaf 100 micron (bonding agent) MAR:- ITER_D_QDASPX	✗	✝	✗	✗	✗	✗	✗	✗

KEY: ✓ = approved for use. ✗ = not approved for use. ✝ = restricted use

Material / Material Class	Grades, (or composition applicable to ITER)	Vacuum Quality Classification							
		1A	1B	2A	2B	3A	3B	4A	4B
Gold based braze	Nioro brazing materials (AuNi 82/18%) MAR: ITER_D_TVU72E	✓	✓	✓	✓	✓	✓	✓	✓
Silver		✝	✝	✝	✓	✓	✓	✓	✓
Silver-based braze	BAg-8 (Japanese Industrial Standard; JIS Z3261) Ag as filler material for brazing on the DNB bushing MAR :- ITER_D_AJL8YX Deviation request ITER_D_4AHGK6 Transmutation data ITER_D_4FJRHJ, ITER_D_7PGX7C	×	✝	×	×	×	×	×	×
Silver-based braze	BrazeTec_CB10 MAR: ITER_D_UMF87D		✝						

KEY: ✓ = approved for use. × = not approved for use. ✝ = restricted use

Material / Material Class	Grades, (or composition applicable to ITER)	Vacuum Quality Classification							
		1A	1B	2A	2B	3A	3B	4A	4B
Silver-based braze	BPd-2 MAR: ITER_D_UXN7AY				✝				
Tantalum	Sheet MAR:-ITER_D_2LN64R	✓	✓	✓	✓	✓	✓	✓	✓
Germanium		✝	✓	✝	✓	✝	✓	✝	✓
Samarium Cobalt ($Sm_2Co^{17)}$)	R26HS	×	✓	×	✓	×	✓	×	✓
Zinc		×	×	×	×	×	×	×	×
Cadmium		×	×	×	×	×	×	×	×
Titanium	Pure or alloys	✝	✝	✝	✓	✝	✓	✝	✓

KEY: ✓ = approved for use. × = not approved for use. ✝ = restricted use

Material / Material Class	Grades, (or composition applicable to ITER)	Vacuum Quality Classification							
		1A	1B	2A	2B	3A	3B	4A	4B
Titanium	Titanium ASTM Grade2 T2 & 5 T5 ICH & CD antenna: Removable vacuum transmission lines MAR:- ITER_D_6R2ZJW Related attachments ITER_D_6R2ZJW, ITER_D_6R2ZJW, ITER_D_6R2ZJW	✝	✗	✗	✗	✝	✗	✗	✗
Titanium based braze	Ticuni Braze MAR: ITER_D_UMFFFP		✝						
Quartz		✓	✓	✓	✓	✓	✓	✓	✓
Silicon	Mono-crystalline, 380 µm thick board Ex-vessel magnetic sensor (55.A5/A6 MEMS) Total mass ~2.5g for all sensors MAR:- ITER_D_DFVQ4C	✗	✗	✗	✝	✗	✗	✗	✗

KEY: ✓ = approved for use. ✗ = not approved for use. ✝ = restricted use

Material / Material Class	Grades, (or composition applicable to ITER)	Vacuum Quality Classification							
		1A	1B	2A	2B	3A	3B	4A	4B
Silicon	Poly-crystalline 40 µm diameter plugs through 380 µm thick mono-Si circuit board Ex-vessel magnetic sensor (55.A5/A6 MEMS) Total mass ~0.001g (1mg) for all sensors MAR ITER_D_DG5JJR	×	×	×	✝	×	×	×	×
Silica,	Fused SiO2	✓	✓	✓	✓	✓	✓	✓	✓
Composite (diamond, silicon carbine, silicon)	Sckeleton-1 MAR:- ITER_D_64NG84	×	✓	×	×	×	×	×	×
Diamond	Pure and DLC, CVD	✓	✓	✓	✓	✓	✓	✓	✓
Graphite	Pyrolytic (Langmuir Probe) MAR:- ITER_D_2LUWMJ	×	✝	×	✝	×	×	×	×

KEY: ✓ = approved for use. × = not approved for use. ✝ = restricted use

Material / Material Class	Grades, (or composition applicable to ITER)	Vacuum Quality Classification							
		1A	1B	2A	2B	3A	3B	4A	4B
(see note 1)	GR-1 (restricted to allow tracking). MAR:- ITER_D_4CRPVS	✗	✝	✗	✝	✗	✗	✗	✗
	Papyex: N 998 Flexible Graphite MAR: ITER_D_KZWER7 Technical guide ITER_D_RZM4SU	✗	✝	✗	✗	✗	✗	✗	✗
Composite (Carbon Fibre Composite CFC, see note 1)	SNECMA and Dunlop: various grades Supercarb NB 31 (3D), NIC-01 Toyo Tanso:CX2002U (2D)	✗	✓	✗	✓	✗	✓	✗	✓
Porcelain	C221	✓	✓	✓	✓	✓	✓	✓	✓
Ceramic	Kyocera A479	✓	✓	✓	✓	✓	✓	✓	✓

KEY: ✓ = approved for use. ✗ = not approved for use. ✝ = restricted use

Material / Material Class	Grades, (or composition applicable to ITER)	Vacuum Quality Classification							
		1A	1B	2A	2B	3A	3B	4A	4B
Glass Ceramic	DuPont 951 Green Tape For Low-Temperature Co-fired Ceramics sensor applied to PBS 55.AA/AB/AC MAR ITER_D_S22ME4 Outgassing test reports ITER_D_QYRA8N ITER_D_QYM8ZD	✗	✓	✗	✓	✗	✓	✗	✓
	MACOR (MGC) Small machined parts MAR:-ITER_D_LF5RDE Vac data:- ITER_D_LEYH7S	✗	✓	✗	✓	✗	✓	✗	✓
	Shapal Hi-M SOFT (machinable AlN) In-vessel Magnetic Sensors (55.AA/AB/AC/AJ) applications Outgassing data ITER_D_C9TP4H Material datasheet ITER_D_C9XYVT	✗	✓	✗	✓	✗	✓	✗	✓

KEY: ✓ = approved for use. ✗ = not approved for use. ✝ = restricted use

Material / Material Class	Grades, (or composition applicable to ITER)	Vacuum Quality Classification							
		1A	1B	2A	2B	3A	3B	4A	4B
$MgAl_2O_4$		✓	✓	✓	✓	✓	✓	✓	✓
MgO	Magnesium oxide as base insulation material for the In-Vessel Coils conductor. Powder glued and sintered in blocks, confined in the conductor jacket MAR ITER_D_STESWL	✗	✓	✗	✓	✗	✓	✗	✓
Titanium dioxide TiO_2		✗	✓	✗	✓	✗	✓	✗	✓
Alumina Al_2O_3	Grade IV to ASTM D2442	✓	✓	✓	✓	✓	✓	✓	✓

KEY: ✓ = approved for use. ✗ = not approved for use. ✝ = restricted use

Material / Material Class	Grades, (or composition applicable to ITER)	Vacuum Quality Classification							
		1A	1B	2A	2B	3A	3B	4A	4B
Alumina (Al_2O_3)	Aluminum Oxide (TS-03312) Surface coating for slid pin, internal shield etc MAR:- ITER_D_4CQG7F	✗	✓	✗	✗	✗	✗	✗	✗
Alumina cyanate ester	Alumina Filled Cyanate Ester (MC7885-UF) Ex-vessel Magnetic Sensors (55.A5/A6 MEMS), Qty ~30g for all sensors MAR:- ITER_D_DFZ4YK	✗	✗	✗	✓	✗	✗	✗	✗
Aluminium Nitride	Shapal SH-15 (Small moulded/machined parts) MAR:- ITER_D_EH72BL	✗	✝	✗	✝	✗	✗	✗	✗

KEY: ✓ = approved for use. ✗ = not approved for use. ✝ = restricted use

Material / Material Class	Grades, (or composition applicable to ITER)	Vacuum Quality Classification							
		1A	1B	2A	2B	3A	3B	4A	4B
Aluminium Nitride	Shapal M-soft (sintered composite of Al nitrate and B nitrate) MAR:- ITER_D_C9TCXH Outgassing data:- ITER_D_C9TP4H	×	✝	×	✝	×	×	×	×
Aluminium Nitride	Aluminium Nitride (Circuit Board Substrate) Ex-vessel sensor, total quantity 1.3kg maximum MAR:- ITER_D_DG7QJY Outgassing Data :- ITER_D_DG46FA	×	×	×	✝	×	×	×	×
Aluminium Nitride	AlN (high purity sintered for IVS RF shield) MAR ITER_D_SMX5GR Outgassing data ITER_D_DG46FA Chemical analysis ITER_D_SLZRLQ	×	✓	×	✓	×	✓	×	✓

KEY: ✓ = approved for use. × = not approved for use. ✝ = restricted use

Material / Material Class	Grades, (or composition applicable to ITER)	Vacuum Quality Classification							
		1A	1B	2A	2B	3A	3B	4A	4B
Silicon Nitride (SiN_4)	TSN-03 (in vacuum ball brearing) MAR:- ITER_D_4C5QZJ	×	✓	×	×	×	×	×	×
Caesium Iodide CsI	Ti activated	×	✓	×	✓	×	✓	×	✓
Resin -Epoxy	TGDDM	×	×	✝	✓	✝	✓	×	✓
Resin -Epoxy	Araldite rapid MAR: ITER_D_UELUT4								✓
Resin -Cyanate Ester	Quartz Filled Cyanate Ester (MC7883-UF or MC9883-LPM) Bonding agent in sensor silicon wafer Ex-vessel Magnetic Sensors (55.A5/A6 MEMS), Qty ~30g for all sensors MAR:- ITER_D_DG4HDK	×	×	×	✝	×	×	×	×

KEY: ✓ = approved for use. × = not approved for use. ✝ = restricted use

Material / Material Class	Grades, (or composition applicable to ITER)	Vacuum Quality Classification							
		1A	1B	2A	2B	3A	3B	4A	4B
Optical glue	SKTN-MED optical glue MAR: ITER_D_76JZCP		✝						
Composite (Epoxy / (glass fibre)	G10. Electrical insulator MAR:- ITER_D_4E9Q2M	✗	✗	✗	✓	✗	✗	✗	✓
	G11 / EPGC203. Electrical insulator MAR ITER_D_SRSGTV	✗	✗	✗	✗	✗	✗	✗	✓
Inorganic adhesive	Thermoguss 2000	✗	✓	✝	✓	✝	✓	✗	✓
	Thermoguss 2000 MAR:- ITER_D_R69NWA Performance as a seal on MI cable must be demonstrated by qualification tests on actual cables	✗	✗	✗	✗	✓	✗	✗	✗
Glass	S 2, R- and T	✗	✝	✗	✓	✗	✓	✗	✓

KEY: ✓ = approved for use. ✗ = not approved for use. ✝ = restricted use

Material / Material Class	Grades, (or composition applicable to ITER)	Vacuum Quality Classification							
		1A	1B	2A	2B	3A	3B	4A	4B
Polyimide	Vespel	✗	✓	✗	✓	✗	✓	✗	✓
Polyimide	ERTALON 66 Application is VQC N/A (approved for installation use only) MAR: ITER_D_UG2BMP								
Polyimide	Thermopastic Polyimide (TPI), Axon Cable MAR: ITER_D_RTNM3U This sample accepted by outgassing test in MAR				✝				
PEEK (Polyether ether ketone)	As shrink tubing for steady-state sensors 55.A5/A6 MAR ITER_D_RT2T5V Product datasheet ITER_D_RMLNSM	✗	✗	✗	✓	✗	✓	✗	✓

KEY: ✓ = approved for use. ✗ = not approved for use. ✝ = restricted use

Material / Material Class	Grades, (or composition applicable to ITER)	Vacuum Quality Classification							
		1A	1B	2A	2B	3A	3B	4A	4B
EPDM (Ethylene-propylene)	Use restricted to 2nd , outer, seal gasket only (i.e. between SVS pumped volume/Air) in VQC 2A double sealed flanges (1st, inner seal, being metallic)	✗	✗	✝	✗	✗	✗	✗	✗
Nitrile rubber (Buna – N)	Use restricted to 2nd , outer, seal gasket only (i.e. between SVS pumped volume/Air) in VQC 2A double sealed flanges (1st, inner seal, being metallic)	✗	✗	✝	✗	✗	✗	✗	✗
Superinsulation	Aluminium deposited Kapton, Mylar. Aluminium foil	✗	✗	✗	✝	✗	✗	✗	✓
	Aluminium deposited Polyester	✗	✗	✗	✗	✗	✗	✗	✝
Halogenated materials	PTFE, Fibreslip (Teflon fibre-glass weave)‡ ‡ PTFE bearings are approved for positions where the predicted radiation fluence over the full operational life of ITER is less than 103 Gray (Gamma or Neutron dose equivalents)	✗	✗	✗	✓	✗	✗	✓	✓

KEY: ✓ = approved for use. ✗ = not approved for use. ✝ = restricted use

Material / Material Class	Grades, (or composition applicable to ITER)	Vacuum Quality Classification							
		1A	1B	2A	2B	3A	3B	4A	4B
	Viton	✗	✗	✝	✝	✝	✓	✓	✓
	Kalrez Non-vacuum application (3rd party pump) VQC=N/A MAR:- ITER_D_L5MK2Q								
	Bromine (In Halogen lamp for CXRS Diagnostic in-situ calibration. MAR:- ITER_D_48D5EX	✗	✝	✗	✗	✗	✗	✗	✗
Barium Fluoride	Barium Fluoride vacuum windows MAR:- ITER_D_P8Q4NT ITER_D_32KTBX	✓	✗	✗	✗	✓	✗	✗	✗
Molybdenum	Molybdenum as solid pure form (i.e. not powdered or compound form)	✓	✓	✓	✓	✓	✓	✓	✓

KEY: ✓ = approved for use. ✗ = not approved for use. ✝ = restricted use

Material / Material Class	Grades, (or composition applicable to ITER)	Vacuum Quality Classification							
		1A	1B	2A	2B	3A	3B	4A	4B
Molybdenum	Tracks on surface of silicon wafer sensor Ex-vessel Magnetic Sensors Qty ~0.001g (1mg) total for all sensors MAR:- ITER_D_DG5ZG5	×	×	×	✝	×	×	×	×
Molybdenum alloy	Mo alloy (Titanium(0.5)-Zirconium(0.08)-Molybdenum, TZM) MAR: ITER_D_TRZ5LS Outgassing data ITER_D_TR7YZC	✓	✓	✓	✓	✓	✓	✓	✓
MoS_2	Molykote D-321 R Anti-Friction Coating MAR: ITER_D_U3HP3S								✝
MoS_2	Molykote D-321 R Anti-Friction Coating MAR: ITER_D_UAT6CB				✝				

KEY: ✓ = approved for use. × = not approved for use. ✝ = restricted use

Material / Material Class	Grades, (or composition applicable to ITER)	Vacuum Quality Classification							
		1A	1B	2A	2B	3A	3B	4A	4B
MoS_2	Sputtered MoS_2 MAR: ITER_D_TL5DS8		✝						
MoS_2		×	✝	×		×	✝	×	✝
$MoSe_2$		×	✝	×	✝	×	✝	×	✝
WS_2		×	✝	×	✝	×	✝	×	✝
WSe_2		×	✝	×	✝	×	✝	×	✝
Boron Nitride		×	✓	×	✓	×	✓	×	✓
Titanium Nitride (TiN)	PVD hard coating (anti-seizing of bolt threads, used generally) MAR:- ITER_D_2LPCE9	×	✓	×	✓	×	✓	×	✓

KEY: ✓ = approved for use. × = not approved for use. ✝ = restricted use

Material / Material Class	Grades, (or composition applicable to ITER)	Vacuum Quality Classification							
		1A	1B	2A	2B	3A	3B	4A	4B
Boron Carbide		×	✝	×	✝	×	✝	×	✝
	Boron Carbide, Hot pressed sintered MAR: ITER_D_T7DB99		✝						
Zirconium Nitride	Chemical Vapour Deposition Coating	×	✝	×	✝	×	✝	×	✝
Zirconia	ZrO_2 with TiN coating Non-vacuum application (3rd party pump) VQC=N/A MAR:- ITER_D_L239S5								

KEY: ✓ = approved for use. × = not approved for use. ✝ = restricted use

Material / Material Class	Grades, (or composition applicable to ITER)	Vacuum Quality Classification							
		1A	1B	2A	2B	3A	3B	4A	4B
Zirconia	ZrO_2 ceramic can in a mechanical vacuum pump Non-vacuum application (3rd party pump) VQC=N/A MAR :- ITER_D_KZAGJN								
	ZrO_2 sintered or plasma sprayed MAR:- ITER_D_R64Q62	✗	✓	✗	✗	✗	✗	✗	✗
	Zirconia based adhesive RESBOND 940. MAR & Outgassing data ITER_D_RUDVER:				✝				

KEY: ✓ = approved for use. ✗ = not approved for use. ✝ = restricted use

3.4 Example Material Request Form

Material Approval Request*(v1.0)*						Ref No: Mat-Cha-1 *(Assigned by Vacuum RO)*			
Material submitted for approval:	Ceramic TRADE Name xxx								
Proposed form:	Solid								
Proposed Use:	HV Bushing								
VQC of proposed use:	1A	1B	2A	2B	3A	3B	4A	4B	N/A
	☒	☒	☒	☒	☒	☒	☒	☒	☐
If restricted give details of coverage (e.g. amount, surface area etc)									
Chemical Analysis / Material Safety Data Sheet available:	YES	*Attached Copy document ref. (electronic if available)*							
Agreed test plan:	NO	*Attached Copy document ref. (electronic if available)*							
Vacuum Test data Available:	YES	*Attached Copy document ref. (electronic if available)*							
Outgassing rate (at 100 °C)	N/A								
Vapour pressure (at 100 °C)	N/A								
Max temperature:	1000		Operating temperature:		240				
Pre installation treatment *(baking, electropolishing etc)*			Baked clean						
Requested by:	A.N.Other		Date Submitted:		25/03/09				
Affiliation :	USA		E-Mail		A.Other@USA.org				
Vacuum Material Approval Status: (*To be completed by ITER Vacuum Group RO)*									
Approved for VQC:	1A	1B	2A	2B	3A	3B	4A	4B	N/A
	☒	☒	☒	☒	☒	☒	☒	☒	☐
Limits / Restrictions (Attached Doc.)†									
ITER Vacuum RO	Approver:	L.Pressure							
	Date:30/03/09								

Grey boxes to be completed by requesting officer. Boxes in Red to be completed by ITER Vacuum RO.

† Reasons for material rejections shall be supplied with the notification of material refusal.

3.5 Notes:-

1. Carbon and carbon composites shall be conditioned for (vacuum) use in accordance with the ITER Vacuum Handbook. ITER vacuum handbook ITER_D_29DFGH

IDM UID
2ELN8N

VERSION CREATED ON / VERSION / STATUS
17 Jul 2017 / 1.14 / Approved

EXTERNAL REFERENCE / VERSION

Guideline (not under Configuration Control)

Appendix 4 Accepted Fluids

Approval Process			
	Name	*Action*	*Affiliation*
Author	**Vine G.**	**17 Jul 2017:signed**	**IO/DG/COO/PED/FCED/VS**
Co-Authors			
Reviewers	**Pearce R.** **Worth L.**	**31 Aug 2017:recommended** **17 Jul 2017:recommended**	**IO/DG/COO/PED/FCED/VS** **IO/DG/COO/PED/FCED/VS**
Approver	**Lee G.- S.**	**08 Sep 2017:approved**	**IO/DG/COO**
#SecureIDM# *RO: Chiocchio Stefano*			
Read Access	**GG: MAC Members and Experts, GG: STAC Members & Experts, AD: ITER, AD: External Collaborators, AD: IO_Director-General, AD: EMAB, AD: EUROfusion-DEMO, AD: Auditors, AD: ITER Management Assessor, project administrator, RO, LG: [CCS] CCS-All for Ext AM, LG: [CCS] CCS-Section Leaders, LG: [CCS] JACOBS,...**		

Change Log			
Appendix 4 Accepted Fluids (2ELN8N)			
Version	***Latest Status***	***Issue Date***	***Description of Change***
v1.0	In Work	27 Aug 2008	
v1.1	In Work	12 Jan 2009	
v1.2	In Work	18 Jun 2009	Name change from approved to accepted. Cutting fluid removed.
v1.3	Approved	02 Sep 2009	Minor textual changes for consistency with Vacuum Handbook
v1.4	Approved	29 Feb 2012	New fluids added
v1.5	Approved	05 Oct 2012	Included new cutting fluid and approved liquid dye penetrant product families (with restrictions)
v1.6	Signed	26 Jan 2015	Fluids added:- Cutting fluids Blasocut Castrol SYNTILO 75 EF Cut1 - Carecut S cuting fluid Garia 2608 S-12 Green Star SINTOL Micro Jokisch Foam Cut Magicutsynth-g-60 QUAKER 3755 BIO Hocut 2000 SWISSCOOL 7722 Vasco 1045 Acids 20% Sulphuric Acid solution Concentrated Nitric Acid Hydroflouric Acid LDP FluidLDP W divertor Couplants Babb Co matrix UT coupling agent CGM US Paste U49 Other Demin Water Elektrolyt EH01 Neutralix NG01
v1.7	Signed	10 Feb 2015	Fluids added:- Cutting fluids Blasocut Castrol SYNTILO 75 EF Cut1 - Carecut S cuting fluid Garia 2608 S-12 Green Star SINTOL Micro Jokisch Foam Cut Magicutsynth-g-60 QUAKER 3755 BIO

			Hocut 2000 SWISSCOOL 7722 Vasco 1045 Acids 20% Sulphuric Acid solution Concentrated Nitric Acid Hydroflouric Acid LDP FluidLDP W divertor Couplants Babb Co matrix UT coupling agent CGM US Paste U49 Other Demin Water Elektrolyt EH01 Neutralix NG01
v1.8	Approved	11 Feb 2015	Document version in header matched to IDM version Fluids added:- Cutting fluids Blasocut Castrol SYNTILO 75 EF Cut1 - Carecut S cuting fluid Garia 2608 S-12 Green Star SINTOL Micro Jokisch Foam Cut Magicutsynth-g-60 QUAKER 3755 BIO Hocut 2000 SWISSCOOL 7722 Vasco 1045 Acids 20% Sulphuric Acid solution Concentrated Nitric Acid Hydroflouric Acid LDP FluidLDP W divertor Couplants Babb Co matrix UT coupling agent CGM US Paste U49 Other Demin Water Elektrolyt EH01 Neutralix NG01
v1.9	Approved	19 May 2015	Fliuds and other processing media added:- Cutting fluids:- Xtreme Cut 250

			Pickling and passivation:- Avesta Passivator 601 Avesta Cleaner 401 Avesta picking paste BlueOne TM 130 Markers:- Intrama SL.250 SL2100 Abrasive media:- Cutting wheel: Abratec TIPO 42 Cutting wheel: Sait “A30S” [Thk. 2 mm] Cutting wheel: Sait “XA24Q” [Thk. 3,2 mm] Cutting wheel: Sait “XA24Q” [Thk. 7 mm] Cutting wheel: Sait “XA46R” [Thk. 1,6 mm] Flapper wheel: Abratec LAMELLARE Flapper wheel: Abratec LAMELLARE Flapper wheel: Sait "SAITLAM UK 3A" Flapper wheel: S.L.F. Abrasivi LASER DISC Rough Wheel: Abratec TIPO 27 Rough Wheel: 3M “987C CUBITRON 2”
v1.10	Approved	19 Aug 2015	Temporary fixings incorporating adhesive tape added, all VQC N/A. 3M™ Aluminum Foil Tape 431 3M™ Preservation sealing Tape 481 Delvigo DVC 48040/7 A5 weld backing strip Delvigo DVC 44040/6 A5 weld backing strip Scapa 336 Aluminium adhesive tape For any use on higher VQC categories, verification of full cleaning process required on sample coupons
v1.11	Approved	05 Nov 2015	Fluids added to previous version:- Metalsierra DF Cutting fluid Stratomet Protective paint (for processing equipment-not vacuum components) HC 1100-Passivator. Cleansafe 787-Cleaning agent VK Jelly / VK Jelly – Power / VK Spray / VK Spray - 1000 -Pickling and passivation K-2 Jelly / K-2 Jelly – Power / K-2 Spray / K-2 Paste -Pickling and passivation Ultrasonic couplant, Rock Oil 09060 -Ultra Sonic Testing (UT) coupling fluid Dodecane, 297879, Sigma-Aldrich -Ultra Sonic Testing (UT) coupling fluid
v1.12	Approved	07 Jun 2016	Fluids added:- Blasocut BC 935 Kombi, cutting fluid Vasco 7000, cutting fluid HE 111 Electrolytic polisher, HC 1100-K3W1, passivator HC 500, cleaning agent HE 310 Electrolytic Polisher, DR60, as LDP remover, NGL 17.40 P, ultrasonic cleaning PROSOLV HP, solvent ALCATUM / ALCATUM HO, cleaning agent

			DOWCLENE 1601, cleaning agent Kool Mist Formula 78, machining coolant Oil Eater, degreaser Rebound 7, degreaser Trim E206, machining coolant Trim Tap Heavy, cutting fluid Trim Tap Light, cutting fluid Blasocut 4000, cutting fluid
v1.13	Approved	06 Dec 2016	Abrasive media added:- Klingspor KL 315 abrasive paper PMUC 10067 3M Roloc Disc 984F Abrasive disk 3M Cloth Belts 984F. Abrasive Belt for belt grinder 3M Cubitron™ II: Cut off Wheels 3M Flap Disc 967A. Lukas Tungsten carbide burrs. Stainless steel brush 3M XT-RD-Cleaning Disc Cleaning agent -Surtec®089 with Surtec®132 Cleaning agent -PROCIV CUP Cutting Fluid -Hocut 795 HX Cutting Fluid -SWISSCOOL 7722 Markers-Edding 750 white, Silver and Blue Pickling and passivation-PROCAP 137 Tape-3M 425 & 431 Aluminium Foil Tape Handling material-Kraitec Elastomer pad UT coupling fluids-MR 750 Ultrasonic Coupling Agent
v1.14	Approved	17 Jul 2017	Fluids / other process media added:- Paper KL361 grain 240, grain 120 and grain 80 ; Grinding tool RB Adhesive Technologies Glue Stick, Part #229 Tacky tape SM 5142 Cleaning fluid RBS826 CitriSurf 2310 Oemeta Novamet 100 Coolant SemiSyn-200 Blue Coolant S-787_Request__Fluid_Acceptance Castrol CareCut S 600 HOCUT 795 MP Hocut 795 H Blasocut BC 25 MD Pentagon Coolcut S Blasocut BC 35 Kombi MK-SOL Soluble metal working oil Synergy 915 APIEZON T Markal paint marker Edelstahlbeize Typ 14 AveryDennison HP MPI 2121 Tesa 4613 – Utility grade Duct Tape Soundclear 60 Soundclear 40 UT Couplant for ITER Cryostat

ITER Vacuum Handbook
Appendix 4

Accepted Fluids

	Name	Affiliation
Author/Editor	Liam Worth	Vacuum Group - CEP
Vacuum Responsible Officer	Robert Pearce	Vacuum Group - CEP

4 ITER *Accepted* Fluids

4.1 Scope

This Appendix relates to fluids *accepted* to be used in the preparation and processing of materials and components which are exposed to the ITER vacuum environments, e.g. cutting fluids and cleaning solvents.

The ITER Vacuum Handbook (Section 6.1) states that

> "Cutting fluids for use on VQC 1 and 3 systems shall be water soluble, non-halogenated and phosphorus and sulphur free"[1].
>
> "*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, stored on IDM, to the ITER Vacuum Responsible Officer (RO).
>
> "For VQC 2 & 4 vacuum applications it is recommended that cutting fluids be water soluble, non-halogenated and phosphorus and sulphur free[1]. 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"

The ITER Vacuum Handbook Section 24 states that

> "Lists of *accepted* cleaning fluids can be found in Appendix 4"

Pursuant to this, materials which may be used freely for use on vacuum system items with the Vacuum Classifications stated are listed in the tables below.

4.2 Fluids not on the Accepted List

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

Details of fluids to be considered for *acceptance* should be submitted to the ITER Vacuum RO using the Fluid *Acceptance* Request Form. The proposer shall agree in advance with the ITER Vacuum RO a plan detailing the type and method of testing to qualify the material for use. The Fluid *Acceptance* Request Form along with the test data, report and supporting documentation, including any *supplier's* data (Certificates of Conformity, etc.), is to be submitted for consideration.

Fluids qualified in this way may be added to the *accepted* list.

[1] Sulphur, phosphorus and halogen (fluoride & chloride) content below 200 ppm for each.

A completed sample of the Fluid *Acceptance* Form is to be found at the end of this Appendix.

4.3 Fluid Selection / Qualification

The fluids listed in the following tables have been considered in terms of usage for vacuum purposes.

The properties of interest for this purpose include, *inter alia*,

- Fitness for purpose, i.e. how well it does the job for which it is used
- Easy and complete removal from the vacuum surface
- No induced degradation of the vacuum properties of the surface, e.g. increased outgassing
- No significant physical change to the surface
- Health and safety considerations

Fluids

Type	Name / type	Applicable to Vacuum Quality Classification							
		1A	1B	2A	2B	3A	3B	4A	4B
Cleaning fluids	Isopropyl Alcohol	✓	✓	✓	✓	✓	✓	✓	✓
	Ethyl Alcohol	✓	✓	✓	✓	✓	✓	✓	✓
	Acetone	✓	✓	✓	✓	✓	✓	✓	✓
	Axarel 9100♠ ,	✓	✓	✓	✓	✓	✓	✓	✓
	Citrinox™	✓	✓	✓	✓	✓	✓	✓	✓
	P3 Almeco♠ , P36 or T5161	✓	✓	✓	✓	✓	✓	✓	✓
	RBS 25	✓	✓	✓	✓	✓	✓	✓	✓
	RBS 35								

KEY: ✓ = *accepted* for use. × = not *accepted* for use. ✝ =*accepted* for restricted use only

Type	Name / type	Applicable to Vacuum Quality Classification							
		1A	1B	2A	2B	3A	3B	4A	4B
	RBS A350	✓	✓	✓	✓	✓	✓	✓	✓
	Cleansafe 787 MAR: ITER_D_RWAQR3 Datasheet:- ITER_D_RWH2NT	✓	✓	✓	✓	✓	✓	✓	✓
	HC 500 Liquid cleaning agent (Used in electropolishing process for cryogenic piping for the pre-production cryopump) FAR ITER_D_RZ3F5Q SDS ITER_D_RZ7ZFP MDS ITER_D_RZJVUT Approved cleaning procedure ITER_D_S2FG8X	✓	✓	✓	✓	✓	✓	✓	✓
	NGL 17.40 P Precision Cleaning for Ultrasonic processes FAR ITER_D_SEW4QA	✓	✓	✓	✓	✓	✓	✓	✓

KEY: ✓ = *accepted* for use. ✗ = not *accepted* for use. ✝ =*accepted* for restricted use only

Type	Name / type	Applicable to Vacuum Quality Classification							
		1A	1B	2A	2B	3A	3B	4A	4B
	DOWCLENE* 1601 Cleaning Fluid FAR ITER_D_STQSEK	✓	✓	✓	✓	✓	✓	✓	✓
	Oil Eater Manufacture of ITER-style vacuum flanges. FAR ITER_D_Q8DUKT SDS ITER_D_SRFUYV Cleaning Aqueous wash with Rebound 7 followed by DI water rinse	✓	✓	✓	✓	✓	✓	✓	✓
	CitriSurf 2310 MAR : ITER_D_UHXTT3	✓	✓	✓	✓	✓	✓	✓	✓
	RBS826 Cleaning fluid MAR : ITER_D_TF3G4P							✓	✓

KEY: ✓ = *accepted* for use. × = not *accepted* for use. ✝ =*accepted* for restricted use only

Type	Name / type	Applicable to Vacuum Quality Classification							
		1A	1B	2A	2B	3A	3B	4A	4B
	Rebound 7 Manufacture of ITER-style vacuum flanges. Aqueous wash followed by DI water rinse FAR ITER_D_QCK53E SDS ITER_D_SRF2G7	✓	✓	✓	✓	✓	✓	✓	✓
	Surtec®089 with Surtec®132 FAR:- ITER_D_TTWQVK	✓	✓	✓	✓	✓	✓	✓	✓
	PROCIV CUP FAR ITER_D_STHJGP	✓	✓	✓	✓	✓	✓	✓	✓
Cutting fluids	Castrol CareCut S 125	✓	✓	✓	✓	✓	✓	✓	✓
	Vasco 1045	✓	✓	✓	✓	✓	✓	✓	✓

KEY: ✓ = *accepted* for use. × = not *accepted* for use. ✝ =*accepted* for restricted use only

Type	Name / type	Applicable to Vacuum Quality Classification							
		1A	1B	2A	2B	3A	3B	4A	4B
	Vasco 7000 MAR ITER_D_RFQND9 MDS ITER_D_RAW9TK Chemical Analysis ITER_D_RZBSEF SDS ITER_D_RF4MWR	✓	✓	✓	✓	✓	✓	✓	✓
	Alusol M-FX Only approved for use for the processing of base material which is subject to subsequent machining / cleaning operations utilising accepted water miscible fluids.	✝	✝	✝	✝	✝	✝	✝	✝
	Hocut 2000	✓	✓	✓	✓	✓	✓	✓	✓
	Hocut 795 HX Soluble Metalworking Oil FAR:- ITER_D_4H3QL6 Use accepted cleaning procedure	✓	✓	✓	✓	✓	✓	✓	✓

KEY: ✓ = *accepted* for use. ✗ = not *accepted* for use. ✝ =*accepted* for restricted use only

Type	Name / type	Applicable to Vacuum Quality Classification							
		1A	1B	2A	2B	3A	3B	4A	4B
	Fluid Blasocut BC 35 Kombi SW ITER_D_HY3BCT	✓	✓	✓	✓	×	×	×	×
	Blasocut Kombi 935 MAR: ITER_D_RGD6JH Chemical analysis ITER_D_RZKU4T Safety datasheet ITER_D_=RGCLWS	✓	✓	✓	✓	✓	✓	✓	✓
	Blasocut 4000 Cleaning: Remove with water or solvent wipes FAR ITER_D_N54G6D	×	×	✓	✓	✓	✓	✓	✓
	CASTROL SYNTILO 75 EF ITER_D_PVM8M6	✓	×	×	×	×	×	×	×
	Garia 2608 S-12 https://user.iter.org/?uid=LXQXBA Only for use on non-vacuum facing surfaces (which must be protected) and all surfaces cleaned post machining.	✝	×	✝	×	×	×	×	×

KEY: ✓ = *accepted* for use. × = not *accepted* for use. ✝ =*accepted* for restricted use only

Type	Name / type	Applicable to Vacuum Quality Classification							
		1A	1B	2A	2B	3A	3B	4A	4B
	Green Star SINTOL MICRO ITER_D_Q3N7N7	✝	×	×	×	×	×	×	×
	Thread Cutting Oil Jokisch Foam Cut ITER_D_PNPSKN	✝	✝	✝	✝	✝	✝	✝	✝
	Magicutsynth-g-50 ITER_D_N3Q69Y	×	×	✝	✝	✝	✝	✝	✝
	QUAKER 3755 BIO ITER_D_NR4E2J	×	×	✝	✝	✝	✝	✝	✝
	Metalsierra DF Metalworking fluid FAR:- ITER_D_RMNBXQ Chemical analysis ITER_D_RMLNX3 Product data sheet ITER_D_RKLNT9 Safety data sheet ITER_D_RKLNX7	✓	✓	✓	✓	✓	✓	✓	✓

KEY: ✓ = *accepted* for use. × = not *accepted* for use. ✝ =*accepted* for restricted use only

Type	Name / type	Applicable to Vacuum Quality Classification							
		1A	1B	2A	2B	3A	3B	4A	4B
Cutting fluids	SWISSCOOL 7722 FAR: ITER_D_NFJ2N8 Approved for the spider application only	✝	✝	✝	✝	✝	✝	✝	✝
	SWISSCOOL 7722 FAR:- ITER_D_TTWU7X Use accepted cleaning procedure	✓	✓	✓	✓	✓	✓	✓	✓
	Xtreme Cut 250 MAR:- https://user.iter.org/?uid=QT8QGH Chemical analysis:- https://user.iter.org/?uid=QQ6LSM Subject to accepted cleaning procedure	✗	✗	✓	✓	✓	✓	✓	✓
	Hangsterfer's S787 Cutting Fluid MAR: ITER_D_SGMMPE				✓	✓	✓	✓	✓
	Castrol CareCut S 600 MAR: ITER_D_UCWFVD	✓	✓	✓	✓	✓	✓	✓	✓

KEY: ✓ = *accepted* for use. ✗ = not *accepted* for use. ✝ =*accepted* for restricted use only

Type	Name / type	Applicable to Vacuum Quality Classification							
		1A	1B	2A	2B	3A	3B	4A	4B
	HOCUT 795 MP MAR : ITER_D_TR7XRQ			✓	✓	✓	✓	✓	✓
	Hocut 795-H MAR : ITER_D_UDSBHL			✓	✓	✓	✓	✓	✓
	Blasocut BC 25 MD MAR : ITER_D_UFCFJC				✓	✓	✓	✓	✓
	Pentagon Coolcut S MAR : ITER_D_UJ8YF4			✓	✓	✓	✓	✓	✓
	Blasocut BC 35 Kombi MAR : ITER_D_U4EZRD	✓	✓	✓	✓	✓	✓	✓	✓
	MK_SOL_LUBE MAR : ITER_D_U4F3YE	✓	✓	✓	✓	✓	✓	✓	✓
	Hocut 795MP MAR : ITER_D_UVF5MT								

KEY: ✓ = *accepted* for use. ✗ = not *accepted* for use. ✝ =*accepted* for restricted use only

Type	Name / type	Applicable to Vacuum Quality Classification							
		1A	1B	2A	2B	3A	3B	4A	4B
	Synergy 915 MAR : ITER_D_UXSKL9			✓	✓	✓	✓	✓	✓
	Trim Tap Heavy FAR ITER_D_N9XD58 SDS ITER_D_T3BGTK (manufacture of ITER-style vacuum flanges) Cleaning: Aqueous wash with Rebound 7 followed by DI water rinse	✓	✓	✓	✓	✓	✓	✓	✓

KEY: ✓ = *accepted* for use. × = not *accepted* for use. ✝ =*accepted* for restricted use only

Type	Name / type	Applicable to Vacuum Quality Classification							
		1A	1B	2A	2B	3A	3B	4A	4B
Machining Coolant	Trim Tap Light FAR ITER_D_Q5UH9M SDS ITER_D_T3C35D (manufacture of ITER-style vacuum flanges) Cleaning: Aqueous wash with Rebound 7 followed by DI water rinse	✓	✓	✓	✓	✓	✓	✓	✓
	Kool Mist Formula 78 (manufacture of ITER-style vacuum flanges) FAR ITER_D_RCAFRL SDS ITER_D_SYC4EU Cleaning: Aqueous wash with Rebound 7 followed by DI water rinse	✓	✓	✓	✓	✓	✓	✓	✓
	Oemeta Novamet 100 Coolant MAR : ITER_D_U8W2E5			✓	✓	✓	✓	✓	✓

KEY: ✓ = *accepted* for use. × = not *accepted* for use. ✝ =*accepted* for restricted use only

Type	Name / type	Applicable to Vacuum Quality Classification							
		1A	1B	2A	2B	3A	3B	4A	4B
	SemiSyn-200 Blue MAR : ITER_D_UVF66V			✓	✓	✓	✓	✓	✓
	Trim E206 (manufacture of ITER-style vacuum flanges) Cleaning: Aqueous wash with Rebound 7 followed by DI water rinse FAR ITER_D_RZEV86 SDS ITER_D_SZWMS6	✓	✓	✓	✓	✓	✓	✓	✓
Solvents	Nefras S2-80/120 Wiping of Dome divertor parts for degreasing after machining FAR ITER_D_JREV32	✓	✓	✓	✓	✓	✓	✓	✓
	PROSOLV HP Degreasing of Copper & Tungsten for IVT Phase I FAR ITER_D_ST35B5	✓	✓	✓	✓	✓	✓	✓	✓

KEY: ✓ = *accepted* for use. ✗ = not *accepted* for use. ✝ =*accepted* for restricted use only

Type	Name / type	Applicable to Vacuum Quality Classification							
		1A	1B	2A	2B	3A	3B	4A	4B
Acids	Nitric acid (65%) FAR https://user.iter.org/?uid=PNAPTE https://user.iter.org/?uid=PNHPFU https://user.iter.org/?uid=PQA6AW	✓	✓	✓	✓	✓	✓	✓	✓
	Sulphuric Acid (20% solution) FAR https://user.iter.org/?uid=PJRKC5 https://user.iter.org/?uid=PK32SY https://user.iter.org/?uid=PKZE6A	✓	✓	✓	✓	✓	✓	✓	✓
	Nitric Acid Concentrated FAR https://user.iter.org/?uid=D29SZG https://user.iter.org/?uid=CZMVE5 https://user.iter.org/?uid=DBQPL9 https://user.iter.org/?uid=DBQPL9	✝	✝	✝	✝	✝	✝	✝	✝

KEY: ✓ = *accepted* for use. ✗ = not *accepted* for use. ✝ =*accepted* for restricted use only

Type	Name / type	Applicable to Vacuum Quality Classification							
		1A	1B	2A	2B	3A	3B	4A	4B
Acids	Hydrofluoric acid (in the manufacture of Divertor components prior to HIP) FAR https://user.iter.org/?uid=JQH3BW https://user.iter.org/?uid=JQH73T https://user.iter.org/?uid=JQHPHU	✝	✝	✝	✝	✝	✝	✝	✝
Alkaline solution	ALCATUM / ALCATUM HO Degreasing of Copper & Tungsten for IVT Phase I FAR ITER_D_STLR2W	✓	✓	✓	✓	✓	✓	✓	✓
Demin Water	Demin Water https://user.iter.org/?uid=N3PDHF	✓	✓	✓	✓	✓	✓	✓	✓
Etch and neutralise	Elektrolyt EH01 FAR https://user.iter.org/?uid=JEZ7DD	✓	✓	✓	✓	×	×	×	×
	Neutralix NG01 FAR https://user.iter.org/?uid=JF7ME6	✝	✝	✝	✝	✝	✝	✝	✝

KEY: ✓ = *accepted* for use. × = not *accepted* for use. ✝ =*accepted* for restricted use only

Type	Name / type	Applicable to Vacuum Quality Classification							
		1A	1B	2A	2B	3A	3B	4A	4B
Lubricant	APIEZON Medium Temperature Approved for VQC N/A only MAR : ITER_D_TF84U8								
Pickling and passivation	Avesta Passivator 601 FAR:- https://user.iter.org/?uid=NVPBLQ Datasheets:- https://user.iter.org/?uid=NW5VLQ https://user.iter.org/?uid=P3WC76 Subject to accepted cleaning procedure	✓	✓	✓	✓	✓	✓	✓	✓
	Avesta Cleaner 401 FAR:- https://user.iter.org/?uid=NSE9MN Datasheets:- https://user.iter.org/?uid=NSEMN4 https://user.iter.org/?uid=NSH4DX Subject to accepted cleaning procedure	✓	✓	✓	✓	✓	✓	✓	✓

KEY: ✓ = *accepted* for use. ✗ = not *accepted* for use. ✝ =*accepted* for restricted use only

Type	Name / type	Applicable to Vacuum Quality Classification							
		1A	1B	2A	2B	3A	3B	4A	4B
Pickling and passivation	Avesta picking paste BlueOne TM 130 FAR:- https://user.iter.org/?uid=NQ4Y7N Datasheets:- https://user.iter.org/?uid=NQTMJC https://user.iter.org/?uid=NS77X8 Subject to accepted cleaning procedure	✓	✓	✓	✓	✓	✓	✓	✓
	HC 1100 Passivation solution for Stainless Steel (cryogenic piping for the pre-production cryopump) FAR:- ITER_D_RXJZB7 Datasheet :- ITER_D_RYMSKU	✓	✓	✓	✓	✓	✓	✓	✓

KEY: ✓ = *accepted* for use. ✗ = not *accepted* for use. ✝ =*accepted* for restricted use only

Type	Name / type	Applicable to Vacuum Quality Classification							
		1A	1B	2A	2B	3A	3B	4A	4B
	HC 1100-K3W1 Stainless steel passivator (cryogenic piping for the pre-production cryopump) FAR ITER_D_RZ5MBE MDS ITER_D_RZ7JP4 SDS ITER_D_RZK5GK Cleaning procedures ITER_D_S2FG8X to be used	✓	✓	✓	✓	✓	✓	✓	✓
	VK Jelly / VK Jelly – Power / VK Spray / VK Spray – 1000 FAR:- https://user.iter.org/?uid=RUGXSS			✓	✓	✓	✓	✓	✓
	Edelshahlbeize Typ 14 MAR : ITER_D_U7VKQS	✓	✓	✓	✓	✓	✓	✓	✓
	K-2 Jelly / K-2 Jelly – Power / K-2 Spray / K-2 Paste FAR:- ITER_D_RVVJ9S			✓	✓	✓	✓	✓	✓

KEY: ✓ = *accepted* for use. ✗ = not *accepted* for use. ✝ =*accepted* for restricted use only

Type	Name / type	Applicable to Vacuum Quality Classification							
		1A	1B	2A	2B	3A	3B	4A	4B
	PROCAP 137 FAR:- ITER_D_STGBAW Use with approved cleaning procedure	✓	✓	✓	✓	✓	✓	✓	✓
Liquid Dye Penetrant product families	**Sherwin Inc. USA: NDT Europa BV:** Developer: D100 Cleaner: DR62 Penetrant: DP51 ***For VQC 1A/B This product is restricted and may only be used if component / system under test is subsequently baked at T ≥ 200 °C for a minimum of 24 hours prior to vacuum leak testing.*** ***For VCQ2A, 3A& 4A this product may only be used to accepted procedures on the prior acceptance of a deviation request from the ITER Vacuum Handbook to cover the proposed area of use.***	✝	✝	✝	✓	✝	✓	✝	✓

KEY: ✓ = *accepted* for use. ✗ = not *accepted* for use. ✝ =*accepted* for restricted use only

Type	Name / type	Applicable to Vacuum Quality Classification							
		1A	1B	2A	2B	3A	3B	4A	4B
	DR60 as remover of dye penetrant FAR ITER_D_S7UXTC Accepted for this application on basis of post-use impregnation processes. Other uses will require approved cleaning process	×	×	✓	✓	×	×	×	×

KEY: ✓ = *accepted* for use. × = not *accepted* for use. ✝ =*accepted* for restricted use only

Type	Name / type	Applicable to Vacuum Quality Classification							
		1A	1B	2A	2B	3A	3B	4A	4B
	CGM CIGIEMME Developer : Rotrivel U (R2.82) 02011200 Cleaner: Velnet / Solnet (R2.60) 02011000 Penetrant: Rotvel Avio B (R2.72) 02021800 ***For VQC 1A/B This product is restricted and may only be used if component / system under test is subsequently baked at T ≥ 200 °C for a minimum of 24 hours prior to vacuum leak testing.*** ***For VCQ2A, 3A& 4A this product may only be used to accepted procedures on the prior acceptance of a deviation request from the ITER Vacuum Handbook to cover the proposed area of use.***	✝	✝	✝	✓	✝	✓	✝	✓

KEY: ✓ = *accepted* for use. ✗ = not *accepted* for use. ✝ =*accepted* for restricted use only

Type	Name / type	Applicable to Vacuum Quality Classification							
		1A	1B	2A	2B	3A	3B	4A	4B
	GS CHEM Co LTD Developer: DA (P101017D) Cleaner: RA (P101015C) Penetrant: PA (P101016P) ***For VQC 1A/B This product is restricted and may only be used if component / system under test is subsequently baked at T ≥ 200 °C for a minimum of 24 hours prior to vacuum leak testing.*** ***For VCQ2A, 3A& 4A this product may only be used to accepted procedures on the prior acceptance of a deviation request from the ITER Vacuum Handbook to cover the proposed area of use.***	✝	✝	✝	✓	✝	✓	✝	✓

KEY: ✓ = *accepted* for use. ✗ = not *accepted* for use. ✝ =*accepted* for restricted use only

Type	Name / type	Applicable to Vacuum Quality Classification							
		1A	1B	2A	2B	3A	3B	4A	4B
	EISHINKAGAKU corp. Japan Developer: R-1S (NT) Special Cleaner: R-1M (NT) Special Penetrant: R-1A (NT) Special ***For VQC 1A/B This product is restricted and may only be used if component / system under test is subsequently baked at T ≥ 200 °C for a minimum of 24 hours prior to vacuum leak testing.*** ***For VCQ2A, 3A& 4A this product may only be used to accepted procedures on the prior acceptance of a deviation request from the ITER Vacuum Handbook to cover the proposed area of use.***	✝	✝	✝	✓	✝	✓	✝	✓

KEY: ✓ = *accepted* for use. ✗ = not *accepted* for use. ✝ =*accepted* for restricted use only

Type	Name / type	Applicable to Vacuum Quality Classification							
		1A	1B	2A	2B	3A	3B	4A	4B
	MAGNAFLUX Dye penetrant testing of Tungsten monoblocks for ITER IVT https://user.iter.org/?uid=JP6EW8 Penetrant: Zyglo ZL-27A, fluorescent post emulsifiable penetrant Cleaner: Zyglo ZR-10C, hydrophilic remover Developer: Zyglo ZP-4B, dry powder developer Fluid to be removed by hot demineralised water rinse followed by baking.	✝	✝	✝	✝	✝	✝	✝	✝
Ultra Sonic Testing (UT) coupling fluids	Babb Co matrix UT coupling agent FAR https://user.iter.org/?uid=PTZ2WR https://user.iter.org/?uid=PUW2LU Part to be cleaned to an accepted procedure after UT	✝	✝	✝	✝	✝	✝	✝	✝
	CGM US Paste U49 FAR https://user.iter.org/?uid=PUXQHP https://user.iter.org/?uid=PVAE22 Remove residues with clean cloth and acetone.	✝	✝	✝	✝	✝	✝	✝	✝

KEY: ✓ = *accepted* for use. ✗ = not *accepted* for use. ✝ =*accepted* for restricted use only

Type	Name / type	Applicable to Vacuum Quality Classification							
		1A	1B	2A	2B	3A	3B	4A	4B
Ultra-Sonic Testing (UT) coupling fluids	09060, Rock Oil, Vacuum test data https://user.iter.org/?uid=RRAZ87 ITER_D_RMSL86	✓	✓	✓	✓	✓	✓	✓	✓
	Dodecane, 297879, Sigma-Aldrich Vacuum test data ITER_D_RRAZ87 ITER_D_RMSL86	✓	✓	✓	✓	✓	✓	✓	✓
	Soundclear Grade 60 MAR : ITER_D_U2WF3L (can be recommended for use as component is baked)	✓	✓	✓	✓	✓	✓	✓	✓
	Soundclear Grade 40 MAR : ITER_D_U348TX (can be recommended for use as component is baked)	✓	✓	✓	✓	✓	✓	✓	✓

KEY: ✓ = *accepted* for use. ✗ = not *accepted* for use. ✝ =*accepted* for restricted use only

Type	Name / type	Applicable to Vacuum Quality Classification							
		1A	1B	2A	2B	3A	3B	4A	4B
	Pentagon Ultra 30 for use as UT couplant (approved for this application only, on basis of post –use surface removal by machining) MAR : ITER_D_UVC2BJ			✓					
	MR 750 Ultrasonic Coupling Agent FAR:- ITER_D_TX5XPV Cleaning as per ITER approved procedure document no. ITER CR-LTTS-602.	✓	✓	✓	✓	✓	✓	✓	✓

KEY: ✓ = *accepted* for use. ✗ = not *accepted* for use. ✝ =*accepted* for restricted use only

Type	Name / type	Applicable to Vacuum Quality Classification							
		1A	1B	2A	2B	3A	3B	4A	4B
Markers	Intrama SL.250 SL2100 MAR https://user.iter.org/?uid=QZSP86 Outgassing test report_MarkerPen_Intrama.SL.250 https://user.iter.org/?uid=QXVLSU Outgassing test report_MarkerPen_Intrama.SL.2100 https://user.iter.org/?uid=QXM5QJ Material acceptance report https://user.iter.org/?uid=HK7F54 Subject to accepted cleaning procedure	✓	✓	✓					
	Markal Certified Valve Action Paint Marker MAR : ITER_D_UBF44E (Certified for <200ppm halogen - agreed but should not be used on thin wall boundaries with material < 1.5mm.)			✓	✓				

KEY: ✓ = *accepted* for use. ✗ = not *accepted* for use. ✝ =*accepted* for restricted use only

Type	Name / type	Applicable to Vacuum Quality Classification							
		1A	1B	2A	2B	3A	3B	4A	4B
	Edding 750 White, Silver & Blue FAR:- ITER_D_AFEQ97 Cleaning as per approved procedure ; ITER-CR-LTTS-602			✓	✓	✓	✓	✓	✓
Protective paint (on material processing equipment)	Stratomet Protective paint FAR:- ITER_D_R7TFB7 Chemical analysis:- ITER_D_R6CD9Z Safety data sheet:- ITER_D_R6CCRZ	✓	✓	✓	✓	✓	✓	✓	✓
Abrasive media	Cutting wheel Abratec TIPO 42 MAR:- https://user.iter.org/?uid=QZRF3E Outgassing report :- https://user.iter.org/?uid=GGREMQ Subject to accepted cleaning procedure	✓	✓	✓	✓	✓	✓	✓	✓

KEY: ✓ = *accepted* for use. ✗ = not *accepted* for use. ✝ =*accepted* for restricted use only

Type	Name / type	Applicable to Vacuum Quality Classification							
		1A	1B	2A	2B	3A	3B	4A	4B
	Cutting wheel: Sait "A30S" [Thk. 2 mm] MAR:- https://user.iter.org/?uid=QURJQL Outgassing report:- https://user.iter.org/?uid=HK7F54 Subject to accepted cleaning procedure	✓	✓	✓	✓	✓	✓	✓	✓
	Cutting wheel: Sait "XA24Q" [Thk. 3,2 mm] MAR:- https://user.iter.org/?uid=QURJQL Outgassing report:- https://user.iter.org/?uid=HK7F54 Subject to accepted cleaning procedure	✓	✓	✓	✓	✓	✓	✓	✓

KEY: ✓ = *accepted* for use. ✗ = not *accepted* for use. ✝ =*accepted* for restricted use only

Type	Name / type	Applicable to Vacuum Quality Classification							
		1A	1B	2A	2B	3A	3B	4A	4B
	Cutting wheel: Sait “XA24Q” [Thk. 7 mm] MAR:- https://user.iter.org/?uid=QURJQL Outgassing report:- https://user.iter.org/?uid=HK7F54 Subject to accepted cleaning procedure	✓	✓	✓	✓	✓	✓	✓	✓
	Cutting wheel: Sait “XA46R” [Thk. 1,6 mm] MAR:- https://user.iter.org/?uid=QURJQL Outgassing report:- https://user.iter.org/?uid=HK7F54 Subject to accepted cleaning procedure	✓	✓	✓	✓	✓	✓	✓	✓
	Flapper wheel: Abratec LAMELLARE MAR:- https://user.iter.org/?uid=QZRF3E Outgassing report:- https://user.iter.org/?uid=GJ584M Subject to accepted cleaning procedure	✓	✓	✓	✓	✓	✓	✓	✓

KEY: ✓ = *accepted* for use. × = not *accepted* for use. ✝ =*accepted* for restricted use only

Type	Name / type	Applicable to Vacuum Quality Classification							
		1A	1B	2A	2B	3A	3B	4A	4B
	Flapper wheel: Sait "SAITLAM UK 3A" MAR:- https://user.iter.org/?uid=QURJQL Outgassing report:- https://user.iter.org/?uid=HK7F54 Subject to accepted cleaning procedure	✓	✓	✓	✓	✓	✓	✓	✓
	Flapper wheel; S.L.F. Abrasivi LASER DISC – "SERIE 10-ALU DISC" MAR:- https://user.iter.org/?uid=QURJQL Outgassing report:- https://user.iter.org/?uid=HK7F54 Subject to accepted cleaning procedure	✓	✓	✓	✓	✓	✓	✓	✓
	Rough Wheel: Abratec TIPO 27 MAR:- https://user.iter.org/?uid=QZRF3E Outgassing report ;- https://user.iter.org/?uid=HD5Z3U Subject to accepted cleaning procedure	✓	✓	✓	✓	✓	✓	✓	✓

KEY: ✓ = *accepted* for use. ✗ = not *accepted* for use. ✝ =*accepted* for restricted use only

Type	Name / type	Applicable to Vacuum Quality Classification							
		1A	1B	2A	2B	3A	3B	4A	4B
	Rough Wheel: 3M "987C CUBITRON 2" MAR:- https://user.iter.org/?uid=QURJQL Outgassing report:- https://user.iter.org/?uid=HK7F54 Subject to accepted cleaning procedure	✓	✓	✓	✓	✓	✓	✓	✓
	Klingspor KL 361 Abrasive paper. PMUC 10067 FAR:- ITER_D_TXD2ZJ Cleaning with alcohol after usage	✓	✓	✓	✓	✓	✓	✓	✓
	3M Roloc Disc 984F Abrasive Disc FAR:- ITER_D_4H8PDW Area to be cleaned with solvent after processing	✓	✓	✓	✓	✓	✓	✓	✓
	3M Cloth Belts 984F Abrasive Belt for belt grinder FAR:- ITER_D_4HBVE3 Must be followed by cleaning procedure	✓	✓	✓	✓	✓	✓	✓	✓

KEY: ✓ = *accepted* for use. ✗ = not *accepted* for use. ✝ =*accepted* for restricted use only

Type	Name / type	Applicable to Vacuum Quality Classification							
		1A	1B	2A	2B	3A	3B	4A	4B
	3M™ Abrasive Products, High Performance Cut off Wheels, Depressed Center Grinding Wheels, Grind Wheels Type 27, Cubitron™ II FAR:- ITER_D_4HD79D Must be followed by cleaning procedure	✓	✓	✓	✓	✓	✓	✓	✓
	3M Flap Disc 967A Flap disc FAR:- ITER_D_T79GNQ Area to be cleaned with solvent after operations with flapper	✓	✓	✓	✓	✓	✓	✓	✓
	3M XT-RD-Cleaning Disc FAR:- ITER_D_4H3ZHJ Must be followed by cleaning with solvent	✓	✓	✓	✓	✓	✓	✓	✓
	Tungsten carbide burrs Lukas Abrasive Pencil FAR:- ITER_D_T8FBAG	✓	✓	✓	✓	✓	✓	✓	✓
	Stainless steel brush FAR:- ITER_D_T8FUKG	✓	✓	✓	✓	✓	✓	✓	✓
	Paper KL361 grain 240, grain 120 and grain 80 ; Grinding tool RB 317 LX-R grain 80 FAR : ITER_D_UAMCD5	✓							

KEY: ✓ = *accepted* for use. × = not *accepted* for use. ✝ =*accepted* for restricted use only

Type	Name / type	Applicable to Vacuum Quality Classification							
		1A	1B	2A	2B	3A	3B	4A	4B
	Tetrabor lapping paste (water/polyalcohol based) FAR:- https://user.iter.org/?uid=QF6X54 Datasheets:- Safety https://user.iter.org/?uid=QED2DQ https://user.iter.org/?uid=QEJ42W https://user.iter.org/?uid=QERFGW https://user.iter.org/?uid=QF2HJZ https://user.iter.org/?uid=QEH9AG https://user.iter.org/?uid=QF7K99 Subject to accepted cleaning procedure	✓	✓	✓	✓	✓	✓	✓	✓

KEY: ✓ = *accepted* for use. ✗ = not *accepted* for use. ✝ =*accepted* for restricted use only

Type	Name / type	Applicable to Vacuum Quality Classification							
		1A	1B	2A	2B	3A	3B	4A	4B
	HE 111 Electrolytic polisher (cryogenic piping for the pre-production cryopump) FAR ITER_D_RN4QKV Cleaning procedures ITER_D_S2FG8X to be used SDS ITER_D_RN6FUA	✓	✓	✓	✓	✓	✓	✓	✓
	HE 310 Electrolytic Polisher (cryogenic piping for the pre-production cryopump) FAR ITER_D_RYS3HQ SDS ITER_D_RYTRXG Cleaning procedures ITER_D_S2FG8X to be used	✓	✓	✓	✓	✓	✓	✓	✓

KEY: ✓ = *accepted* for use. ✗ = not *accepted* for use. ✝ =*accepted* for restricted use only

Type	Name / type	Applicable to Vacuum Quality Classification							
		1A	1B	2A	2B	3A	3B	4A	4B
Adhesive tapes	3M™ Aluminum Foil Tape 431 FAR:- ITER_D_R23U88 For use on VQC N/A surfaces only with solvent clean. Before use on higher VQC categories, verification of full cleaning process cleaning required on sample coupons								
	3M™ Preservation sealing Tape 481 FAR:- ITER_D_R24JEX For use on VQC N/A surfaces only with solvent clean. Before use on higher VQC categories, verification of full cleaning process cleaning required on sample coupons								

KEY: ✓ = *accepted* for use. ✗ = not *accepted* for use. ✝ =*accepted* for restricted use only

Type	Name / type	Applicable to Vacuum Quality Classification							
		1A	1B	2A	2B	3A	3B	4A	4B
Adhesive tapes	Delvigo DVC 48040/7 A5 weld backing strip FAR:- ITER_D_R477ZK For use on VQC N/A surfaces only with solvent clean. Before use on higher VQC categories, verification of full cleaning process cleaning required on sample coupons								
	Delvigo DVC 44040/6 A5 weld backing strip FAR:- ITER_D_R25TST For use on VQC N/A surfaces only with solvent clean. Before use on higher VQC categories, verification of full cleaning process cleaning required on sample coupons								

KEY: ✓ = *accepted* for use. ✗ = not *accepted* for use. ✝ =*accepted* for restricted use only

Type	Name / type	Applicable to Vacuum Quality Classification							
		1A	1B	2A	2B	3A	3B	4A	4B
	Scapa 336 Aluminium adhesive tape FAR:- ITER_D_R4AZFV For use on VQC N/A surfaces only with solvent clean. Before use on higher VQC categories, verification of full cleaning process cleaning required on sample coupons								
	AveryDennison HP MPI 2121 MAR : ITER_D_UDWANR (Recommended as component is cleaned and baked after use)	✓							
	Tesa 4613 – Utility grade Duct Tape (use of cryostat) MAR : ITER_D_UPXQCQ (Ok for VQC 2 but avoid to use on thin walled bellows or lips <1.5 mm thick)			✓					

KEY: ✓ = *accepted* for use. ✗ = not *accepted* for use. ✝ =*accepted* for restricted use only

Type	Name / type	Applicable to Vacuum Quality Classification							
		1A	1B	2A	2B	3A	3B	4A	4B
	3M 425 & 431 Aluminium Foil Tape FAR: ITER_D_U33P6M			✓	✓	✓	✓	✓	✓
Handling / transport materials	Kraitec anti-slip elastomer pads FAR:- ITER_D_4GRXXK	✓	✓	✓	✓	✓	✓	✓	✓
Adhesives	Adhesive Technologies Glue Stick, Part 229 MAR : ITER_D_UHDX7N (glue pucks for laser tracking to tie plate)			✓	✓				
	TACKY TAPE SM5142 (vacuum bag tape sealant) MAR : ITER_D_TX66XF			✓					

KEY: ✓ = *accepted* for use. × = not *accepted* for use. ✝ =*accepted* for restricted use only

Request for Acceptance of Fluid	Ref No: fluid-01 *(Assigned by Vacuum RO)*							
Fluid submitted for *acceptance*:	Cut ace 123							
Proposed Use:	Metal Cutting fluid							
VQC of proposed use:	1A	1B	2A	2B	3A	3B	4A	4B
	✓							
Chemical Composition / suppliers data sheet	Yes	*Attached Copy (electronic if available)*						
Agreed test plan:	No	*Attached Copy (electronic if available)*						
Vacuum Test data Available:	Yes	*Attached Copy (electronic if available)*						
Solubility in water (at ambient temperature)								
Cleaning method (if applicable)	Rinse in de mineralised water							
Vapour pressure (at 100 °C)	No	Pa						
Supporting information	Evaporates in air leaving oily residue							
Requested by	L.Pressure		Date Submitted		29/07/08			
Affiliation:	US DA		E-Mail		L.Pressure@iter.org			
Fluid *Acceptance* Status: **(*To be completes by ITER Vacuum Group RO*)**								
Acceptance for VQC:	1A	1B	2A	2B	3A	3B	4A	4B
	✓	✓	✓	✓	✓	✓	✓	✓
Limits / Restrictions (Attached Doc.)	Fluid to be removed by hot demineralised water rinse (Cut ace 123 .doc IDM Ref 15R8UI)							
ITER Vacuum RO	*Acceptor*:	H.M. Self						
	Date: 09/08/08							

Grey boxes to be completed by requesting officer. Boxes in Red to be completed by ITER Vacuum RO.

IDM UID
2N4NDK

VERSION CREATED ON / VERSION / STATUS
02 Sep 2009 / 1.2 / Approved

EXTERNAL REFERENCE / VERSION

Guideline (not under Configuration Control)

Appendix 5 Acceptance Checklist

Approval Process			
	Name	*Action*	*Affiliation*
Author	**Worth L.**	**02 Sep 2009:signed**	**IO/DG/COO/PED/FCED/VS**
Co-Authors			
Reviewers			
Approver	**Pearce R.**	**09 Sep 2009:approved**	**IO/DG/COO/PED/FCED/VS**
Document Security: Internal Use *RO: Chiocchio Stefano*			
Read Access	**GG: MAC Members and Experts, GG: STAC Members & Experts, AD: ITER, AD: External Collaborators, AD: IO_Director-General, AD: EMAB, AD: Auditors, AD: ITER Management Assessor, project administrator, RO, LG: Section Scheduling, AD: OBS - Vacuum Section (VS) - EXT, AD: OBS - Vacuum Section (VS)**		

Change Log			
Appendix 5 Acceptance Checklist (2N4NDK)			
Version	***Latest Status***	***Issue Date***	***Description of Change***
v1.0	In Work	18 Jun 2009	
v1.1	Signed	18 Jun 2009	Minor update
v1.2	Approved	02 Sep 2009	Minor textual changes for consistency with Vacuum Handbook

ITER Vacuum Handbook
Appendix 5

Acceptance Checklist

	Name	Affiliation
Author/Editor	Liam Worth	Vacuum Group - CEP
Vacuum Responsible Officer	Robert Pearce	Vacuum Group - CEP

5 *Acceptance* Checklist

5.1 Scope

To satisfy the requirements of the ITER Vacuum Handbook *acceptance* or *accepted* is called for in various places throughout the ITER Vacuum Handbook .

Acceptance can be granted through the submission of procedures (etc) or through the signed Procurement Arrangement as detailed in the ITER Vacuum Handbook .

This appendix is intended as a tool to manage the *acceptance* of the requirements as laid out in the ITER Vacuum Handbook and contains a list of all the items from the ITER Vacuum Handbook where *acceptance* is required.

An *acceptance* checklist can be completed for PAs by a representative of the ITER Vacuum Responsible Officer. On completion of the checklist, the reviewer can indicate where further *acceptance* is required for the PA to be in compliance with the requirements of the ITER Vacuum Handbook .

In the following table *acceptances* which are highlighted appear in similar form at more than one place in the Handbook. The main occurrence for each group is highlighted in the table in *blue* and subsequent occurrences are highlighted in dark *yellow*. A single acceptance is then valid for the whole group of *acceptances*.

.

#	ITER Vacuum Handbook Section Reference	*Acceptance*	Proc.	PA	Note
1	5 - Appendix 3	Only materials *accepted* to be used on ITER Vacuums	☐	☐	Materials listed in Appendix 3 can be used subject to their classification / restriction as described in Appendix 2. Other materials may be used once qualified as *acceptable*. Requires *acceptance* of qualification plan. ***Mandatory for all materials not listed in Appendix 3.***
2	5.3 - Metallic Machined Components and Fittings	Other forms of achieving low inclusion count material may be used	☐	☐	If a supplier has a process other than ESR or VAR to produce low inclusion material this method must be *accepted*. ***Mandatory if ESR or VAR is not used in the production of low inclusion material.***
3	5.4 - Outgassing	Novel, high surface area components require *acceptance*	☐	☐	The supplier must submit for review and *acceptance* a method by which components can be shown to conform to the requirements of the ITER Vacuum Handbook . Published data and /or experimental qualification may be used. ***Mandatory if novel high surface area components are used.***

#	ITER Vacuum Handbook Section Reference	*Acceptance*	Proc.	PA	Note
4	VH 5.4 - outgassing	Outgassing rate *acceptance* test to be performed on VQC 1 components	☐	☐	The supplier shall submit to the ITER Vacuum RO the *acceptance* test procedure for review and *acceptance*. This *acceptance* may also allow for testing of representative samples of components. Procedures should pay due regard to Appendix 17. For specific components, it may be agreed that conformity to a clean work and quality plan is *acceptable*. ***Mandatory for all VQC 1 components except if operation in vacuum above 1 Pa in which case the ITER Vacuum RO will assess the use and accept the component on a case by case basis.***
5	5.5 - Hot Isostatic Pressing	*Acceptance* at the design stage for the use of HIP formed components and *acceptance* of qualification procedure of such components	☐	☐	The use of HIP formed material *accepted* at the design stage. The ITER Vacuum RO shall also review and *accept* the procedure for qualification of such components to demonstrate that they conform to the requirements of the ITER Vacuum Handbook . ***Mandatory for components formed by Hot Isostatic Pressing.***
6	5.6 - Castings	Validation programme for the qualification of castings to show they conform to the VH shall be *accepted* by the ITER Vacuum RO	☐	☐	If a casting is required for use on systems with VQC = 1, 2A or 3 a qualification programme (to show that they conform to the requirements of the ITER Vacuum Handbook) shall be reviewed and *accepted*. ***Mandatory for castings with VQC =1, 2A or 3.***

#	ITER Vacuum Handbook Section Reference	*Acceptance*	Proc.	PA	Note
7	6.1.2 - VQC 1 & 3 cutting fluids	Cutting fluids not listed in Appendix 4 require *acceptance*.	☐	☐	Cutting fluids listed in Appendix 4 can be used subject to their classification / restriction as described in Appendix 4. Other cutting fluids may be used once qualified as *acceptable*. Requires *acceptance* of qualification plan. ***Mandatory for cutting fluids not listed in Appendix 4.***
8	7 - Permanent joining processes	Permanent joining processes not listed in Table 7.1 require *acceptance*	☐	☐	The supplier shall submit proposals for other permanent joining processes not listed to be *accepted*. ***Mandatory for all permanent joining processes not listed in table 7.1.***
9	7.1.1 - Joint Configuration	Welds for which at completion leak detection is not practical require that a test plan including provision for repair shall be *accepted*.	☐	☐	Where welds are not leak testable the supplier must submit for review and *acceptance* at the design stage a test plan which also details how such a weld could be repaired if it fails. ***Mandatory for welds which cannot be tested at the time of manufacture.***
10	7.1.4 - Inspection and Testing of Production welds	The selection process for codes which *require* the use of LPT for the build of vacuum equipment shall be recorded and *accepted*.	☐	☐	If there is a mandatory requirement (such as nuclear regulator) to ***build*** a vacuum system to a code which requires the use of LPT to satisfy the code then the selection of that code shall be *accepted*. ***Mandatory only where there is, for example, a regulatory requirement to build a vacuum system to a code and only then if the code requires the use of LPT without exception.***

#	ITER Vacuum Handbook Section Reference	*Acceptance*	Proc.	PA	Note
11	7.1.4 - Inspection and Testing of Production welds	If LPT is to be used then it must be used only according to procedures qualified and *accepted*	☐	☐	The supplier shall submit for *acceptance* a procedure for the use of ITER qualified LDP. This shall include how the LDP is removed from the surface. ***Mandatory when LDP is used.***
12	7.1.5 - Weld Finish & Repair	Weld repairs shall be carried out to *accepted* procedures	☐	☐	The supplier shall submit for review and *acceptance* of weld repairs on vacuum boundary components. ***Only mandatory for welds not produced to a code (e.g. RCC-MR – ASME 8).***
13	7.1.6 - Helium Leak Testing of Production Welds.	Procedure for helium leak testing to be *accepted*.	☐	☐	The supplier shall submit for review and *acceptance* a procedure detailing how the helium leak testing of production welds shall be carried out and details of the equipment to be used ***Mandatory for all vacuum welds. Accepted with #45***
14	7.2 - Brazed and soldered joints	Brazing flux is not normally permitted	☐	☐	If brazing flux is required for use on vacuum systems a procedure for cleaning the components shall be submitted for review and *acceptance*. ***Only required if brazing flux is to be used.***
15	7.2 - Brazed and soldered joints	The use of brazing materials containing silver is subject to quotas	☐	☐	Specific acceptance is required for use of silver bearing braze amerials on any individual component ***Mandatory for all use of silver alloys in brazed joints except in VQC4***

#	ITER Vacuum Handbook Section Reference	*Acceptance*	Proc.	PA	Note
16	7.2 - Brazed and soldered joints	Brazing should be performed to an *accepted* standard or to an *accepted* procedure.	☐	☐	If brazing is required the supplier shall submit for review and *acceptance* either a procedure detailing how the brazing operations are qualified and produced ***or*** an international brazing standard detailing the qualification and production procedure. ***Mandatory for all brazing operations.***
17	7.2.2 - Qualification of brazed joints	The procedure for the qualification of brazed joints shall be *accepted.*	☐	☐	If brazing is required the qualification procedure shall be *accepted* ***or*** performed to an *accepted* international standard for brazing. ***Mandatory for brazing operations. Acceptance can be granted with #16.***
18	7.2.3 – Inspection and testing of brazed joints	No braze shall be rerun for rectification of any sort without prior agreement	☐	☐	Procedure for any rerun to be agreed ***Mandatory where rectification of a braze is required***
19	7.3 – Diffusion bonding	Diffusion bonded joints shall be subject to the same qualification procedures as brazed joints	☐	☐	Note: Numbers 15-17 (inclusive) above apply ***Mandatory for all diffusion bonded joints***
20	7.3 – Explosion bonding	Explosion bonded joints shall be subject to the same qualification procedures as brazed joints	☐	☐	Note: Numbers 15-17 (inclusive) above apply ***Mandatory for all explosion bonded joints***
21	8.2 - Coatings	VQC 1 coatings subject to qualification and *acceptance.*	☐	☐	The supplier must provide for review and *acceptance* a method for the qualification of coatings. ***Mandatory only for VQC1.***

#	ITER Vacuum Handbook Section Reference	*Acceptance*	Proc.	PA	Note
22	9 - Confinement and Vacuum Containment	Single containment of VQC 1A vulnerable components may be *accepted* if the component is accessible for access and fitted behind an *accepted*, interlocked, isolating valve.	☐	☐	Details of single vacuum contained VQC 1A shall be supplied for review and *acceptance* at the design stage. ***Mandatory only for VQC1A components.***
23	9 - Confinement and Vacuum Containment	Single containment of VQC 2A components.	☐	☐	For Vulnerable VQC 2A components, which are not doubly vacuum contained, an alternative method for leak mitigation and localisation shall be submitted for review and *acceptance* at the design stage. ***Mandatory only for VQC2A components.***
24	11 - Connections to the SVS	All connections to the SVS shall be as defined in the VH with the exception of interspaces pumped to P< $5x10^{-1}$ Pa	☐	☐	The supplier shall submit for *acceptance* the detailed design of interspaces for connection to the SVS for interspaces where the required pressure is <$5x10^{-1}$ Pa. ***Mandatory for all SVS connections of this type.***
25	12.1 - Pipework General	VQC 1A and VQC2A pipes and fittings shall be seamless	☐	☐	Specific *acceptance* is required for the use of non-seamless pipes and fittings on the vacuum boundary of VQC1 and 2 systems. **Mandatory for VQC 1A and VQC 2A.**
26	12.1 - Pipework General	Water pipes passing through the cryostat shall have interspaces for leak localisation	☐	☐	Where water pipes passing through the cryostat are not installed with interspaces for leak localisation an alternative method of localisation shall be proposed for review and *acceptance*. ***Mandatory for all water pipes crossing the cryostat.***

#	ITER Vacuum Handbook Section Reference	*Acceptance*	Proc.	PA	Note
27	13 - Demountable Joints	All demountable joints require *acceptance*	☐	☐	The supplier shall provide details of proposed type and configuration of demountable vacuum joints (including seals) for use on ITER vacuum systems. ***Requirement is diminished if standard demountable vacuum joints are selected from Appendix 8.***
28	13 - Demountable joints	VQC 4 demountable vacuum joints shall use all-metal seals	☐	☐	If all metal seals are not to be used on VQC 4 systems a proposal for other types of seal shall be submitted for review and *acceptance*. ***Requirement for VQC 4.***
29	13 - Demountable joints	All demountable joints to be helium leak tested to *accepted* installation procedures	☐	☐	The supplier shall submit for review and *acceptance* installation procedure detailing how demountable vacuum joints are made (bolt torque, sequence etc). This procedure shall include leak testing of the made joint. ***Mandatory for all demountable vacuum*** ***General approval of leak testing techniques (only) may be made with #52***
30	14.1 – Tapped holes	Tapped holes to be cut using approved cutting fluids	☐	☐	Cutting fluids listed in Appendix 4 can be used subject to their classification / restriction as described in Appendix 4. Other cutting fluids may be used once qualified as *acceptable*. Requires *acceptance* of qualification plan. ***Mandatory for cutting fluids not listed in Appendix 4.*** ***Acceptance will be granted with #7***

#	ITER Vacuum Handbook Section Reference	*Acceptance*	Proc.	PA	Note
31	14.2.2 - Prevention of Bolt Seizing	Dry lubricants to be selected from Appendix 3	☐	☐	If a lubricant is not listed in Appendix 3 then *acceptance* to use the proposed lubricant shall be sought. ***Acceptance will be granted with #1.***
32	14.4 - Bearings and sliding joints	Design of bearings and sliding joints for use on VQC 1 to 3 subject to *acceptance*	☐	☐	The supplier shall submit for review and *acceptance* at the design stage proposals for the design of bearings and/or sliding joints for use on systems with VQC 1 to 3. ***Excludes sliding joints used in VQC 4.***
33	14.4 Bearings and sliding joints	Type of cross linked PTFE requires *acceptance*	☐	☐	If Cross linked PTFE is to be used the supplier shall submit for review and *acceptance* details of the type of cross-linked PTFE, it's operational position and quantity. ***Applicable to cross-linked PTFE for use on VQC 2 or 4.***
34	15.2 - Qualification of Windows	Qualification plan to be *accepted*	☐	☐	The supplier shall submit for review and *acceptance* a detailed plan for the qualification of window assemblies for use on a vacuum boundary. ***Mandatory for all window assemblies.***
35	15.3 - Testing of Window Assemblies	Testing plan to be *accepted*	☐	☐	The supplier shall submit for review and *acceptance* a detailed plan for the testing of window assemblies manufactures to a procedure *accepted* in #29. ***Mandatory for all window assemblies.***

#	ITER Vacuum Handbook Section Reference	*Acceptance*	Proc.	PA	Note
36	16 - Vacuum Valves and Valve Assemblies	Use of elastomers for closure seals	☐	☐	Where valves are to be used on VQC 2 and an elastomer closure seal is required the supplier shall provide details of the type of valve and it's operational position (etc) for review and *acceptance*. ***Applicable to VQC 2 Valves only.***
37	16 - Vacuum Valves and Valve Assemblies	Use of compressed gas to maintain closure seal	☐	☐	Valves should not require compressed gas to maintain the closure seal. If it is required that a valve utilises compressed gas to maintain the closure seal, the type of valve, operational position, etc., shall be provided for review and *acceptance*. ***Mandatory for all such valves.***
38	16.1 - Acceptance testing of Valves and Valve Assemblies	Valves to be leak tested to *accepted* procedures	☐	☐	The supplier shall submit for review and *acceptance* a leak test procedure to prove the leak integrity of valves prior to delivery. ***Mandatory for all Valves, although can be waived for proprietary valves.*** ***General approval of leak testing techniques (only) may be made with #52***
39	17.1 - Bellows and Flexibles - General	Bellows in water circuits not allowed for any VQC unless by exception.	☐	☐	If a bellows is required for use in a water circuit and is installed behind an isolating valve, the supplier shall provide for review and *acceptance* details of position, operational parameters, design etc. ***Mandatory for all bellows in water circuits inside vacuum systems.***

#	ITER Vacuum Handbook Section Reference	*Acceptance*	Proc.	PA	Note
40	17.2 - Design of Bellows	Bellows shall be designed to EJMA or equivalent.	☐	☐	If bellows are not to be designed using the EJMA design rules then an alternative set of rules shall be submitted, with a bellows qualification plan, for review and *acceptance*. ***All non-proprietary Bellows.***
41	17.2 - Design of Bellows	The use of multilayer design requires *acceptance*	☐	☐	If vulnerable bellows used on VQC 1&2 systems are not of double wall construction then bellows of mulitilayer construction may be allowable if the multilayer design is *accepted*. ***For VQC 1& 2 Vulnerable Bellows.***
42	17.3 - Qualification of bellows	Procedure for the qualification of bellows required	☐	☐	The supplier shall submit for review and *acceptance* a plan detailing the tests to be performed in the qualification of bellows assemblies. ***For all non –proprietary bellows.***
43	17.4 - Testing and Inspection of Bellows	Procedure for the testing of bellows required	☐	☐	The supplier shall submit for review and *acceptance* a plan detailing the tests to be performed on the manufactured bellows assemblies. ***For all non –proprietary bellows.***
44	VH 18.1 - Feedthroughs General	Vulnerable VQC1A and 2A feedthroughs penetrating an air boundary shall be doubly vacuum contained	☐	☐	If the feedthroughs are not to be doubly vacuum contained then the supplier shall submit for review and *acceptance* an alternative arrangement which will ensure sufficient vacuum integrity of the component. ***VQC 1A&2A feedthroughs crossing an air boundary.***

#	ITER Vacuum Handbook Section Reference	*Acceptance*	Proc.	PA	Note
45	18.2 - Paschen breakdown	Choice of backfill gas in interspace where there is a risk of Paschen breakdown shall be *accepted*	☐	☐	The supplier shall agree which gas shall be used to backfill the interspace. ***For interspaces at risk of Paschen breakdown only.***
46	20.1 - Cables for use in Vacuum	Cables that are not listed in Appendix 10 require *acceptance* for use in ITER vacuum systems.	☐	☐	The supplier shall submit for review and *acceptance* at the design stage details of proposed cables not listed in Appendix 10. ***Applies to all VQC.***
47	20.1 - Cables for use in Vacuum	Qualification of cable manufacturing techniques	☐	☐	The supplier shall provide for review and *acceptance* a procedure for the manufacture and qualification of cables for use in ITER vacuum systems. ***Applies to all VQC. Complementary to #41***
48	24.1 - Cleaning	Cleaning procedures to be agreed	☐	☐	The supplier shall submit for review and *acceptance* a clean work plan detailing the procedures and methods to be used in the cleaning of vacuum components for use on ITER. ***Applies to all VQC.***
49	24.1 - Cleaning	Degreasing procedures	☐	☐	The supplier shall submit for review and *acceptance* a plan detailing the procedures and methods to be used in the degreasing of vacuum components for use on ITER. ***Applies to all VQC. Accepted with #48***
50	24.3 - Mechanical Processes on Vacuum Surfaces	Use of abrasive techniques on vacuum surfaces	☐	☐	All such techniques require agreement before being used In VQC2 shot and dry bead blasting are acceptable ***Mandatory for all VQC***

#	ITER Vacuum Handbook Section Reference	*Acceptance*	Proc.	PA	Note
51	24.3 - Mechanical Processes on Vacuum Surfaces	Use of grinding wheels	☐	☐	If a grinding wheel is to be used on components with VQC 1 then the details of the grinding wheel (composition, manufacturing process, etc.) shall be submitted for review and *acceptance* prior to the grinding wheel being used. ***For VQC 1 only.***
52	25.1 - Leak testing General	Leak testing procedures require *acceptance*	☐	☐	Prior to any acceptance leak testing the supplier shall submit for review and *acceptance* a leak testing procedure detailing the methods , equipment to be used, etc, for acceptance leak testing. ***Mandatory for all acceptance leak tests, for all VQC. May be waived for proprietary components supplied with C of C.***
53	25.4 - Scheduling of Leak Tests	Timing of tests	☐	☐	Prior to manufacture the supplier shall provide a leak test plan detailing the timing and type of leak tests to be performed. ***Mandatory for all acceptance leak tests, for all VQC. May be waived for proprietary components supplied with C of C.***
54	25.4 - Scheduling of Leak Tests	Derogation of acceptance leak testing of complete system.	☐	☐	For VQC 2A components where final acceptance leak testing of the system as a whole may be impractical the suppler shall submit for review and *acceptance* a procedure to leak test individual parts of the system and the method of scaling of such tests to the system whole. ***VQC 2A components only. Accepted*** **with #52.**

#	ITER Vacuum Handbook Section Reference	*Acceptance*	Proc.	PA	Note
55	25.5 - Methods and Procedures	Leak test procedures require acceptance	☐	☐	Full details required ***Accepted with #52***
56	25.5 - Methods and Procedures	Cold leak testing	☐	☐	The supplier of a vacuum system which operates at cryogenic temperatures shall submit for *acceptance* a method of cold leak testing joints. ***For all VQC. General approval of leak testing techniques (only) may be made with #52.***
57	25.6 - Acceptance leak testing at the suppliers Premises	Rectification of detected leak	☐	☐	If a leak is detected any rectification work (except remaking demountable joints) must be agreed in advance ***All VQC***
58	25.6 - Acceptance leak testing at the suppliers Premises	Delivery to ITER of equipment which fails the acceptance leak test	☐	☐	If a component fails the acceptance leak test at the suppliers premises then the supplier shall request *acceptance* before that component can be delivered to ITER. ***For All VQC.***
59	26.1 - Baking	Baking procedures	☐	☐	The supplier shall submit for review and *acceptance* procedures detailing the method of baking vacuum components. ***For All VQC.***
60	26.7 - Vacuum Conditioning of Carbon Composites	Conditioning (baking) procedures	☐	☐	The supplier shall submit for review and *acceptance* procedure detailing the method of vacuum conditioning carbon composite components. ***For All VQC.***

#	ITER Vacuum Handbook Section Reference	*Acceptance*	Proc.	PA	Note
61	28 – Marking of Vacuum Equipment	Chemical etching procedures	☐	☐	The supplier shall submit for review and *acceptance* details of chemical etching operations to be carried out on vacuum equipment. ***Applies to VQC1.***
62	29 – Packing and Handling of Vacuum Equipment	Backfilling of volumes	☐	☐	Where it is not practical to backfill volumes pumped for leak testing to 0.12 MPa the supplier shall submit for review and *acceptance* an alternative method. ***For All VQC.***
63	29 – Packing and Handling of Vacuum	Component packaging	☐	☐	Where it is not practical to seal components in polyethylene for shipping (sealed bag filled with dry air) the supplier shall propose for review and *acceptance* alternative methods of packing. ***For All VQC.***

IDM UID
2DXZZ3

VERSION CREATED ON / VERSION / STATUS
02 Sep 2009 / 1.3 / Approved

EXTERNAL REFERENCE / VERSION

Guideline (not under Configuration Control)

Appendix 6 Windows

Approval Process			
	Name	*Action*	*Affiliation*
Author	**Worth L.**	**02 Sep 2009:signed**	**IO/DG/COO/PED/FCED/VS**
Co-Authors			
Reviewers			
Approver	**Pearce R.**	**09 Sep 2009:approved**	**IO/DG/COO/PED/FCED/VS**
Document Security: Internal Use *RO: Chiocchio Stefano*			
Read Access	**GG: MAC Members and Experts, GG: STAC Members & Experts, AD: ITER, AD: External Collaborators, AD: IO_Director-General, AD: EMAB, AD: Auditors, AD: ITER Management Assessor, project administrator, RO, LG: [CCS] CCS-All for Ext AM, LG: [CCS] CCS-Section Leaders, LG: [CCS] JACOBS, LG: [CCS] CCS-Doc Co...**		

Change Log			
Appendix 6 Windows (2DXZZ3)			
Version	***Latest Status***	***Issue Date***	***Description of Change***
v1.0	In Work	27 Aug 2008	
v1.1	In Work	22 Sep 2008	
v1.2	In Work	12 Jan 2009	
v1.3	Approved	02 Sep 2009	Minor textual changes for consistency with Vacuum Handbook

ITER Vacuum Handbook
Appendix 6

Guide to the Supply of Vacuum Windows for the ITER Project

	Name	Affiliation
Author/Editor	Liam Worth	Vacuum Group - CEP
Vacuum Responsible Officer	Robert Pearce	Vacuum Group - CEP

6 Requirements for the Supply of Vacuum Windows for the ITER project

6.1 Scope

This appendix is written as a guide for the manufacture and supply of vacuum window assemblies for use on the ITER project.

It is intended that the *suppliers* of vacuum bellows and flexibles should follow the guidance in this appendix to achieve the requirements of the ITER Vacuum Handbook.

The *supplier* is at liberty to utilise other techniques not described in this appendix provided that the components manufactured comply with the requirements of ITER Vacuum Handbook.

“Supply” includes the design, manufacture, testing and delivery of windows as described in the specifications, including the design, manufacture and testing of beryllium windows for use on ITER diagnostic systems.

6.2 Design

ITER IO is responsible for specifying the interface between ITER systems and the window assemblies.

The supplier is responsible for the detailed design of the window assemblies.

Flanges or end fittings will be specified by ITER in accordance with The ITER Vacuum Handbook Appendix 8 and the design of the window assembly must conform to the ITER remote handling requirements as detailed in the ITER Remote Handling Code of Practice.

Window assemblies for use on ITER vacuum vessels forming part of the vacuum containment boundary for VQC1A should be bakeable to 250 °C and, to conform to the ITER Vacuum Handbook Section 15, should be of a double window design (either pre-assembled or installed as separate elements) unless permanently installed behind an Ultra High Vacuum (UHV) isolating valve. The interspace between the two windows will be backfilled with a suitable gas (as *accepted* by the ITER Vacuum Responsible Officer) and connected to the Service Vacuum System.

Similarly, window assemblies for use on ITER vacuum vessels forming part of the vacuum containment boundary for VQC2A should be of double construction. However, there is no requirement to operate at elevated temperatures.

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

Window assembly interspace volumes are to be manufactured with suitable connections to the Service Vacuum System, as detailed in the ITER Vacuum Handbook Section 8.

Windows used in VQC, 3 & 4 may be of a single window construction.

All joining processes, bonding of the window to the ferrule and brazing or welding of the metallic components, have to be pre-qualified and production proof samples should be made during the manufacturing process (see Attachment 1).

6.3 Materials

All vacuum facing materials for use in the manufacture of window assemblies should comply with the ITER *accepted* materials list (Appendix 3).

6.3.1 Windows

CVD Diamond, natural crystal quartz, synthetic crystal quartz and sapphire are *accepted* for use in ITER window assemblies forming primary vacuum containment. Beryllium Oxide is *accepted* for use in vacuum windows that form part of the primary vacuum containment after qualification of the window in accordance Section 6.5 of this Appendix. Sodium chloride and other hygroscopic materials are not *accepted* for use in VQC1 & VQC2 systems.

6.3.2 Window (body) Assemblies

All tubes/pipes are to be of seamless construction and comply with the ITER Vacuum Handbook Appendix 11.

In accordance with the ITER Vacuum Handbook Appendix 8 flanges should be manufactured from forged material and supplied as follows:

1. Materials selection is to comply with Appendix 3
2. When there is a vacuum boundary across the grain of thickness <5 mm, the material must be Electro-Slag Remelted (ESR) or Vacuum Arc Remelted (VAR). The use of plate is prohibited. Alternative processes for achieving the required inclusion limits may be *accepted* if successfully validated.
3. The rate of inclusions in such steels should be checked in accordance with ASTM E-45 Method D (or equivalent) to be within the following inclusion limits:
    - Inclusion Type A $\leq$ 1.0
    - Inclusion Type B $\leq$ 1.0
    - Inclusion Type C $\leq$ 1.0
    - Inclusion Type D $\leq$ 1.5

6.4 Manufacture

Before assembly commences the supplier should submit to ITER for *acceptance* the documents listed in Section 6.10.

Tools used during the manufacture of the window assemblies must not contaminate the vacuum surfaces. Cutting fluids need be *accepted* before use and will be water based, oil free, non-halogenated, sulphur and phosphorus free. Those listed in Appendix 4 are *accepted* and, if chosen, should be specified in the quality plan and agreed in advance.

Cleaning operations need to be performed to an *accepted* procedure in accordance with the ITER Vacuum Handbook Appendix 13. The use of chlorine and other halogen containing fluids (e.g. trichloroethylene) is strictly forbidden.

All assemblies must be individually identified, packaged and shipped to the ITER site in accordance with Section 22 of the ITER Vacuum Handbook .

6.4.1 Welding of Window Assemblies

Prior to manufacture the supplier should submit a weld plan in accordance with the ITER Vacuum Handbook Attachment 1. The weld plan is a drawing which cross references each welded joint to a supporting Weld Procedure Specification (WPS).

Welding procedures and the Procedure Qualification Records should be qualified in accordance with Attachment 1

Where practical, all welds shall be full penetration butt welds unless otherwise *accepted*.

100 % visual examination of welds should be carried out in accordance with the ITER Vacuum Handbook Attachment 1

Butt welds are to be 100 % radiographed in accordance with the ITER Vacuum Handbook Attachment 1

Where radiography is not feasible, production proof samples must be performed in accordance with the ITER Vacuum Handbook Attachment 1

Dye-Penetrant examination of production welds is only permitted in accordance with the ITER Vacuum Handbook..

6.4.2 Bonding of Windows

All windows should be bonded into metal ferrules.

6.4.2.1 VQC 1

Windows should be bonded into the window assemblies by aluminium bonding. Other bonding methods may be used with the advance agreement of the ITER Responsible Officer after *acceptance* of the method.

6.4.2.2 VQC 2

In addition to aluminium bonding, Sliver-Lead-Tin Eutectic may be used for windows for use on the outer cryostat boundary.

6.5 Qualification of Windows (type testing)

Prior to the manufacture of window assemblies the *supplier* must qualify the window design. The *supplier* should submit for *acceptance* a qualification plan (as part of the quality plan) detailing the tests to be performed on window assemblies. After the completion of all manufacturing processes the window assemblies should undergo the following qualification tests.

1. Pressure test[1]
2. Mechanical shock testing
3. Thermal shock test
4. Helium leak test
5. High power RF transmission (where applicable)
6. Voltage stand-off (including Paschen breakdown where applicable)

[1] The pressure test should include a rapid vent "type test" in which the window is mounted in a small evacuated vessel which is then vented rapidly (simulating survival of a Vacuum Vessel loss of vacuum event).

In each case the method of testing should be *accepted* before manufacture shall commence.

6.5.1 Pressure testing

Prior to leak testing it must be demonstrated that the window assemblies can withstand, and remain unaltered by, a 0.2 MPa pressure differential in either direction. Proof tests to 0.3 MPa are required to qualify the window assemblies.

6.5.2 Mechanical shock

Type testing of the window bonded elements must show no failure at 15 g acceleration for 1000 cycles.

6.5.3 Thermal Shock

Type testing of the window bonded elements must exhibit no change in helium leak rate when sprayed with water at 100^{o} C while at the window normal operating temperature

6.5.4 Leak Testing

The supplier should perform leak testing of the window assemblies in accordance with the ITER Vacuum Handbook Appendix 12

Window assemblies for use on VQC1 systems should be baked and hot leak tested at 250 °C as follows:

1. Global leak test of the window assembly
2. Leak test of the water cooling circuits (if applicable)
3. Leak test of the window interspace (both to vacuum and to atmosphere)

The leak test procedure should include three operating cycles of the window assembly at each test temperature before leak testing.

The procedure for baking windows should be in accordance with the ITER Vacuum Handbook Appendix 15 and should be submitted for *acceptance* before baking operations start.

Immediately after bake-out, these tests should be repeated at room temperature.

In both cases the acceptance leak rate shall be met with the background reading on the leak detector being at least one order of magnitude below the acceptance leak rate without electronic correction. Leak rates for window assemblies for VQC1 (including the window interspace) should not exceed 1 x 10^{-10} Pam^3s^{-1} at 250 °C

Window assemblies for use on VQC 2 systems should be subject to the same tests as VQC 1 but with the requirement for temperature cycling waived. Leak rates for window assemblies for VQC2 should not exceed 1 x 10^{-10} Pam^3s^{-1} at ambient temperature.

Acceptance criteria for window assemblies is summarised in Table 6-1.

Table 6-1 Window assembly Leak Rates

	VQC 1[1]	VQC 2[2]
Max global leak rate	1 x 10^{-10} Pam^3s^{-1}	1 x 10^{-10} Pam^3s^{-1}
Max leak rate from / to window interspace	1 x 10^{-10} Pam^3s^{-1}	1 x 10^{-10} Pam^3s^{-1} (if applicable)
Max cooling channel leak rate	1 x 10^{-10} Pam^3s^{-1}	1 x 10^{-10} Pam^3s^{-1}(if applicable)

1. Acceptance criteria at 250 °C
2. Acceptance criteria at ambient

6.5.5 High Power RF Transmission

On windows designed for the transmission of high power RF it must be demonstrated that the vacuum properties of the window remain unaltered when high power RF is applied. The *supplier* shall submit for *acceptance* a test plan detailing the method and type of transmission tests to be performed in the qualification of the windows assemblies.

6.5.6 Voltage Stand-off

The supplier must demonstrate that windows required to stand off high voltage can do so with no degradation of the vacuum performance of the windows. It must also be demonstrated that the window assemblies are suitable protected from Paschen discharges (if applicable). The *supplier* shall submit for *acceptance* a test plan detailing the method and type of tests to be performed in the qualification of the window assemblies.

6.6 Testing and Inspection of Window Assemblies

Prior to the manufacture of window assemblies the *supplier* should provide 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 should undergo a vacuum baking cycle to the operating temperature and a helium leak test according to 6.6.1 below.

6.6.1 Leak Testing

Prior to delivery to the ITER site, windows should be subject to helium leak testing in accordance with Section 6.5.4. Windows will be subject to acceptance helium leak testing on delivery to the ITER site.

6.7 Marking

Each window assembly should be individually marked with a unique identification which is traceable to the window assembly document package. The use of dyes, paints, pens and other such markers that transfer marking material into any window assembly surface should not be used for the marking of window assemblies. Scribing with a clean sharp point and vibro-etching are acceptable marking processes. Chemical etching is also acceptable, but not for use on for VQC1 vacuum facing surfaces.

6.8 Packaging & Delivery

The packaging and delivery of window assemblies to the ITER site should be in accordance with the ITER Vacuum Handbook.

Where practical, window assemblies should be entirely enclosed in heat sealed polyethylene and backfilled with a suitable dry gas. Nitrogen is preferred but other gasses may be permitted with prior *acceptance*. All window assemblies shall be shipped dry internally and externally irrespective of final acceptance testing at the manufacturer's site.

The use of adhesive tape for the protection and packaging of components must be limited to prevent the risk of contamination from the tape. In particular tape used on austenitic stainless steel should meet leachable chloride and fluoride limits of 15 ppm and 10 ppm, respectively. Where used, tape must be fully removable without residue, using isopropyl alcohol or acetone as the solvent if necessary.

All window assemblies should be transported in rigid packing cases or containers which are lined with waterproof material. Components must be packed with adequate protection from thermal and mechanical stresses (particularly shock loads resulting from dropping and mal-handling) which may adversely affect the operation of the window. All packing case joints should be sealed and cases marked with individual window specific identification. Handling instructions should also be clearly marked on the outer packaging. Chemical or radiological hazards, etc., should be identified on the packaging. All packaging markings will be in English and French and include the Vacuum Classification of the component(s).

6.9 Incoming inspection at the ITER Site

In addition to the inspection detailed in this Appendix, window assemblies will be subject to an incoming inspection on delivery to the ITER site. This will include, as a minimum, dimensional inspection for compliance with the technical specification and helium leak testing in accordance with the ITER Vacuum Handbook Appendix 12.

6.10 Documentation

The following documents shall be *accepted* before pre-manufacture activities commence:

- Weld Plan
- Quality Plan (including test plan /schedule)
- Welding Procedures and Welder Qualifications
- Dimensional Drawings
- Qualification test plan

The following documents shall be *accepted* before manufacture commences:

- Type testing report

On completion of manufacturing, two sets of the following documents should be supplied as data books:

- Signed-off Quality Plan
- Welding Procedures and Welder Qualifications
- Radiographic Reports (if applicable)
- Production Proof Sample Reports (if applicable)
- Material Certificates, traceable to assemblies, in accordance with EN 10204 2.2 ,3.1 or 3.2
- Dimensional drawings identifying welds
- Type testing report (s)
- Dimensional Inspection Report

IDM UID
2EPFG4

VERSION CREATED ON / VERSION / STATUS
02 Sep 2009 / 1.3 / Approved

EXTERNAL REFERENCE / VERSION

Guideline (not under Configuration Control)

Appendix 7 Valves

Approval Process			
	Name	*Action*	*Affiliation*
Author	**Worth L.**	**02 Sep 2009:signed**	**IO/DG/COO/PED/FCED/VS**
Co-Authors			
Reviewers			
Approver	**Pearce R.**	**09 Sep 2009:approved**	**IO/DG/COO/PED/FCED/VS**
Document Security: Internal Use *RO: Chiocchio Stefano*			
Read Access	**GG: MAC Members and Experts, GG: STAC Members & Experts, AD: ITER, AD: External Collaborators, AD: IO_Director-General, AD: EMAB, AD: Auditors, AD: ITER Management Assessor, project administrator, RO, LG: [CCS] CCS-All for Ext AM, LG: [CCS] CCS-Section Leaders, LG: [CCS] JACOBS, LG: [CCS] CCS-Doc Co...**		

Change Log			
Appendix 7 Valves (2EPFG4)			
Version	***Latest Status***	***Issue Date***	***Description of Change***
v1.0	In Work	27 Aug 2008	
v1.1	In Work	12 Jan 2009	
v1.2	In Work	12 Jan 2009	
v1.3	Approved	02 Sep 2009	Minor textual changes for consistency with Vacuum Handbook

ITER Vacuum Handbook
Appendix 7

Guide to the Supply of All Metal Vacuum Valves for the ITER Project

	Name	Affiliation
Author/Editor	Liam Worth	Vacuum Group - CEP
Vacuum Responsible Officer	Robert Pearce	Vacuum Group - CEP

7 Requirements for the Supply and Modification of All-Metal Ultra High Vacuum Valves for use on the ITER Project

This Appendix is written as a guide for the manufacture and supply and modification of all metal ultra high vacuum vacuum valves for use on ITER vacuum systems. It is intended that the *suppliers* of such vacuum valves should follow the guidance in this Appendix to achieve the requirements of the ITER Vacuum Handbook.

The *supplier* is at liberty to utilise other techniques not described in this Appendix provided that the components manufactured comply with the requirements of the ITER Vacuum Handbook.

“Supply” includes the design, manufacture, testing and delivery of bellows and flexibles as described in the specifications

7.1 Design

ITER is responsible for specifying the interface between ITER systems and the valves.

The supplier is responsible for the detailed design of the valves including any modifications as specified by ITER.

Flanges or end fittings shall be specified by ITER and supplied in accordance with the ITER Vacuum Handbook Appendix 8.

Valves used for ITER vacuum vessel isolation (VQC1A) should be bakeable to 250°C in the open and closed positions and, in accordance with the requirements of the ITER Vacuum Handbook, should be of double bellowed design. VQC 1 valves should be able to operate at 250°C and be of all metal construction (seal, body etc). Demountable valves for use on VQC 1A should utilise a metal double seal arrangement conforming with the requirements of the ITER Vacuum Handbook Appendix 8

VQC 2 & 3 valves are not required to operate at elevated temperature but must be of all metal vacuum containment.

There is no requirement for VQC 4 valves to be bakeable or of all metal design.

Pneumatic seals and electrical components for valves used in systems with classification VQC1 should withstand a total radiation integrated dose of 10^8 Gray (TDB)

Where valves require to be remotely handled as a unit rather than as part of an integrated remotely handled assembly, they should be designed in accordance with the requirements ITER Remote Handling Code of Practice.

The design life of valves for use on ITER should be such as to limit intervention for replacement or repair during the operational phase of the ITER Project. Typically valves for ITER vacuum vessel isolation should be designed to operate for a minimum of 5000 cycles without the requirement for intervention. This requirement applies to all torus isolation valves with the exception of valve sizes larger than DN1500 mm (e.g. Neutral Beam isolation valves)

7.2 Additional requirements for the supply of standard valves with modified ends

The requirements of the ITER Vacuum Handbook and this Appendix should also apply to valves with modified ends. In addition, the following requirements will apply to the modified parts only.

7.2.1 Materials

7.2.1.1 General

All vacuum facing materials for use in the manufacture of bellows should comply with the requirements of the ITER Vacuum Handbook. In particular materials should be taken from the ITER Vacuum *accepted* materials list (ITER Vacuum Handbook Appendix 3) and be consistent with the outgassing requirements of the ITER Vacuum Handbook.

7.2.1.2 Metallic Machined Components and Fittings

All VQC 1A components which are machined from steel, austenitic steel or superalloys and which are of final thickness less than 5 mm, should be made from cross-forged material which is Electro-Slag Remelted (ESR) or Vacuum Arc Remelted (VAR). The use of plate is prohibited. Alternative processes for achieving the required inclusion limits may be *accepted* if successfully validated.

The rate of inclusions in such steels should 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

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

Stainless steel knife-edge sealed flanges of any thickness for all vacuum classifications should be manufactured from cross-forged ESR grade material blanks.

All VQC 1A and 2A demountable vacuum flanges should be made from cross-forged or upset forged material.

7.2.2 Fabrication

Before assembly commences the supplier shall submit to ITER for *acceptance* the documents listed in Section 7.7

Tools used during the manufacture of the valves must not contaminate the vacuum surfaces. Cutting fluids need be *accepted* before use and will be water based, oil free, non-halogenated, sulphur and phosphorus free. Those listed in Appendix 4 are *accepted* and, if chosen, should be specified in the quality plan and agreed in advance.

Cleaning operations need to be performed to a procedure *accepted* by ITER in accordance with the ITER Vacuum Handbook Appendix 13. The use of chlorine and other halogen containing fluids (e.g. trichloroethylene) is strictly forbidden.

All assemblies must be individually identified, packaged and shipped to the ITER site in accordance with Section 22 of the ITER Vacuum Handbook.

7.2.2.1 Welding

The qualification, production and testing of welds should be in accordance with the ITER Vacuum Handbook Attachment 1.

In particular:

1. Before fabrication can commence the *supplier* should prepare for *acceptance* a weld plan. The weld plan is a drawing which cross references each welded joint to a supporting Weld Procedure Specification (WPS).
2. All welds should be qualified prior to manufacture.
3. 100% visual examination of production welds should be performed.
4. 100% volumetric examination of production welds should be performed, unless a method of pre-production proof sampling is *accepted*.
5. Dye-Penetrant examination of production welds is only permitted in accordance with the ITER Vacuum Handbook.

7.3 Leak Testing

Prior to shipping all valves should be subject to an acceptance vacuum leak test. Detailed leak testing procedures in accordance with the ITER Vacuum Handbook Appendix 12 should be submitted for *acceptance*.

Helium leak testing should include the following steps:

Valves for use on VQC1 systems should be baked and hot leak tested at 250°C as follows:

1. Valve body
2. Across the valve seat.
3. Valve actuator bellows.
4. Internal pressure element.
5. Double bellows interspace.
6. VQC 1A double seal interspace.

Immediately after bake-out, the same tests must be repeated at ambient temperature. In both cases the acceptance leak rate shall be met with the background reading on the leak detector being at least one order of magnitude below the acceptance leak rate without electronic correction. In each case, the leak test procedure should include three operating cycles of the valve at each test temperature before leak testing. Leak rates for valve assemblies (including double bellows interspace), and across the valve seat, should not exceed 1 x 10^{-10} Pam^3s^{-1} at 250 °C

Valves for use on VQC 2 systems are subject to the same tests as VQC 1 with the requirement for temperature cycling waived. Leak rates for valve assemblies (including double bellows interspace), and across the valve seat, should not exceed 1 x 10^{-10} Pam^3s^{-1}

It is expected that valves for use on VQC 3 & 4 systems will be delivered to ITER as proprietary items and hence be delivered with a manufacturer's certificate of conformity confirming leak tightness. In this case, proprietary valves may be subjected only to an ambient temperature acceptance test at the ITER site prior to installation. Leak rates for proprietary valve assemblies (including double bellows interspace), and across the valve seat, should not exceed 1 x 10^{-10} Pam^3s^{-1}

All leak tests and test facilities may be the subject of inspection by the ITER Vacuum Responsible Officer or nominated representative and hence the ITER Vacuum Responsible Officer must be notified as of the final timing of tests a minimum of 4 weeks prior to the tests commencing.

7.4 Marking

Each valve should be individually marked with a unique identification which is traceable to the valve document package. The use of dyes, paints, pens and other such markers that transfer marking material into any window assembly surface must not be used for the marking of window assemblies. Scribing with a clean sharp point and vibro-etching are acceptable marking processes.

Each valve shall be marked with an arrow clearly identifying the seal face direction of the valve.

7.5 Documentation

Valve data sheets are to be supplied for all valves.

A suppliers' certificate of conformity is required confirming that the valves supplied conform to the valve data sheet as revised and accepted by ITER.

Leak test reports and / or Certificates of Conformity must be supplied in accordance with the relevant requirements of the ITER Vacuum Handbook.

7.6 Packaging & Delivery

The packaging and delivery of valves to the ITER site should be in accordance with ITER Vacuum Handbook.

Valves should be entirely enclosed in heat sealed polyethylene and backfilled with a suitable dry gas. Nitrogen is preferred but other gasses may be *accepted*. All valve assemblies must be shipped dry internally and externally irrespective of final acceptance testing at the manufacturer's site.

The use of adhesive tape for the protection and packaging of components must be limited to prevent the risk of contamination from the tape. In particular tape used on austenitic stainless steel should meet leachable chloride and fluoride limits of 15 ppm and 10 ppm, respectively. Where used, tape should be fully removable without residue, using isopropyl alcohol or acetone as the solvent if necessary.

All valve assemblies should be transported in rigid packing cases or containers which are lined with waterproof material. Components should be packed with adequate protection from thermal and mechanical stresses which may adversely affect the operation of the valves. All packing case joints should be sealed and cases marked with individual valve specific identification. Handling instructions should also be clearly marked on the outer packaging. Any chemical or radiological hazards, etc., must be identified on the packaging. All packaging markings should be in English and French and include the VQC of the valve.

7.6.1 Incoming inspection at ITER Site

In addition to the inspection detailed in this Appendix, window assemblies will be subject to an incoming inspection on delivery to the ITER site. This will include, as a minimum, dimensional inspection for compliance with the technical specification and helium leak testing in accordance with the ITER Vacuum Handbook Appendix 12.

7.7 Documentation

Valve data sheets should be supplied for all valves.

A suppliers' certificate of conformity is required confirming that the valves supplied conform to the valve data sheet as revised and *accepted* by ITER.

Leak test reports and / or Certificates of Conformity must be supplied in accordance with the relevant requirements of the ITER Vacuum Handbook.

The following documents should be accepted before pre-manufacture activities commence:

- Weld Plan
- Quality Plan (including test plan /schedule)
- Welding Procedures and Welder Qualifications
- Dimensional Drawings

On completion of manufacturing, two sets of the following documents should be supplied as data books:

- Signed-off Quality Plan
- Welding Procedures and Welder Qualifications
- Radiographic Reports (if applicable)
- Production Proof Sample Reports (if applicable)
- Material Certificates, traceable to assemblies, in accordance with EN 10204 2.2 ,3.1 or 3.2

- Dimensional drawings identifying welds
- Test reports
- Dimensional inspection report

IDM UID
2DJYQA

VERSION CREATED ON / VERSION / STATUS
08 Jan 2015 / 2.5 / Approved

EXTERNAL REFERENCE / VERSION

Guideline (not under Configuration Control)

Appendix 8 Flanges

Approval Process			
	Name	*Action*	*Affiliation*
Author	**Worth L.**	**08 Jan 2015:signed**	**IO/DG/COO/PED/FCED/VS**
Co-Authors			
Reviewers	**Hughes S.**	**09 Jan 2015:recommended (Fast Track)**	**IO/DG/COO/PED/FCED/VS**
Previous Versions Reviews	**Quinn E.**	**28 Jan 2014:recommended v2.3**	**IO/DG/COO/PED/FCED/VS**
Approver	**Pearce R.**	**12 Jan 2015:approved**	**IO/DG/COO/PED/FCED/VS**
Document Security: Internal Use *RO: Chiocchio Stefano*			
Read Access	**GG: MAC Members and Experts, GG: STAC Members & Experts, AD: ITER, AD: External Collaborators, AD: IO_Director-General, AD: EMAB, AD: Auditors, AD: ITER Management Assessor, project administrator, RO, LG: [CCS] CCS-All for Ext AM, LG: [CCS] CCS-Section Leaders, LG: [CCS] JACOBS, LG: [CCS] CCS-Doc Co...**		

Change Log			
Appendix 8 Flanges (2DJYQA)			
Version	***Latest Status***	***Issue Date***	***Description of Change***
v1.0	In Work	27 Aug 2008	
v1.1	In Work	12 Jan 2009	
v1.2	In Work	18 Jun 2009	New version states development of the appendix is required
v2.0	Approved	03 Apr 2013	Details of demountable vacuum flange sets accepted for use on the ITER project
v2.1	Signed	20 Nov 2013	Added section on demounting flanges in-situ.
v2.2	Revision Required	20 Nov 2013	Updated silver coating to silver jacket for helicoflex class 1 flange set
v2.3	Approved	28 Jan 2014	Revision as requested with expanded table detailing accepted flange/seal combinations
v2.4	Signed	08 Jan 2015	Removed reference to flange class
v2.5	Approved	08 Jan 2015	Header corrected

ITER Vacuum Handbook
Appendix 8

Demountable Vacuum Flanges for use on the ITER Project

	Name	Affiliation
Author/Editor	Liam Worth	Vacuum Group - CEP
Vacuum Responsible Officer	Robert Pearce	Vacuum Group - CEP

Contents

8.1 Terms and acronyms

The terms and acronyms detailed in Table 1 are used throughout this document

Term / Acronym	Contextual meaning
Accepted	Accepted by ITER Vacuum RO through submission for Request for *Acceptance* [1].
COTS	Commercial Off The Shelf (item listed in a suppliers catalogue)
Flange set	Demountable vacuum joint and gasket seal
Flange	1 half of demountable joint
Gasket seal	Replaceable piece which forms the vacuum containment.
Mounting	Joining of a flange pair & gasket to make the flange set.
RO	Responsible Officer

Table 1 Terms and acronyms

8.2 Scope

The scope of this appendix is to define the vacuum demountable flange sets *accepted* for use on the ITER Vacuum Systems.

Flange sets (demountable vacuum joint and specified seal arrangements) listed herein may be used, as specified, without further approval.

Demountable vacuum joints not detailed in this appendix shall only be utilised after *acceptance* by the ITER vacuum RO. *Acceptance* of a demountable vacuum joint / seal combination not listed herein will require qualification of the flange set. Qualification of a flange set shall be performed to an *accepted* procedure.

In the case of the ITER style flanges the information included herein shall only be used for information. Finalised drawings, and gasket seal part numbers, will be made available on completion of the qualification process.

8.3 Accepted Flange Set Combinations

8.3.1 Standard Flange Set Nominal Diameter

The flange set nominal diameters used shall comply with Table 2.

	DN10DN16	DN25	DN40	DN50	DN63	DN100	DN150	DN200	DN250	DN300
CF*	✓	✓	✓	✓	✓	✓	✓	✓	✓	
ISO - KF	✓	✓	✓	✓	✓					
ISO-K					✓	✓	✓	✓	✓	✓
VCR[1]	✓	✓								
ITER Style					✓	✓	✓	✓	✓	✓

✓ *Accepted* for use

***** CF sizes shall be in accordance with ISO 3669-2:2007

[1] VCR from 6 to 25 mm (1/4 to 1 inch)

Table 2 Flange Size

8.3.2 Type of Flange Set

The type of flange set and seal combinations shall comply with Table 3.

Vacuum Classification (VQC)	**Behind an *Accepted* Isolating Valve (Y/N)[1]**	**Flange Set**	**Double Seal Required (Yes = Y / No= N / R = recommend)**	**Range of size (DN)**	**1st (Vacuum) Seal Material**	**2nd (Atmosphere) Seal Material**
1	N	ITER Style	Y	63 - 300	Metallic – Silver jacketed Helicoflex [2]	Metallic – Silver jacketed Helicoflex [2]
1	Y	ITER Style	R	63 - 300	Metallic – Silver jacketed Helicoflex [2]	Metallic – Silver jacketed Helicoflex [2]
1	Y	ISO-CF	N	16 - 250[2]	Silver coated copper gasket	N/A
1	Y	ISO-K	N	63 – 100	Aluminium edge type Table 5 [3]	N/A
1	Y	ISO-KF	N	16 - 63	Aluminium edge type Table 5 [3]	N/A
1	Y	VCR [4]	N	¼ -1 inch	Silver coated gasket in carrier Table 4	N/A
2	N/A	ITER Style	Y	63 - 300	Metallic – Silver jacketed Helicoflex [2]	Metallic – Silver jacketed Helicoflex [2]
2	N/A	ITER Style	Y	63 - 300	Metallic – Silver jacketed Helicoflex [2]	Seal material from Table 6
2	N/A	ISO-CF	N	16 - 250[2]	Silver coated copper gasket	N/A
2	N/A	ISO-K	N	63 – 100	Aluminium edge type Table 5 [3]	N/A
2	N/A	ISO-KF	N	16 - 63	Aluminium edge type Table 5 [3]	N/A
2	N/A	VCR [4]	N	¼ -1 inch	Silver coated gasket in carrier Table 4	N/A

3	N/A	ITER Style	Y	63 - 300	Metallic – Silver jacketed Helicoflex [2]	N/A
3	N/A	ITER Style	Y	63 - 300	Metallic – Silver jacketed Helicoflex [2]	N/A
3	N/A	ISO-CF	N	16 - 250[2]	Silver coated copper gasket	N/A
3	N/A	ISO-K	N	63 – 100	Aluminium edge type Table 5 [3]	N/A
3	N/A	ISO-KF	N	16 - 63	Aluminium edge type Table 5 [3]	N/A
3	N/A	VCR [4]	N	¼ -1 inch	Silver coated gasket in carrier Table 4	N/A
4	Y	ISO-CF	N	16 - 250[2]	Silver coated copper gasket	N/A
4	Y	ISO-K	N	63 – 100	Aluminium edge type Table 5 [3]	N/A
4	Y	ISO-KF	N	16 - 63	Aluminium edge type Table 5 [3]	N/A
4	Y	VCR [4]	N	¼ -1 inch	Silver coated gasket in carrier Table 4	N/A
4	N/A	ISO-K	N	63 - 400	Table 6	N/A
4	N/A	ISO-KF	N	16 - 63	Table 6	N/A

[1] Isolates system from main VV

[2] See section 8.4.1 for CF flange restrictions

Table 3 Accepted flange set and seal combination

8.3.3 Flange Mounting / Demounting

8.3.3.1 Design of Vacuum Flanged Systems

The design of VQC 1 systems utilizing flanges shall be such that the system, or components of the system, can be removed from the area of service through the demounting of ITER style flange set (Table 3).

8.3.3.2 Flange Demounting

Where there is a requirement to breach a VQC 1 boundary through the demounting of an accepted vacuum flange (Table 3) the breach shall only be made at an ITER style flange set.

It is prohibited to demount VQC 1 flange sets other than ITER style in the area of service (e.g. in the port cell). The system, or components of the system, shall be transported to a suitably contamination controlled area (e.g. the hot cell) prior to the demounting of a VQC 1 flange set other than ITER style.

8.3.3.3 Vacuum Testing

100 % of vacuum flange sets shall be helium leak tested to ensure the vacuum performance of the flange set is compliant with its VQC.

Where a system or component of a system has been removed from the area of service VQC 1 flange other than ITER style shall be helium leak tested prior to the system / component installation in the area of service.

ITER style flange sets shall be helium leak tested on mounting.

8.3.4 Seal Material Type

8.3.4.1 Metallic Seal Combinations

8.3.4.1.1 ITER Style Flanges

ITER style flanges have been qualified with specific gasket seals. The manufacturer's part number of seals to be used with ITER style flanges is detailed on the manufacturing drawings (Table 8). The use of gasket seals other than those with part numbers compliant with the manufacturing drawings is prohibited unless *accepted* by the ITER Vacuum RO.

8.3.4.1.2 VCR

VCR is a trade name of Swagelok. VCR flange sets shall utilise silver coated stainless steel gaskets with the Swagelok part numbers as listed in Table 4.

VCR (inch)	Product description (part number)[4]
1/4	316 SS VCR Face Seal Fitting, 1/4 in. Silver-Plated Gasket Retainer (SS-4-VCR-2-GR)
1/2	316 SS VCR Face Seal Fitting, 1/2 in. Silver-Plated Gasket Retainer Assembly (SS-8-VCR-2-GR)
3/4	316 SS VCR Face Seal Fitting, 3/4 in. Silver-Plated Gasket Retainer (SS-12-VCR-2-GR)
1	316 SS VCR Face Seal Fitting, 1 in. Silver-Plated Gasket Retainer (SS-16-VCR-2-GR)

Table 4 VCR gasket product description and manufacturers part number

8.3.4.1.3 CF

CF type flange sets shall utilise silver coated high-purity, oxygen-free (OFHC) copper gaskets.

8.3.4.1.4 Aluminium Edge Type

Aluminium edge type seals shall be utilised for ISO – K and ISO - KF flange sets.

For reference a manufacturers part number of aluminium edge type gasket seals are provided in Table 5.

Nominal Diameter (DN)	Manufacturers Part Number[3]	
	ISO - K	ISO - KF
16		34.016001.142.116-iz1
25		34.016001.142.125-iz1
40		34.040001.142.140-iz1
50		34.050001.142.150-iz1
63	34.063001.342.106	34.063001.142.163-iz1
80	34.080001.342.108	
100	34.100001.342.110	

Table 5 EVAC Al edge type gasket seal part numbers

8.3.4.2 Non-metallic Seals

Non-metal seal gasket material shall be chosen from Table 6. The seal gasket material chosen shall be compatible with the area of service. The radiation environment that the seal shall operate is defined in the ITER Environmental Conditions Room Book [5].

Material	Temperature limit (◦C)	Maximum allowable accumulated lifetime dose 1 MeV equivalent (Gray)
Viton	150	1×10^3
EPDM (Ethylene-propylene)	120	5×10^5
Nitrile rubber (Buna – N)	80	1×10^4

Table 6 Seal material temperature and radiation limits

8.3.5 Clamping Arrangement

The flange set clamping arrangement utilised shall comply with Table 7.

Flange set	Clamping Arrangement	Flange Option
ITER Style	Bolt ring	Fixed, rotatable
ConFlat	Bolt arrangement	Fixed, rotatable
ISO - KF	Chain clamp, ISO-K cold steel double clamp.	N/A
ISO - K		

Table 7 Flange clamping arrangement

8.4 Flange Set Manufacture

8.4.1 COTS Flange Sets

CF, VCR ISO-K and ISO-KF flange sets are commercially available items readily available in all parties' countries. It is recommended that these items be purchased from companies supplying vacuum equipment as part of their core business. The use of flange sets which are not purchased from a company supplying vacuum equipment as part of its core business shall only be by prior *Acceptance*.

To ensure compatibility between flanges (knife edge dimensions etc.) manufacturers of CF > DN 150 shall be *accepted* by the ITER Vacuum RO.

8.4.2 ITER Style Flange Set

ITER style flanges shall be manufactured according to the requirements of this Appendix and following the requirements of the ITER Vacuum Handbook.

8.4.2.1 Manufacturing Drawings

ITER Style flanges shall be manufactured in accordance with the drawings listed in Table 8.

DN	Drawing Reference[1]
63	ITER_D_BFGFDN v1.0
100	ITER_D_BLZJ8N v1.0
150	ITER_D_BLZK9E v1.0
200	ITER_D_BM3LDD v1.0
250	ITER_D_BM3ZRG v1.0
300	ITER_D_BM43TL v1.0
[1]ITER style flange drawings issued at V1.0 are for information only. After the completion of the qualification program drawings will be up-issued to version 2.0 and shall be used for manufacture.	

Table 8 ITER Style flange drawing reference

8.5 Reference

[1] Request for Acceptance (ITER_D_9AY4HD v1.0).

[2] http://www.techneticsgroup.com/products/sealing-solutions/metal-seals/helicoflex/.

[3] www.NEYCO.Fr

[4] http://www.swagelok.com/products/fittings/vcr-metal-gasket-face-seal.aspx.

[5] Environmental Conditions Room Book (ITER_D_2UUZ23)

[6] ITER Vacuum Handbook (ITER_D_2EZ9UM)

IDM UID
2E5LJA

VERSION CREATED ON / VERSION / STATUS
02 Sep 2009 / 1.3 / Approved

EXTERNAL REFERENCE / VERSION

Baseline Report (not under Configuration Control)

Appendix 9 Bellows

This Appendix is written as a guide for the manufacture and supply of vacuum bellows and flexibles for use on ITER vacuum systems. It is intended that the suppliers of vacuum bellows and flexibles should follow the guidance in this Appendix to achieve the requirements of the ITER Vacuum Handbook.

Approval Process			
	Name	*Action*	*Affiliation*
Author	**Worth L.**	**02 Sep 2009:signed**	**IO/DG/COO/PED/FCED/VS**
Co-Authors			
Reviewers			
Approver	**Pearce R.**	**09 Sep 2009:approved**	**IO/DG/COO/PED/FCED/VS**
Document Security: Internal Use *RO: Chiocchio Stefano*			
Read Access	**GG: MAC Members and Experts, GG: STAC Members & Experts, AD: ITER, AD: External Collaborators, AD: IO_Director-General, AD: EMAB, AD: Auditors, AD: ITER Management Assessor, project administrator, RO, LG: [CCS] CCS-All for Ext AM, LG: [CCS] CCS-Section Leaders, LG: [CCS] JACOBS, LG: [CCS] CCS-Doc Co...**		

Change Log			
Appendix 9 Bellows (2E5LJA)			
Version	***Latest Status***	***Issue Date***	***Description of Change***
v1.0	In Work	27 Aug 2008	
v1.1	In Work	12 Jan 2009	
v1.2	In Work	12 Jan 2009	
v1.3	Approved	02 Sep 2009	Minor textual changes for consistency with Vacuum Handbook

ITER Vacuum Handbook
Appendix 9

Guide to the Supply of Bellows for use on ITER Vacuum Systems

	Name	Affiliation
Author/Editor	Liam Worth	Vacuum Group - CEP
Vacuum Responsible Officer	Robert Pearce	Vacuum Group - CEP

9 Guide to the Supply of Double Wall Vacuum Bellows for use on ITER Vacuum Systems

9.1 Scope

This Appendix is written as a guide for the manufacture and supply of vacuum bellows and flexibles for use on ITER vacuum systems. It is intended that the *suppliers* of vacuum bellows and flexibles should follow the guidance in this Appendix to achieve the requirements of the ITER Vacuum Handbook.

The *supplier* is at liberty to utilise other techniques not described in this Appendix provided that the components manufactured comply with the requirements of the ITER Vacuum Handbook.

“Supply” includes the design, manufacture, testing and delivery of bellows and flexibles as described in the specifications

9.2 General

Bellows are considered as inherently vulnerable components due to their method of construction and because they are designed to facilitate movement.

Circular bellows are to be designed to the Expansion Joint Manufacturers Association (EJMA) code or to another *accepted* design code. Where design codes do not apply, design shall be by analysis and proven by testing.

Care shall be taken to ensure that the operational loading parameters are fully considered including all design loads and combinations. 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.

In all test situations and after installation, the bellows should be protected against all abnormal load conditions.

9.3 Design of bellows

All bellows for use on VQC 1 and 2 systems should be of double wall construction unless they are accessible for maintenance and fitted behind an *accepted*, interlocked, isolating valve. For VQC 1A bellows separating torus vacuum from air, double wall bellows are a mandatory safety design requirement as specified in the ITER Vacuum HAndbook. For VQC 2A where regular and significant movement is to be compensated by a bellows that is not required to be double walled by safety rules, the use of double wall bellows is to be determined by considerations of reliability, maintainability, maintainability and ALARA. Bellows which are of edge-welded construction shall be *accepted* provided that they comply with the ITER Vacuum Handbook Section 7.1.

The interspace between the two walls of the bellows assembly will normally be filled with a suitable tracer gas and the pressure in the interspace will be monitored continuously. The interspace will be connected to the Service Vacuum System in accordance with the ITER Vacuum Handbook Section 11.

9.4 Materials

9.4.1 General

All vacuum facing materials for use in the manufacture of bellows should comply with the requirements of the ITER Vacuum Handbook. In particular materials should be selected from the ITER Vacuum *Accepepted* Materials list (ITER Vacuum Handbook Appendix 3) and be consistent with the outgassing requirements of the ITER Vacuum Handbook section 5.4.

9.4.2 Metallic Machined Components and Fittings

All VQC 1A components which are machined from steel, austenitic steel or superalloys and which are of final thickness less than 5 mm, should be made from cross-forged material which is Electro-Slag Remelted (ESR) or Vacuum Arc Remelted (VAR) in accordance with the ITER Vacuum Handbook. The use of plate is prohibited. Alternative processes for achieving the required inclusion limits may be *accepted* if successfully validated.

The rate of inclusions in such steels should 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

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

Stainless steel knife-edge sealed flanges of any thickness for all vacuum classifications should be manufactured from cross-forged ESR grade material blanks.

All VQC 1A and 2A demountable vacuum flanges shall be made from cross-forged upset forged material.

9.5 Manufacture

9.5.1 General

Hydrostatic, rolling or elastomeric formation of bellows is *accepted* for all vacuum classes

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

Bellows which are of edge-welded construction may be *accepted* provided that they comply with the requirements of the ITER Vacuum Handbook Section 7.1.

9.5.2 Welding of bellows assemblies

The qualification, production and testing of welds should be in accordance with the Vacuum Handbook Attachment 1.

In particular:

1. Before fabrication can commence the *supplier* should prepare for approval a weld plan in accordance with the Vacuum Handbook Attachment 1. The weld plan is a drawing which cross references each welded joint to a supporting Weld Procedure Specification (WPS).
2. Welding procedures and the Procedure Qualification Records are to be qualified in accordance with Attachment 1.
3. 100% visual examination of production welds should be performed.
4. 100% volumetric examination of production welds should be performed, unless a method of pre-production proof sampling is *accepted*.
5. Dye-Penetrant examination of production welds is only permitted in accordance with the ITER Vacuum Handbook.

9.6 Qualification of Bellows (type testing)

Prior to the manufacture of bellows assemblies the manufacturer should qualify the bellows design. The supplier should submit for *acceptance* a qualification plan (as part of the quality plan) detailing the tests to be performed on bellows assemblies. After the completion of all manufacturing processes the bellows assemblies should undergo the following qualification tests.

- Pressure test
- Mechanical shock test
- Fatigue life test
- Helium leak test
- ITER-specific tests as prescribed in the procurement specification documentation

In each case, the method of testing should be *accepted* before manufacture begins..

9.6.1 Pressure testing

Prior to leak testing it should be demonstrated that with the bellows assemblies displaced axially and radially to the maximum design values, and subjected to a 0.2 MPa pressure differential applied internally or externally to the assembly, that the bellows can survive and remain unaltered when the bellows interspace is at the following pressures

- $< 10^{-3}$ MPa (evacuated interspace)
- 0.05 MPa (interspace normal operation)
- 0.2 MPa (Interspace over pressure)

In all cases pressure testing should be followed by leak testing.

9.6.2 Mechanical shock testing

Type testing of the bellows assemblies should show no failures at 15 g acceleration after 1000 cycles under the conditions specified in 9.6.1

9.6.3 Fatigue life tests

The *supplier* should demonstrate that the bellows assemblies will remain mechanically unaltered over the expected life of the ITER machine. Fatigue life tests should be performed under load conditions similar to the ITER loading conditions.

9.6.4 Leak Testing

The supplier should perform leak testing of the bellows assemblies in accordance with the ITER Vacuum Handbook. Guides to helium leak testing can be found in the ITER Vacuum Handbook Appendix 12.

Bellows assemblies for use on VQC1 systems should be baked and hot leak tested at the maximum operating temperature as follows:

- Global test of bellows assembly
- Leak test of bellows interspace (to vacuum and to atmosphere)
- Leak test of water cooling circuits (if applicable)

VQC 1A or VQC 3A components which include joints of dissimilar materials should be subjected to a minimum of three thermal cycles from ambient to the maximum possible operating temperature prior to leak testing. Normally, the time taken for any component to reach the specified bake temperature from ambient should be less than 100 hours.

Immediately after bake-out, the above tests should be repeated at ambient temperature. In both cases, the acceptance leak rate should be met with the background reading on the leak detector being at least one order of magnitude below the acceptance leak rate without electronic correction. In each case, the leak test procedure should include three operating cycles of the bellows assembly at each test temperature before leak testing.

Bellows for use on systems with VQC 2, & 4 should be subjected to the same leak testing requirements as for VQC 1 & 3, but there is no requirement to test at temperatures above ambient.

Leak rates for bellows assemblies are summarised in Table 9-1.

	Acceptance Leak Rate ($Pa.m^3.s^{-1}$ air equivalent) at maximum operating temperature			
	VQC			
	1	**2**	**3**	**4**
Global leak rate	1×10^{-10}	1×10^{-9}	1×10^{-9}	1×10^{-7}
Bellows interspace to atmosphere	1×10^{-10}	1×10^{-9}	1×10^{-9}	1×10^{-7}
Bellows interspace to vacuum	1×10^{-10}			

Cooling channels (if applicable)	1×10^{-10}

Table 9-1 Maximum acceptance leak rates for bellows assemblies

9.7 Testing and Inspection of Bellows

Prior to the manufacture of bellows assemblies the *supplier* should provide for *acceptance* a test plan and test procedures detailing the tests to be performed on bellows assemblies before delivery to the ITER site.

After the completion of all manufacturing processes and before delivery to the ITER site the bellows assemblies should undergo a vacuum baking cycle to their operating temperature and the following tests should then be carried out

9.7.1 Leak testing

The bellows should be subject to helium leak testing in accordance with 9.6.4.

9.7.2 Dimensional inspection

The supplier shall perform a survey of the bellows convolutions to confirm compliance with the bellows technical specification. The survey results will be supplied to ITER and any non-conformance may lead to rejection of the bellows.

9.8 Cleaning

Great care has to be exercised when cleaning thin walled metal bellows, particularly those of edge-welded, nested construction. If any cleaning residues are trapped between the convolutions, either inside or outside, these can result in corrosion which can rapidly cause leaks to develop. Similarly, if any particulates are deposited in the convolutions, mechanical puncturing can take place. Alkaline degreasing solutions such as Almeco are prone to particulate precipitation and therefore must not be used for bellows assemblies.

9.8.1 Procedure for Bellows for Class VQC 1 use

The bellows should be fixed in an extended position if at all possible.

1. Any traces of visible, loose contamination should be removed with a gentle jet of clean, dry air or nitrogen.
2. The bellows should be immersed in an ultrasonically agitated bath of isopropyl alcohol (IPA) or ethyl alcohol (ethanol).
3. The bellows should be vapour washed immediately in vapour of the same solvent.
4. The bellows, including the interspace where appropriate, should be thoroughly dried inside and out using a gentle jet of clean, dry, particulate free air or nitrogen.
5. The bellows should be placed in a dry air oven at 100 °C for at least 1 hour with the interspace vented and open to atmosphere.

6. The bellows should be baked in a clean vacuum oven at a pressure <10^{-4} Pa for 24 hours at 250 °C with the bellows interspace pumped or open to the vacuum environment of the oven.
7. The bellows should be sealed under dry nitrogen in a polyethylene bag.

This procedure can be used for bellows used on VQC 2, 3 & 4 systems with the vacuum bake requirement waived.

9.9 Proprietary bellows

Proprietary bellows fully meeting the ITER specification of the item and the requirements of each VQC may be allowable.

For VQC 1, 2 and 3, proprietary bellows should be supplied with an individual certificate of conformity, stating that the item is suitable for the design, operation and test conditions as stipulated in the technical specification,.

For VQC 4, proprietary bellows should 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.

9.10 Bellows Protection

Normally accessible bellows assemblies and bellows assemblies which become accessible during machine maintenance should 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 convolutions.

9.11 Marking

Surfaces which are to be exposed to vacuum should only be marked or identified if absolutely necessary, and should be marked by scribing with a clean sharp point. Seal faces should not be used. Chemical etching is an acceptable alternative for all VQC except VQC 1

Dyes, marker pens, paints, etc. should not be used on surfaces which will be exposed to vacuum. Furthermore, their use should be avoided on other surfaces to eliminate the potential for cross-contamination during subsequent cleaning operations. The use of such substances may block porosity in material and result in leaks which are initially undetectable but may open up after some time.

9.12 Packaging & delivery

Where practical, bellows assemblies should be entirely enclosed in heat sealed polyethylene and backfilled with a suitable dry gas. Bellows interspaces should be backfilled to 0.1 MPa with the connections sealed by a closed valve. Nitrogen is preferred but other gasses may be *accepted.* All bellows assemblies must be shipped dry internally and externally irrespective of final acceptance testing at the manufacturer's site.

The use of adhesive tape for the protection and packaging of components should be limited 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 must be fully removable, without residue, using isopropyl alcohol or acetone as the solvent

Where practical all bellows assemblies should be transported in rigid packing cases or containers which are lined with waterproof material. Components should be packed with adequate protection from thermal and mechanical stresses (particularly shock loads resulting from dropping and mal-handling) which may adversely affect the operation of the bellows. All packing case joints should be sealed and cases marked with bellows specific identification. Handling instructions should also be clearly marked on the outside of the packaging. Any chemical or radiological hazards, etc., must be identified on the packaging. All packaging markings should be in English and French and should include the VQC of the bellows.

9.13 Incoming inspection at ITER Site

In addition to the inspection detailed in this Appendix, bellows assemblies will be subject to an incoming inspection on delivery to the ITER site. This will include, as a minimum, dimensional inspection for compliance with the technical specification and helium leak testing in accordance with the ITER Vacuum Handbook Appendix 12.

9.14 Documentation

The following documents should be *accepted* before pre-manufacture activities commence:

- Weld Plan
- Quality Plan (including test plan /schedule)
- Welding Procedures and Welder Qualifications
- Dimensional Drawings

The following documents should be *accepted* before manufacture commences:

- Type testing report

On completion of manufacturing, two sets of the following documents should be supplied as data books:

- Signed-off Quality Plan
- Welding Procedures and Welder Qualifications
- Radiographic Reports (if applicable)
- Production Proof Sample Reports (if applicable)
- Material Certificates, traceable to assemblies, in accordance with EN 10204 2.2, 3.1 or 3.2
- Dimensional drawings identifying welds
- Type testing report
- Dimensional inspection report

IDM UID
2ETNLM

VERSION CREATED ON / VERSION / STATUS
02 Sep 2009 / 1.2 / Approved

EXTERNAL REFERENCE / VERSION

Guideline (not under Configuration Control)

Appendix 10 Vacuum Cables

Approval Process			
	Name	*Action*	*Affiliation*
Author	**Worth L.**	**02 Sep 2009:signed**	**IO/DG/COO/PED/FCED/VS**
Co-Authors			
Reviewers			
Approver	**Pearce R.**	**09 Sep 2009:approved**	**IO/DG/COO/PED/FCED/VS**
Document Security: Internal Use *RO: Chiocchio Stefano*			
Read Access	**GG: MAC Members and Experts, GG: STAC Members & Experts, AD: ITER, AD: External Collaborators, AD: IO_Director-General, AD: EMAB, AD: Auditors, AD: ITER Management Assessor, project administrator, RO, LG: [CCS] CCS-All for Ext AM, LG: [CCS] CCS-Section Leaders, LG: [CCS] JACOBS, LG: [CCS] CCS-Doc Co...**		

Change Log			
Appendix 10 Vacuum Cables (2ETNLM)			
Version	***Latest Status***	***Issue Date***	***Description of Change***
v1.0	In Work	27 Aug 2008	
v1.1	Signed	12 Jan 2009	
v1.2	Approved	02 Sep 2009	Minor textual changes for consistency with Vacuum Handbook

ITER Vacuum Handbook
Appendix 10

Guide to the Supply of in-Vacuum Cables for the ITER Project

	Name	Affiliation
Author/Editor	B Boussier	Vacuum Group - CEP
Vacuum Responsible Officer	Robert Pearce	Vacuum Group - CEP

10 Requirements for the Supply of In-Vacuum Cables for the ITER project

10.1 Scope of this Appendix

The ITER project will include up to 80 km of in-vacuum cabling. This Appendix provides information on the various *accepted* forms of cabling for use on the ITER project for each Vacuum Quality Class, as well as general guidelines for their use.

It is intended that the *suppliers* of in-vacuum cables should follow the guidance in this Appendix to achieve the requirements of the ITER Vacuum Handbook.

The *supplier* is at liberty to utilise other techniques not described in this Appendix provided that the components manufactured comply with the requirements of the ITER Vacuum Handbook.

10.2 General

In-vacuum cabling should comply with all the general vacuum requirements for its Vacuum Quality Class (VQC). *Accepted* cable types for each VQC are listed in Table 10-1.

Use of cable insulation containing halogens is strictly forbidden for all VQC. Fluoropolymer (Teflon, Tefzel, PTFE, PFA, FEP, ETFE,etc…), PVC and Fluorosilicone sheathed cables are therefore completely forbidden.

Table 10-1 - *Accepted* vacuum cabling

Cable type	Vacuum Quality Class			
	VQC1	VQC2	VQC3	VQC4
Single Core Coaxial Solid Sleeved Mineral Insulated Cable (MI cable)	✓	✓	✓	✓
Multi-core Coaxial Solid Sleeved Mineral Insulated Cable (MI cable)	†	✓	✓	✓
Tri-axial Mineral Insulated cable	†	✓	✓	✓
Metal braided Fibre insulated cable	†	✓	†	✓
Ceramic coated wire	✓	✓	✓	✓
Bare wire / Non insulated cable with ceramic breads or spacers	†	†	†	†
Optical fibre Ceramic / metal coating	✓	✓	✓	✓
Polyamide, Kapton® coated cable*	×	✓	×	✓
Epoxy / resin insulated cable*	×	†	×	†
Nylon sheathed/braided*	×	†	×	✓
Silicon rubber insulated wire (Fluor free)*	×	×	×	×

Polyurethane, Polyethylene, Polypropylene, Polyester, Plastic *	×	×	×	×
✓ Cable *accepted* for use × Cable prohibited from use † Restricted use conditions apply	* restriction on baking temperature to be considered			

Any other cabling type and changes to Table Table 10-1 is subject to *acceptance* procedures as detailed in the ITER Vacuum Handbook

Silver plated conductors should be avoided in VQC 1.

10.3 Mineral Insulated cable (MI)

The procurement specifications and manufacturing control plan needs to be tightly controlled and should be submitted for *acceptance* before tender in order to mitigate the potential of cabling adversely affecting the ITER vacuum.

The procedures should include:

- A high standard of cleaning for vacuum and of the handling of the constituent parts of the cable.
- Method of packing the insulant (A high and defined packing density of insulate so as to limit the void fraction ideally to <5 % this may be achieved by using preformed solid insulate rather than powder and specifying a hammering operation after each drawing operation during manufacture).

In addition:

- Cables need to be sealed and vacuum leak tested by helium “bombing”, prior to installation. A He leak rate of $<10^{-10}$ $Pa.m^3/s$ shall be achieved.
- Cables should be proven to achieve outgassing rates of lower than 10^{-9} $Pa.m^3/s/m$ for hydrogen and 10^{-11} $Pam^3/s/m$ for other species at $100^{o}C$ (after a 48 hour 200ºC bakeout cycle for cables of <5mm diameter).
- The use of tri-axial MI cable will be limited and subject to specific *acceptance*.
- The use of multi-core cable will be limited and subject to specific *acceptance*.

10.4 Metal braided fibre insulated cable

The use of metal braided ceramic fibre insulated cable is to be limited in VQC 1 and 3 systems and MI cable will be preferred for use whenever possible. Any proposed use requires specific *acceptance* by the ITER Vacuum Responsible Officer at the design stage.

If such cable is *accepted* for use, the procurement specification and manufacturing control plan should be submitted for *acceptance* by the ITER Vacuum Responsible Officer. This plan should ensure that manufacturing processes are tightly controlled to ensure low vacuum outgassing and should include:

- Cleaning and air bakeout of the constituent parts of the cable prior to assembly.
- Vacuum outgassing testing of the constituent parts of the cable prior to assembly.

- Control of cleanliness in assembly, in particular the use of dedicated dry machines.
- A high vacuum standard of handling component parts of the cable.

In addition:

- Cables should be proven to achieve outgassing rates of lower than 10^{-9} Pa.m^3/s/m for hydrogen and 10^{-11} Pam^3/s/m for other species at 100^o C (tested after a 48 hour 200ºC bake out cycle for cables of <5mm diameter).
- Possible nuclear heating of this type cable should be considered and special care shall be taken to avoid any detrimental effects on vacuum.

10.5 Other cables

Any cable used on VQC 1, 2 and 3 will be subjected to an *acceptance* criteria and to a detailed control plan. A high standard of cleaning for vacuum and of handling needs to be applied. An outgassing test should be performed prior to *acceptance*. In addition to initial vacuum compatibility of the cable, fire hazard and radiation resistance need to be considered.

- There is no limitation for Bare Wire with ceramic insulator spacers from a vacuum point of view if the cable is manufactured from *accepted* materials and if the appropriate cleanliness for its VQC has been achieved. From a practical point of view, it is advisable to limit their use to short distance cabling (less than 1m) and to detector internals.
- Polyimide and Kapton® coated cables are *accepted* for use on VQC 2 and 4, and are possible alternatives to MI or Fibre insulated cable for these VQC. PEEK outer weaving is *accepted* for cable bundles if required, but metallic woven sheaths are preferred.
- Any non-listed cable should undergo qualification tests prior to *acceptance*. Tests should, at the minimum, include a vacuum outgassing test over the whole operational temperature range, residual gas analysis and radiation aging tests.
- Silver plated conductors are strictly limited in VQC 1, 2 and 3.

10.6 Connectors and Terminations

All Mineral Insulated cables should be of the vacuum-tight termination type (both ends), and should not be perforated. Leak tightness will be proven by helium "bombing" of the cable, followed by leak detection. A leak rate of $<10^{-10}$ Pa.m^3/s is to be obtained. If the cables are part of a feedthrough assembly, the full feedthrough assembly should be leak tight to $<10^{-10}$ Pa.m^3/s.

Cable terminations made after crossing a boundary for VQC 1 and VQC 2 systems should be within a suitable termination vacuum enclosure connected to the SVS. This space can be within a feedthrough interspace and is to be connected to the SVS by 2 connections (½ inch VCR™ couplings are envisaged).

In-vacuum connectors should be designed for vacuum compatibility and are to comply with the general vacuum requirements for the relevant VQC. This includes, among other factors: design, materials, manufacturing process, cleaning and outgassing.

10.7 Cable Routing

It is not permitted for cables to pass across a pressure boundary to atmosphere.

The following considerations should also be taken into account when routing the cables.

- The routing scheme should offer good protection against damage to cables. Loops should be properly designed to permit adequate gas pumping, whilst protecting the cables from external contamination.
- The routing should offer appropriate thermal contact of the cable with cooled components to avoid any overheating of the cables that might affect vacuum performance or cable integrity.
- Thermal expansion and contraction of cabling shall be considered in the design.
- High voltage cables and signal cables shall be separated where possible.

10.8 References

[1] ITER D 22H4HUv1.0, FDR01-DDD18 31 Vacuum Pumping and Fuelling.

[2] R.J.H. Pearce and Al. Fusion Engineering and Design 82 (2007) 1294–1300 – "ITER relevant outgassing and leakage from different types of in-vessel cabling"

[3] G.Vayakis and Al., ITER IT, JAERI NAKA, N 55 RI 37 04-02-19 W 0.1

[4] R. Pearce and Al., UKAEA, TW3-TPDS-DIADEV, ITER D222N5N

[5] G 55 MD 32 98-06-02 F 1, "Table 2.4.1-2 - cable specifications"

[6] G 55 MD 37 98-06-03 W 0.1, "Table 2.4.4-1 - cable for use in-vessel"

[7] G 55 MD 5 96-12-11 W 0.1,DIAGNOSTIC ENGINEERING NOTE 19

IDM UID
2E5PJK

VERSION CREATED ON / VERSION / STATUS
19 Jul 2017 / 3.0 / Approved

EXTERNAL REFERENCE / VERSION

Guideline (not under Configuration Control)

Appendix 11 Standard Pipe and Pipe Fitting Dimensions

Dimensions of standrad pipe and pipe fittings for use on ITER vacuum systems. Includes weld bevel for weld preparation.

Approval Process			
	Name	*Action*	*Affiliation*
Author	**Worth L.**	**26 Jul 2017:signed**	**IO/DG/COO/PED/FCED/VS**
Co-Authors	**Bansal G.**	**19 Jul 2017:signed**	**IO/DG/COO/PED/FCED/VS**
Reviewers	**Pearce R.** **Woods N.**	**31 Aug 2017:recommended** **31 Jul 2017:recommended**	**IO/DG/COO/PED/FCED/VS** **IO/DG/COO/PED/FEID**
Approver	**Lee G.- S.**	**08 Sep 2017:approved**	**IO/DG/COO**
#SecureIDM# *RO: Chiocchio Stefano*			
Read Access	**GG: MAC Members and Experts, GG: STAC Members & Experts, AD: ITER, AD: External Collaborators, AD: IO_Director-General, AD: EMAB, AD: EUROfusion-DEMO, AD: Auditors, AD: ITER Management Assessor, project administrator, RO, LG: [CCS] CCS-All for Ext AM, LG: [CCS] CCS-Section Leaders, LG: [CCS] JACOBS,...**		

Change Log			
Appendix 11 Standard Pipe and Pipe Fitting Dimensions (2E5PJK)			
Version	*Latest Status*	*Issue Date*	*Description of Change*
v1.0	In Work	27 Aug 2008	
v1.1	In Work	12 Jan 2009	
v2.0	Approved	16 Jul 2015	Data loaded to document
v3.0	Approved	19 Jul 2017	Tables 4, 4-a & 4-b added. Reference [4] added. Text modified appropriately.

ITER Vacuum Handbook
Appendix 11

Standard Vacuum Pipe and Pipe Fitting Dimensions for the ITER Project

	Name	Affiliation
Author/Editor	Liam Worth	PED/ VS
Co-author	Gourab Bansal	PED/ VS
Vacuum Responsible Officer	Robert Pearce	PED/ VS
Reviewed by	Nick Woods	PED/ VS
Approved by	G S Lee	IO/DG/COO

11 Introduction

The IO vacuum pipework systems are designed and constructed to the ASME B31.3 (2010) designated for fluid cat. (M) and NF EN13480 codes.

Pipe and pipefittings (tees, elbows etc.) for use on the IO vacuum systems shall meet the technical requirements as specified in the Technical Specifications [1].

11.1 Scope

The scope of this document is to detail the dimensions for standard pipe and pipefittings (tees, elbows etc.) for use on the IO vacuum systems and to define the weld preparation to be used in fabrication of IO vacuum pipework systems.

The use of pipe and/or pipefittings with dimensions not listed in this document requires *acceptance* [2].

11.2 Dimensions

11.2.1 Standard Pipe

Standard pipe dimensions for use on IO vacuum systems that comply with dimensions as specified in [3] are synopsized in Tables 1, 2, 3.

Standard pipe dimensions for use on IO vacuum systems that comply with dimensions as specified in [4] are synopsized in Table 4 with “Outer Diameter Tolerances” and “Wall Thickness Tolerances” specified in Tables 4-a and 4-b.

11.2.2 Standard Pipe Fittings

Standard pipe fittings (tees, elbows etc.), for pipe dimensions as specified in [3], for use on IO vacuum systems shall comply with dimensions as specified in [5].

11.3 Weld Preparation

The dimensions weld bevels for pipe and pipe fittings shall comply with ASME B16.9 “Plain Bevel” as described in Figure 1.

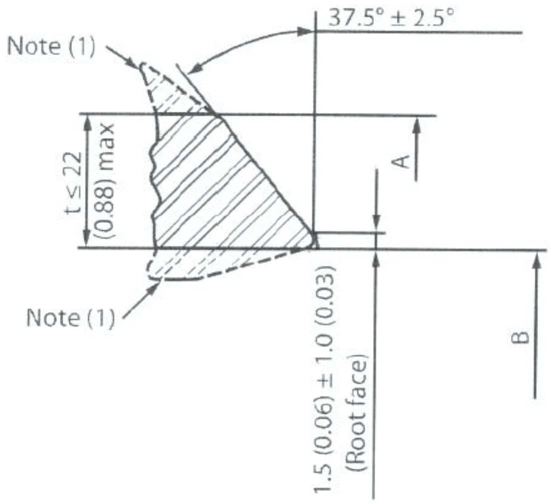


Figure 1 ASME B16.9 Plain bevel

General Notes:

a. Dimensions in parenthesis are in inches
b. Other dimensions are in millimetres.

Note (1) See ASME B16.9 for transition contours

11.4 Bibliography

[1] Supply of Seamless Stainless Steel Pipework and Pipework Components to the ITER IO (ITER_D_R22L3M).

[2] ITER Vacuum Handbook (ITER_D_2EZ9UM).

[3] ASME B36.10M, 2004.

[4] NF EN ISO 1127, 1996.

[5] ASME B16.9M, 2012.

Table 1 Pipe Dimensions Schedule 10s

DN	Sch	Nominal Wall thickness (mm)	Permissible variation in wall thickness (% from nominal), mm		Outer diameter, (mm)	Permissible variation in outer diameter (mm)	
			Over	Under		Over	Under
16# 15		2.11	(20.0), 0.42	(12.5), 0.26	21.30	0.4	0.8
40	10s	2.77	(20.0), 0.55	(12.5), 0.35	48.30	0.4	0.8
63* 65	10s	3.6 3.05	(20.0), 0.72 (20.0), 0.61	(12.5), 0.45 (12.5), 0.38	71.06 73.00	0.8	0.8
100	10s	3.05	(22.5), 0.69	(12.5), 0.38	114.30	0.8	0.8
160** 150	10s	3.0 3.4	(22.5), 0.67 (22.5), 0.76	(12.5), 0.37 (12.5), 0.43	159.00 168.30	1.6	0.8
200	10s	3.76	(22.5), 0.85	(12.5), 0.47	219.10	1.6	0.8
250	10s	4.19	(22.5), 0.94	(12.5), 0.52	273.00	2.4	0.8
300	10s	4.57	(22.5), 1.02	(12.5), 0.57	323.80	2.4	0.8
320	10s	As DN 300					

Where specified in the design that DN 16 pipe is required the dimension of said pipe and/or fittings shall be that of DN15.

* Where specified in the design that DN 63 pipe is required the dimension of said pipe and/or fittings shall be that of DN65.

** Where specified in the design that DN 160 pipe is required the dimension of said and/or fittings pipe shall be that of DN150.

Table 2 Pipe Dimensions Schedule 20s

DN	Sch	Nominal Wall thickness (mm)	Permissible variation in wall thickness (% from nominal), mm		Outer diameter, (mm)	Permissible variation in outer diameter (mm)	
			Over	Under		Over	Under
16# 15	20s	2.11	(20.0), 0.42	(12.5), 0.26	21.30	0.4	0.8
40		2.77	(20.0), 0.55	(12.5),0.35	48.30	0.4	0.8
63* 65		3.05	(20.0), 0.61	(12.5), 0.38	71.06 73.00	0.8	0.8
100		6.35	(15.0),	(12.5),	114.30	0.8	0.8
160** 150		6.35	(22.5), 1.42 (22.5), 1.42	(12.5), 0.79 (12.5), 0.79	159.00 168.30	1.6	0.8
200		6.35	(22.5), 1.42	(12.5), 0.79	219.10	1.6	0.8
250		6.35	(22.5), 1.42	(12.5), 0.79	273.00	2.4	0.8
300		6.35	(22.5), 1.42	(12.5), 0.79	323.80	2.4	0.8
320		As DN 300					

Where specified in the design that DN 16 pipe is required the dimension of said pipe and/or fittings shall be that of DN15.

* Where specified in the design that DN 63 pipe is required the dimension of said pipe and/or fittings shall be that of DN65.

** Where specified in the design that DN 160 pipe is required the dimension of said pipe and/or fittings shall be that of DN150.

Table 3 Pipe Dimensions Schedule 40s

DN	Sch	Nominal Wall thickness (mm)	Permissible variation in wall thickness (% from nominal), mm		Outer diameter, (mm)	Permissible variation in outer diameter (mm)	
			Over	Under		Over	Under
16# 15	40s	2.769			21.30	0.4	0.8
40	40s	3.68	(20), 0.74	(12.5), 0.46	48.30	0.4	0.8
63* 65	40s	3.6 5.16	(20), 0.72 (20), 1.03	(12.5), 0.45 (12.5), 0.65	71.06 73.00	0.8	0.8
100	40s	6.02	(15.0), 0.9	(12.5), 0.75	114.30	0.8	0.8
160** 150	40s	3.0 7.11	(22.5), 0.67 (22.5), 1.59	(12.5), 0.37 (12.5), 0.88	159 168.30	1.6	0.8
200	40s	8.18	(22.5), 1.84	(12.5), 1.02	219.10	1.6	0.8
250	40s	9.27	(22.5), 2.09	(12.5), 1.16	273.00	2.4	0.8
300	40s	10.31	(22.5), 2.32	(12.5), 1.29	323.80	2.4	0.8
320	40s	As DN 300					

Where specified in the design that DN 16 pipe is required the dimension of said pipe and/or fittings shall be that of DN15.

* Where specified in the design that DN 63 pipe is required the dimension of said pipe and/or fittings shall be that of DN65.

** Where specified in the design that DN 160 pipe is required the dimension of said pipe and/or fittings shall be that of DN150.

Table 4 Pipe Dimensions

Outside Diameter (mm)	Wall Thickness (mm)					
	1.0	1.2	1.6	2.0	2.6	3.2
6	Y	Y	-	-	-	-
8	Y	Y	-	-	-	-
10	Y	Y	-	-	-	-
12	Y	-	Y	Y	-	-
14	Y	-	Y	Y	-	-
16	Y	Y	Y	Y	-	-
18	Y	-	Y	Y	-	-
20	Y	Y	Y	Y	-	-
22	Y	-	-	Y	-	-
25	Y	Y	Y	Y	Y	-
30	-	-	Y	Y	-	-
32	-	Y	-	Y	-	-
35	-	Y	-	Y	-	-

38	-	Y	Y	Y	Y	Y
40	-	Y	Y	-	Y	-
Y indicates availability.						
NOTE: Pipes of wall thickness less than 2.0 mm designed to contain cryogenic helium, Electro-Slag Remelted (ESR) or Vacuum Arc Remelted (VAR) material (or equivalent process demonstrated to achieve similar inclusion size and number) shall be used for the pre-extruded material with inclusion limits as specified in [2].						

Table 4-a Outer Diameter Tolerances applicable to Pipe Dimensions presented in Table 4

Tolerance Class	Tolerance on Outside Diameter
D1	±1.5% with ±0.75 mm min.
D2	±1.0% with ±0.50 mm min.
D3	±0.75% with ±0.30 mm min.
D4	±0.5% with ±0.10 mm min.

Table 4-b Wall Thickness Tolerances applicable to Pipe Dimensions presented in Table 4

Tolerance Class	Tolerance on Wall Thickness
T1	±15% with ±0.60 mm min.
T2	±12.5% with ±0.40 mm min.
T3	±10.0% with ±0.20 mm min.
T4	±7.5% with ±0.15 mm min.
T5	±5.0% with ±0.10 mm min.

IDM UID
2EYZ5F

VERSION CREATED ON / VERSION / STATUS
16 Sep 2009 / 1.4 / Approved

EXTERNAL REFERENCE / VERSION

Guideline (not under Configuration Control)

Appendix 12 Leak Testing

Approval Process			
	Name	*Action*	*Affiliation*
Author	**Worth L.**	**16 Sep 2009:signed**	**IO/DG/COO/PED/FCED/VS**
Co-Authors			
Reviewers			
Approver	**Pearce R.**	**16 Sep 2009:approved**	**IO/DG/COO/PED/FCED/VS**
Document Security: Internal Use *RO: Chiocchio Stefano*			
Read Access	**GG: MAC Members and Experts, GG: STAC Members & Experts, AD: ITER, AD: External Collaborators, AD: IO_Director-General, AD: EMAB, AD: Auditors, AD: ITER Management Assessor, project administrator, RO, LG: [CCS] CCS-All for Ext AM, LG: [CCS] CCS-Section Leaders, LG: [CCS] JACOBS, LG: [CCS] CCS-Doc Co...**		

Change Log			
Appendix 12 Leak Testing (2EYZ5F)			
Version	***Latest Status***	***Issue Date***	***Description of Change***
v1.0	In Work	27 Aug 2008	
v1.1	In Work	22 Sep 2008	
v1.2	In Work	12 Jan 2009	
v1.3	Approved	18 Jun 2009	Changed approved to accepted
v1.4	Approved	16 Sep 2009	Maximum detectable leak rate changed from 0.1Mpa.m3.s-1 to 100Pa.m3.s-1

ITER Vacuum Handbook : Appendix 12		
Revision: 1.4	Date: September 16th , 2009	Page 1 of 16

ITER Vacuum Handbook
Appendix 12

Guide to Leak Testing of Components for the ITER Project

	Name	Affiliation
Author/Editor	Liam Worth	Vacuum Group - CEP
Vacuum Responsible Officer	Robert Pearce	Vacuum Group - CEP

12 Vacuum Leak Tightness and Testing

12.1 Scope and Status

As an Appendix to the ITER Vacuum Handbook, the status of this document is advisory and not mandatory on the supplier of any component. Nevertheless, it is strongly advised that the requirements of this document are adhered to for the supply of vacuum components to ITER.

The purpose of this Appendix is to define the criteria for the leak tightness of vacuum related components supplied to ITER. It is applicable to equipment destined for use on the ITER facility and any other area on site, which utilises items and assemblies with a vacuum boundary. It defines the test criteria and gives general instruction and guidelines to those persons, be they on site at the supplier, on site at ITER, or as part of an off site organisation which is called upon to perform vacuum helium leak detection.

12.2 General

Tests shall be performed both at ambient temperature and at the maximum and minimum working temperatures of the component, with the pressure differential in the same direction as for operation of the component. Where possible, component parts shall be tested before assembly. However, final assemblies must also be tested.

Where it is not envisaged that leak tests will be performed at cryogenic temperatures on vacuum components which are for use on cryogenic systems, a method of “thermal shocking” of welded connections shall be agreed in advance.

The supplier is responsible for all jigs, seals and equipment to allow the leak tightness to be proven across all vacuum boundaries, unless otherwise stated in the contract. Where pressure testing is required, this must always be performed prior to final vacuum leak testing. Acceptance tests shall wherever possible use the same type of seal which shall be used after installation of the component.

The supplier is responsible for the supply of tooling and methodologies for the subsequent removal of jigs, seals, temporary closure plates, etc., which have been fitted to components to facilitate the leak testing of such components.

The leak test method shall be agreed in advance with ITER. This will involve the submission for approval of a procedure as part of an external supply contract. The procedure should describe how the leak test will be performed, and include configuration diagrams and full details of the equipment to be used etc.

The ITER Vacuum Responsible Officer (RO) will nominate a Vacuum Specialist to witness the acceptance leak tests and any other leak test deemed necessary as part of a manufacturing process.

In no circumstance shall ***any*** vacuum equipment be installed without an *accepted* pre-installation leak check being performed at the ITER site, without the express permission of the ITER Vacuum Responsible Officer. This applies to ***all*** Vacuum Quality Classifications.

12.3 Leak testing Methodologies

This Appendix describes recommended procedures for carrying out the most widely used methods of helium leak testing; it does not consider all available methods. Other methods may be used, but only with the prior approval of the ITER Vacuum RO

12.3.1 Over Pressure Methods

Over-pressure methods enable thin-walled vacuum chambers to be leak tested which might otherwise collapse under vacuum. This method is also useful when the equipment to be tested is already filled with a gas which can be used as the test gas. However the test gas which flows out through any leaks always mixes with contaminants present in the air, and this might reduce sensitivity.

12.3.1.1 Mass Spectrometer Sniffing Probe

Helium, or some other suitable gas, is used to slightly pressurise the component to be tested and a sampling probe “sniffs” for leaks. Helium passing through the leak is sampled from the surrounding atmosphere through a long narrow flexible tube which is connected to a mechanical pump to give a drop in pressure from atmosphere to about 10^{-2} Pa at the ion source of a mass spectrometer detector. Traces of helium or halogen in the environment can also be detected, which may lead to errors in the measured leak rate.

The helium content of atmospheric air limits the sensitivity of the sampling probe, and the detection limit is typically ~1 x 10^{-7} Pam^3s^{-1} if the volume is filled with pure helium (or the tracer gas appropriate for the detector used such as argon).

The sampling tube should be as short as possible to reduce the response time of the gas flow of the air-helium mixture from the entrance of the tube to the detector. The flow rate may also be limited by the available pumping throughput.

12.3.1.2 Probe Leak Testing (vacuum box or suction cup method)

Open objects can be tested using the vacuum box or suction cup method. A partial enclosure which can be evacuated by a leak detector is tightly pressed against the wall of the component being tested. The enclosure is evacuated and helium tracer gas applied to the opposite surface of the wall by a spray gun or other means. Helium leaking through the wall can pass to the detector via the vacuum box. This method of leak detection is widely used for the testing of welds on incomplete enclosures. The sensitivity is usually limited by diffusion of helium through the seal between the evacuated enclosure and the component wall.

12.3.1.3 Pressurisation – Evacuation ("bombing") Test

Hermetically sealed objects which cannot be pumped out can be leak tested using the so-called "bombing" method. The component to be tested is subjected to a high pressure of tracer gas, usually helium, to force gas into the component through any leaks present. After flushing to remove adsorbed tracer gas from the surface of the component, it is placed in a vacuum chamber which is connected to a leak detector. This can then detect any tracer gas passing out of the sealed volume through the leaks. This method is usually employed as a "go/no go" test since it is very difficult to locate the position of any leaks on such components.

12.3.2 Vacuum Leak Detection Methods

12.3.2.1 Pressure Rise Test

A pressure rise test is a useful way of determining the overall magnitude of any leaks present in a component.

A vessel to be tested of volume V is evacuated and sealed off. The pressure rise ΔP is measured over a time interval Δt and the leak rate q_L (at constant temperature) is evaluated from:

$$q_L = V \cdot \frac{\Delta P}{\Delta t}$$

This calculated leak rate also includes contributions from any other gas sources such as virtual leak and outgassing.

Real leaks may be distinguished from other sources of pressure rise since a real leak gives a pressure rise which is strictly proportional to time, while virtual leaks and outgassing result in an initially rapid pressure rise which tends to level off after some time

12.3.2.2 Helium Leak Detectors

These are based on a mass spectrometer, usually a small magnetic sector device. Leak detection can begin only when high vacuum conditions are obtained in the mass spectrometer. Due to its high sensitivity this method is the most frequently used method of leak detection for vacuum applications. The inlet pressure at the entrance to the leak detector depends on the design of the unit, but can range from atmosphere down to about 10^{-4} Pa.

Helium is usually used as the tracer gas, but other gases such as argon, neon, krypton, hydrogen and mixed gases may be used with the mass analyser suitably tuned. Modern helium leak detectors are usually supplied with the capability of detecting H_2, He^3, and He^4.

To increase the helium detection sensitivity and improve detector stability, the mass analyser in helium leak detection systems is often de-tuned to give lower mass resolution. This can lead to a contribution to the measured mass 4 intensity from mass 2 and mass 3, thus giving a higher leak detector background signal at mass 4. For large component leak testing at high sensitivity, it may be necessary to reduce the partial pressure of hydrogen at the analyser by selectively pumping it with a getter in series with the leak detector input. It may also be necessary to selectively pump condensable gasses at the leak detector inlet. This can be achieved by the addition of a cold (e.g. liquid nitrogen) trap in series with the inlet.

12.4 Procedure for Helium Leak Tightness and Testing

12.4.1 Equipment

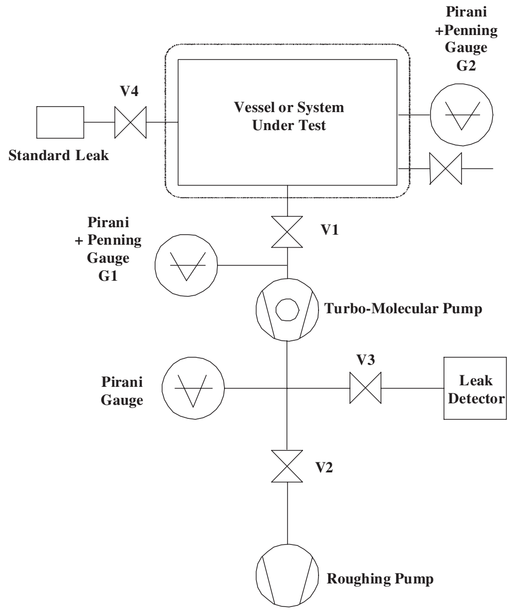


Figure 12-1 Typical Leak Detection Equipment

12.4.2 Pumping System

An indication of the basic elements of a pumping system, which could be used for leak detection, is illustrated in Figure 12-1. In this form it consists of the following items: -

1. A turbo-molecular pump isolated by a valve V1 and backed by a roughing pump via a valve V2, of enough pumping capacity to pump the system under test down to a suitable pressure at the inlet of the leak detector. Ideally all fittings and seals (at least those on the high vacuum side) should be all-metal to alleviate the problem of helium permeation.

2. A Pirani gauge to measure the pressure in the backing line of the turbo-molecular pump and a pressure gauge system (G1) on the high vacuum side of the turbo-molecular pump (but below valve V1) capable of measuring in the range 0.1 MPa to 10^{-7} Pa.

Possible additional options to this pumping system could include a quadrupole or other type of mass spectrometer to measure the residual gas spectrum. This is essential if system cleanliness is to be assessed. A hydrogen getter and liquid nitrogen trap may be used to lower the detector background signal.

A vent valve on the vessel side of V1 is also advisable for venting the item under test to a clean dry gas such as nitrogen to retain cleanliness.

12.4.2.1 Detection System

This is the system used to detect any vacuum leaks which may be present, thus it is the central part of the system and normally consists of the following items:

1. A helium mass spectrometer leak detector installed such that it can be connected into the backing line of the turbo-molecular pump through valve V3. For maximum leak detection sensitivity, it should provide the necessary backing pressure for the turbo-molecular pump. It therefore should have its own pumping system comprising a turbo-molecular and backing pump combination. It must be able to detect leaks at least one order of magnitude smaller than that required by the specification of the item under test, and up to at least 100 Pam^3s^{-1}.

   It should be noted that with modern leak detectors, it is possible to suppress the background and gain up to 2 orders of magnitude in sensitivity. Although this mode is useful in localising leaks, it shall not be used for the purpose of acceptance testing without prior approval by the ITER Vacuum RO.

   An alternative when the item under test is of relatively small volume of less than 1 m^3, and when only a simple cold leak test is required, is to use the mass spectrometer leak detector on its own. In this case the leak detector is connected directly to the item under test. The separate turbo-molecular and roughing pump system is not required.

   If there is a large leak on the item to be tested or where the pumping system is incapable of pumping the item under test to a sufficiently low pressure for the leak detector to be connected directly to the backing line of the turbo molecular pump, valve V2 may be left open and valve V3 partially opened so that the leak detector samples part of the gas stream to the backing pump. This configuration may be used to locate, but not size, any leaks.

2. A pressure gauge system (G2) on the vessel under test, capable of measuring in the range 0.1 MPa to 10^{-7} Pa.

3. A calibrated helium standard leak of value commensurate with the magnitude of leak rate required by the specification of the item under test, mounted on the system under test, and isolated by valve V4. Traceable calibration certificates shall be kept for this item and these should be readily available.

4. A helium bag or other enclosure fashioned in such a way that the test gas can surround all parts of the item under test with a concentration preferably exceeding 50% in air.

5. A system for continuous recording of the leak test process. This can be achieved by using an analogue recording device such as a paper strip chart recorder connected to the output of the helium mass spectrometer leak detector or by continuous logging (and display) of data on a computer or dedicated data logger.

12.4.2.2 Miscellaneous

The following equipment is optional but experience has shown the items to be of use in helium leak tests.

1. A standard vacuum cleaner to pump the helium enclosure out if it is a sealed collapsible type such as a plastic bag before inflating it with helium, to ensure maximum concentration of the helium in the enclosure.
2. A helium-in-air concentration monitor to ascertain the percentage of helium in the bag or other enclosure during the test.
3. A triggered helium spray gun for subsequent probe testing of the item to localise any leaks found during the global leak test.

12.4.3 Preliminaries

12.4.3.1 Initial Checks on the Leak Detection System

1. With valve V2 open and valves V1 and V3 closed, the roughing pump is started. When the pressure falls to a suitable level, the turbomolecular pump is started and left until the pressure on gauge G1 stabilises.
2. The leak detector is switched on and when it is ready, an internal calibration is carried out as per the manufacturer's instructions.
3. The backing line Pirani gauge pressure reading is noted and valve V3 is carefully opened so that the leak detector does not trip out. (Most modern leak detectors can cope with this.)
4. The roughing pump valve V2 is closed.
5. When a relatively stable reading has been obtained on the leak detector, a leak check is carried out, by using a helium gun to probe with helium gas all joints and welds up to and including the pumped sides of V1 and V3.
6. If any leaks are found of magnitude greater than one decade smaller than the maximum leak rate called for in the specification of the item under test, then these shall be rectified and this sequence repeated until no such leaks are found.

12.4.3.2 Pump-down

Before the leak test can be undertaken, the item under test must be pumped down to the requisite pressure. In the case of the system shown in Figure 12-1 which uses a turbo-molecular and roughing pump set, the following actions shall be performed.

1. The roughing pump is started and valves V1 and V2 are opened.

2. When the system Pirani pressure reaches the level given in the manufacturers instructions the turbo-molecular pump is started.
3. The system is ready for initial tests when the pressure reaches 10^{-3} Pa or lower on G1, or such other pressure specified as suitable by the manufacturer of the leak detector. If it does not reach this pressure then there may be a large leak present which must be located and rectified. It should be located using either an overpressure technique as described in Section 12.3.1.1 or the procedures of Section 12.4.5.2 but with valve V3 only partially opened so that the pressure at the inlet of the leak detector remains below the upper pressure limit specified by the manufacturer with the gas flowing to the roughing pump being sampled into the leak detector.

12.4.3.3 Background Determination

After a stable pressure reading has been obtained on gauge G2 with valves V1 and V2 open and the turbomolecular pump set running normally, with the leak detector fully functioning and the data logging device connected and operating, then the roughing valve V2 is closed and the leak detector valve V3 opened.

The leak detector reading is monitored until it has stabilised, without any electronic correction. This should take around 10 minutes, but the time can be longer depending on the size of the system under test.

This reading is recorded as the background level. Any reading above this value during the overall test constitutes a positive indication of a leak.

12.4.4 Leak Detector Calibration

With the system in the state as above for background determination, leak detector calibration shall be performed.

Valve V4 is carefully opened and the reading on the leak detector monitored until it is stable. This should correspond to the value of the standard leak to within ±5% after suitable corrections for the age of the standard leak and its temperature have been applied.

If a response time measurement is not required, then V4 is closed and the reading should then return to the background level.

12.4.4.1 Response and Cleanup Time Measurement

This should be done for a large system or where there is a long path length involving small bore tubes. This ensures that the duration of the overall test will be valid.

1. With the standard leak open to the system and the leak indication stable at the value of the standard leak, suitably corrected for age and temperature, valve V4 is closed.

2. The time taken for the reading on the leak detector to return to the background level is recorded. This is the cleanup time for the system and will depend on the applied pumping speed for helium and the configuration of the system under test.
3. When the background level has been attained, valve V4 is opened and the time taken to return to the level of the standard leak indication, suitably corrected, is recorded. This is the response time for the system.
4. Valve V4 is closed and the system is allowed to return to the background level.
5. This concludes the initial set-up tests and the overall leak test may then be undertaken.

12.4.5 Cold Leak Tests

12.4.5.1 Global Leak Check

If all the preceding conditions have been met with all equipment functioning and ready for use, a global cold leak test may be carried out according to the following procedure.

1. The data recording system is connected to the output of the leak detector and started and the date and time are recorded.
2. Valves V1 and V3 are opened and valves V2 and V4 are closed.
3. When the background reading is stable and is at a level consistent with the leak specification of the item under test, which will be for most purposes at least an order of magnitude lower than the specified maximum leak rate of the component under test and without electronic correction, the global leak check may be started.
4. The component under test is surrounded by a suitable helium enclosure. If the helium enclosure is a flexible type, it should have as small a volume as possible. The enclosure is filled with helium to a concentration of at least 50% in air and the time is recorded in the data log
5. Helium should remain in contact with the item under test for at least 10 minutes or longer, depending on the size of the object and the response time previously measured, or for the time specified in the test specification for the component under test, whichever is longer.

   In the case of components where there might be possible low conductance leak paths, for example porosity, the time required for a sensible test may be significantly longer than the response time measured for the system using the techniques of Section 12.4.4.1. Details of the method and time of duration of helium application shall be included in the leak testing procedure to be *accepted* by the ITER Vacuum Responsible Officer.
6. Where the helium enclosure is not completely sealed, then suitable precautions shall be taken to ensure that helium cannot back-diffuse through the roughing pumps and/or the leak detector pumps into the mass spectrometer detector. In the

case of long-duration global tests, it may be advisable to house these items in a separate enclosure held at a small positive pressure above atmosphere.

7. After the appropriate time interval, the helium supply is closed off (where appropriate), and the enclosure vented to atmospheric air and removed. The time is recorded in the data log.
8. If the leak rate indication on the leak detector has not risen by more than the specified maximum leak rate at any time during this test procedure, the item under test shall be deemed to have passed, subject to the requirements of Section 12.4.5.3.
9. It may be advisable to recheck the background reading and leak detector calibration if the global test has been of significant duration. When that has been done according to the procedures of 12.4.3.3 and 12.4.4, then the global leak test is complete.
10. Valves V1 and V3 are closed and valve V2 opened.
11. The item is vented, or left under vacuum for further work as required.
12. If the leak rate reading during the test has at any time exceeded the specification value, then the item has failed the test, and the leaks shall be located using the procedures of Section 12.4.5.2.

12.4.5.2 Probe Tests

These are necessary to locate any leaks greater than the value in the specification of the component being tested which may have been indicated during the global test. They may be required not only at this stage, but may be needed also after the hot global test and the final cold global test, if those two tests are required as part of the contract or other instruction.

The following procedure shall be used, although others are possible and may be used after prior agreement.

1. Any helium enclosure or other covering or obstruction is removed from the item under test wherever possible.
2. If the component under test is at cryogenic temperatures, it may have to be warmed to ambient temperature before probe tests can be carried out.
3. Valves V1 and V3 should be open and valves V2 and V4 should be closed.
4. In the case of a large item, the data logging system shall continuously record the leak detector signal so that any longer term variations in leak rate may be observed.
5. Using a helium gun, helium gas is sprayed over or into all suspect locations and under any non-removable coverings, starting at the top of the item under test and working down as required. The helium spray should be introduced to the area under test for a time period consistent with the response time of the system measured in accordance with Section 12.4.4.1

6. If a leak indication is found, then the point of maximum reading shall be localised. For subsequent testing to localise any other leaks, it is advisable to blanket that point with a physical barrier such as a polythene bag or sheet or with a stream of another gas whilst checking the remainder of the system.
7. When all detectable leaks have been located, then the leak detector is isolated by closing valve V3. Valve V1 is closed and the item under test shall be vented to dry nitrogen or clean dry air admitted through the vent valve. The ITER Vacuum Responsible Officer shall be contacted to agree a procedure to rectify the leak or leaks.
8. When any agreed repair has been successfully accomplished, the process starting from stage 12.4.3.2 and to point 10 at the end of stage 12.4.5.1 is repeated until the item is proved to meet the relevant specification.

12.4.5.3 Acceptance Criteria

If all the stages above have been successfully completed then the item under test may be accepted by the ITER Vacuum Specialist as having met the relevant specification provided that the following conditions have been met.

1. The leak detector has been correctly calibrated and its calibration value is within ±5% of the standard leak rate value as corrected for the ambient temperature and the age of that item and that standard leak rate value is commensurate with the value of the maximum leak rate specified for the item under test.
2. The leak test has been performed by suitably qualified and experienced personnel to the *accepted* procedure, with no significant deviation from that procedure and has been witnessed by the ITER Vacuum Specialist.
3. The leak rate value as measured by the leak detector has not increased in value above the measured background to a value greater than the specified leak rate during the entire duration of the global leak test.

The location and magnitude of <u>all</u> identified leaks shall be recorded. Normally, all practicable efforts shall be made by means agreed with the ITER Vacuum Responsible Officer to reduce any leak discovered during the manufacturing phase to a level lower than the limit of detection of the leak detection method used for the tests.

12.4.6 Hot Leak Check

12.4.6.1 Test Conditions

If it is required as part of the contract or other instruction to perform a hot leak test on an item which during its life may be subject to increased temperature usage, then the following procedure shall be carried out.

1. Before commencing any part of this leak test procedure, the item under test must have completed one or more temperature cycles as specified and be at that point on the cycle where it is specified that the hot leak test shall take place.

2. The leak detector shall be set up using the procedures of Sections 12.4.3.3 and 12.4.4. If the response time of the system has already been determined, or is not required, it need not be re-measured.
3. If the background is elevated when the item under test is at temperature (as may often be found), then the conditions stipulated in 12.4.5.1 Point 3 may not be met. However with judicious choice of scale it may be possible to do a perfectly valid leak check at a raised background level. It may also be necessary to selectively pump hydrogenic species from the leak detector input gas stream. This can be done by the correct choice of getter installed in series with the leak detector inlet. The applicable conditions for this test must be agreed with the ITER Vacuum Responsible Officer.
4. The helium enclosure used for these tests must be capable of tolerating temperatures above ambient since the increased thermal conductivity of helium will raise the temperature of this item above the level it would reach with only atmospheric air in the enclosure.

12.4.6.2 Global Leak Check with the Component under test Hot

Essentially, this is a repeat of the cold global leak test described in Section 12.4.5.1 except that, if a leak indication is observed, the item may need to be cooled down before probe tests can be performed. The temperature at which the hot leak test is performed shall be recorded and shall be within the limits as specified in the leak testing procedure.

If, with the component at the specified hot temperature, no leak rate of size greater than that specified for the component has been observed, then provided that the conditions of Section 12.4.5.3 have been met, the component will be deemed to have satisfied the hot leak test requirement.

If, however, with the component at the specified hot temperature, a leak rate of size greater than that specified for the component has been observed, then a probe test to localise any leaks present must be undertaken.

The supplier should be aware that under some conditions, a leak may be observed at temperature but may disappear when the component is cooled to ambient temperature. If this is the case, then it may be necessary to implement an agreed procedure for leak location at elevated temperature.

12.4.6.3 Probe Test

1. This method of probe leak testing baked components is the essentially the same procedure as detailed in 12.4.5.2., but with additional steps as noted below:
2. If the probe test cannot be carried out at the hot temperature, the component shall be cooled to ambient temperature
3. Steps 1 – 7 of section 12.4.5.2 shall be carried out.

4. If, after probe testing at ambient temperature, no leak has been identified, then, as agreed with the ITER Vacuum Responsible Officer, a further temperature cycle shall be completed as specified up to the point on the cycle where it is specified that the hot leak test shall take place.
5. Then either

   a. an agreed procedure for leak location at this elevated temperature shall be carried out

   or

   b. the component shall be cooled and step 2 of this Section shall be carried out in the hope that the hot leak may have opened up further and now may be detectable at or close to ambient temperature.
6. Step 5 shall be repeated until no leaks which have not been localised are evident at the hot temperature.
7. When all detectable leaks have been located and the component is close to ambient temperature, then the leak detector is isolated by closing valve V3. Valve V1 is closed and the item under test shall be vented to dry nitrogen or clean dry air admitted through the vent valve. The ITER Vacuum Responsible Officer shall be contacted to agree a procedure to rectify the leak or leaks.
8. When any agreed repair has been successfully accomplished, the global hot leak test procedure of this Section is repeated.

12.4.6.4 Final Cold Acceptance Check

This test shall be carried out following a satisfactory global hot leak test procedure when the item under test has cooled down to a temperature in the range 60°C to 80°C, since experience has shown that small leaks can be blocked by water vapour below this temperature.

It shall follow the procedures of Section 12.4.5.1.

12.4.6.5 Acceptance Criteria

These shall be the same as those specified in Section 12.4.5.3

12.5 Responsibilities

It shall be the responsibility of the supplier to ensure that all vacuum leak tests carried out off-site and of the ITER Vacuum Responsible Officer when such tests are carried out on-site that they be performed in accordance with the contract or other specification. All deviations from such specification or agreed variation thereof shall require a non-conformance to be raised covering each specific case. In the case of any particular component, a nominated ITER Vacuum Specialist may witness the tests.

All records as detailed in the following section shall be completed and shall become part of the final document package for the component concerned.

12.6 Reporting

Full records of the tests carried out on any component shall be completed in order to maintain traceability of the leak test history of a particular item. The records shall consist of the following.

1. 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 tests as well as anything else of relevance, such as the start and finish time of helium gas application to the item under test.
2. A record of the helium concentration during the leak test where that is required. In the case of a simple cold leak test this will be on request of the ITER Vacuum Responsible Officer, but in the case of a full cycle of leak testing involving temperature variation it will be required.
3. A record of the system total pressure throughout a temperature cycle since it may pinpoint the time when a leak opened up and be instrumental in the subsequent diagnosis of the leak.
4. The make, model and date of manufacture of the helium mass spectrometer leak detector used in the tests.
5. 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.
6. The 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, together with the steps taken for any repair or elimination.

   The magnitude and location (if applicable) of ***all*** leaks identified during testing shall be recorded. This includes leaks of magnitude lower than the acceptance criteria for which no remedial action may have been taken.

IDM UID
2ELUQH
VERSION CREATED ON / VERSION / STATUS
02 Sep 2009 / 1.2 / Approved
EXTERNAL REFERENCE / VERSION

Baseline Report (not under Configuration Control)

Appendix 13 Cleaning and Cleanliness

This Appendix specifies typical processes which conform to the requirements of the ITER Vacuum Handbook for the cleaning of vacuum vessels, components and assemblies which are required for the ITER Project. This covers vacuum vessels and any item which will be in a vacuum environment, whether individually or made up into assemblies containing a number of such items.

Approval Process			
	Name	*Action*	*Affiliation*
Author	**Worth L.**	**02 Sep 2009:signed**	**IO/DG/COO/PED/FCED/VS**
Co-Authors			
Reviewers			
Approver	**Pearce R.**	**09 Sep 2009:approved**	**IO/DG/COO/PED/FCED/VS**
Document Security: Internal Use *RO: Chiocchio Stefano*			
Read Access	**GG: MAC Members and Experts, GG: STAC Members & Experts, AD: ITER, AD: External Collaborators, AD: IO_Director-General, AD: EMAB, AD: Auditors, AD: ITER Management Assessor, project administrator, RO, LG: [CCS] CCS-All for Ext AM, LG: [CCS] CCS-Section Leaders, LG: [CCS] JACOBS, LG: [CCS] CCS-Doc Co...**		

Change Log			
Appendix 13 Cleaning and Cleanliness (2ELUQH)			
Version	***Latest Status***	***Issue Date***	***Description of Change***
v1.0	In Work	27 Aug 2008	
v1.1	In Work	12 Jan 2009	
v1.2	Approved	02 Sep 2009	Minor textual changes for consistency with Vacuum Handbook

ITER Vacuum Handbook
Appendix 13

Guide to Cleaning and Cleanliness for the ITER Project

	Name	Affiliation
Author/Editor	Liam Worth	Vacuum Group - CEP
Vacuum Responsible Officer	Robert Pearce	Vacuum Group - CEP

13 Guide for Cleaning and the Cleanliness of ITER Vacuum Components

13.1 Scope

As specified in the ITER Vacuum Handbook all vacuum components to be supplied to ITER are subject to the provision of a “clean work plan” and cleaning procedures. This requirement is waived for proprietary components which are compliant with the mandatory requirements of the ITER Vacuum Handbook and are supplied to ITER with Certification of Conformity.

This Appendix specifies typical processes which conform to the requirements of the ITER Vacuum Handbook for the cleaning of vacuum vessels, components and assemblies which are required for the ITER Project. This covers vacuum vessels and any item which will be in a vacuum environment, whether individually or made up into assemblies containing a number of such items.

This guide is intended to assist the *supplier* of vacuum components to ITER in the preparation of a clean work plan and cleaning procedures for submission to ITER for *acceptance.* Following the guidance in this Appendix should help *suppliers* to achieve the requirements of the ITER Vacuum Handbook.

The *supplier* is at liberty to utilise other techniques not described in this Appendix provided that the components manufactured comply with the requirements of the ITER Vacuum Handbook.

13.2 General Cleaning Requirements

In general, all components classified as VQC1 will need cleaning to Ultra High Vacuum standards. Those components classified as VQC2, VCQ3 and VCQ4 will generally be operated in less stringent vacuum environments and will therefore not require cleaning to such rigorous standards.

However, it is the responsibility of the *supplier* to satisfy themselves that they understand fully the implications of cleaning to the requisite standard.

Any proposed deviation from the procedures and processes described in this Appendix need to be *accepted* in writing by ITER. This is particularly important where the use of any chemical product (solvent, etchant, detergent, etc.) other than those specified is proposed.

13.3 Health and Safety

Some of the chemicals or equipment used in cleaning processes may be classified as hazardous.

It is the responsibility of the *supplier* to satisfy themselves that any cleaning procedure complies fully with local legislative and regulatory standards regarding health and safety of any or all processes used and that all operatives have received the necessary training.

The *supplier* shall have the responsibility of ensuring that all staff fully understand all health and safety information issued by the manufacturer or *supplier* of any chemical or equipment to be used. Neither ITER nor any of its agents shall be held responsible for any consequences arising from the application of any cleaning process described in this handbook unless it is under their direct control.

13.4 Proprietary Items and Trademarks

Where propriety items from particular manufacturers or *supplier*s are mentioned in this specification any or all trademarks are duly acknowledged. Manufacturers or contractors are free to suggest alternative items from other manufacturers or *supplier*s provided that they are chemically identical. Any such substitutions need to be *accepted* in writing by ITER.

13.5 Design Rules for Cleanability

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

13.6 Initial Inspection and Preparation

Prior to cleaning any item, the following inspection should take place:

1. All vacuum flanges or covers should be removed and the item stripped down as much as is permissible, ideally to single components.
2. All items should be clearly identified by scribing a suitable identification mark on an external surface (never a vacuum surface). This identifier will often be a drawing number with component identifier or some such which is carefully recorded. Alternatively, for items which are either small and are to be exposed to a vacuum, a suitable metal label, preferably of the same material as the component and bearing a scribed identifier may be tied with clean bare wire to the component. If none of this is possible, the items should be stored in a suitable container which is marked with an identifier before and after the cleaning process. After cleaning, these items should be packed in such a way that they will not be re-contaminated by the container.
3. The item should be inspected visually to identify any possible traps, etc. (see 13.5 above) which could affect the vacuum performance of the item, taking into account the specified cleaning process and vacuum regime in which the item is to be used.
4. All vacuum sealing faces should be inspected to ensure that there is no damage to the seal area such as scratches, pitting or other defects. If the seal is of the knife edge type, the knife edge should be carefully examined for damage which could affect the sealing properties.

5. Any adhesive tape attached to surfaces of the item whether or not they are to be exposed to vacuum must be removed and any adhesive residue carefully removed with the solvent isopropyl alcohol or ethanol.
6. Any marker pen or paint or similar on any surfaces of the item whether or not they are to be exposed to vacuum should be carefully removed by scraping if necessary followed by washing with the solvent isopropyl alcohol or ethanol and rinsing in demineralised water.
7. Any threaded holes, etc., whether or not they are to be exposed to vacuum, should be examined to see if there are traces of lubricants, cutting fluids or swarf left inside. Any such should be removed carefully using brushing or blowing out with clean compressed air or nitrogen and/or washing with a suitable solvent followed by rinsing with demineralised water, taking care that no residue is transferred to a vacuum surface.

13.7 Mechanical Processes on Vacuum Surfaces

Abrasive techniques to clean or to attempt to improve the appearance of the surfaces of vacuum components should be kept to an absolute minimum and are preferably avoided. The use of grinding wheels, wire brushes, files, harsh abrasives, sand, shot or dry bead blasting, polishing pastes and the like is prohibited under normal circumstances and certainly without prior *acceptance* by ITER.

Accepted techniques are slurry blasting with alumina or glass beads in a water jet; gentle hand use of a dry fine stone or a fine stone lubricated with isopropyl alcohol or ethanol; hand polishing using fine mesh alumina in an isopropyl alcohol or ethanol carrier on a lint free cloth; hand polishing with ScotchBrite™ (Alumina loaded, Grade A).

If any such surface finish technique is employed, care must be taken that any powder or other residues are removed by copious washing in hot water.

Any other such operations may be carried out only with prior *acceptance*.

13.8 Use of acids

Acid treatment of any sort is to be avoided wherever possible and may only be carried out with specific prior *acceptance* by the ITER Vacuum RO. Most acid treatments are for cosmetic purposes only and may result in degradation of vacuum performance.

Where the use of acids is *accepted*, then exposure of the component must be kept to a minimum and must be followed by copious washing in hot demineralised water.

13.9 Treatment of Weld Burn

One particular use of acid pastes is in the removal of weld burn. In general such burns do not affect vacuum performance and are best left alone. Any scaling (i.e. loose oxides) should be removed using the techniques of Section 13.7.

If it is desired to remove burns, then slurry blasting with alumina in water or hand burnishing with alumina powder is a satisfactory alternative. Heavy abrading, grinding or wire brushing is prohibited. Hand finishing with ScotchBrite™ or a dry stone is also *acceptable*.

13.10 Electropolishing for VQC1 Applications

Electropolishing should only be carried out where it is necessary to produce a smooth surface for reasons of electrical discharge or field emission minimisation, emissivity or similar purposes. It is usually unnecessary from a pure vacuum point of view and indeed can be detrimental to vacuum performance.

Electropolishing should be carried out in clean polishing tanks, using fresh electrolyte.

Local electropolishing can be carried out with tampons. Fresh clean pads dipped in clean electrolyte should be used and excessive pressure should be avoided.

After electropolishing, the item should be washed with copious quantities of hot demineralised water.

If required, vacuum Items for use in Class VQC 1 may be baked to 450 ^{o}C for at least 24 hours to remove the residual hydrogen and other contaminants introduced into the surface layers by the electropolishing process.

13.11 Handling and Packing

Handling and packaging of components should be in accordance with the requirements specified in the ITER Vacuum Handbook .

Specifically:

1. Once components have completed initial rough cleaning care should be taken that vacuum surfaces are never touched by bare skin. Powder free latex or nitrile gloves (over cotton or linen if desirable) should always be used when handling components. Coloured gloves are not *acceptable*.
2. Once components have started the cleaning process they should complete the cycle without a break. If it is unavoidable that a delay occurs between stages, then care must be exercised that the component is thoroughly dry before storage, and all seal faces and ports must be protected as below. There must never be a break between any chemical cleaning stage and a subsequent water washing stage.
3. After the component has been cleaned and is completely dry, it should be packed carefully to ensure that it remains clean and free from damage. All vacuum sealing faces should be protected with a clean metal plate or a hardboard or similar fibre free board covered with clean aluminium foil held in place by a number of bolts through the fastener holes. Knife edges should be protected with clean metal gaskets (which may have been used previously, but they should be completely free from loose oxide scale). All ports should be covered with strong clean new aluminium foil and plastic covers. Small items should be wrapped in clean aluminium foil and sealed in a polyethylene bag, under dry nitrogen if possible.

Clean conditions for the handling of vacuum components are also defined in the ITER Vacuum Handbook.

13.12 Spray washing

Where an item is cleaned by spray washing, it should be ensured that all hoses, lances, spray heads, etc are thoroughly cleaned out with clean hot water before the cleaning process starts.

Washing should start at the top of the item and the spray should be worked down to the bottom, ensuring good run-off.

13.13 Standard Cleaning Procedure for Stainless Steel Components

13.13.1 Preclean

All debris, such as swarf, should be removed by physical means such as blowing out with a high pressure air line, observing normal safety precautions. Gross contamination, e.g. greases or cutting oils, etc., should be removed by washing, swabbing and rinsing with any non halogenated general purpose solvent. Scrubbing, wire brushing, grinding, filing or other mechanically abrasive methods may not be used (see 13.7 above).

13.13.2 Wash

1. The item should be washed down using a high pressure jet of hot town water (at approx. 80°C), using a simple mild alkaline detergent. The detergent should then be switched off and the item rinsed thoroughly with hot water until all visible traces of detergent have been eliminated.
2. If necessary, any scaling or deposited surface films should be removed by stripping with alumina or glass beads in a water jet in a slurry blaster.
3. The item should be washed down with a high pressure hot demineralised water jet (at approx. 80°C), with no detergent, ensuring that any residual beads are washed away. Particular attention should be paid to any trapped areas or crevices.
4. The item should be dried using an air blower with clean dry air, hot if possible.

13.14 Chemical Clean for Stainless Steel, or similar Items, for VQC 1 application.

With the addition of the relevant safety precautions, the cleaning process below can also be applied to beryllium,

1. Where possible, the item should be immersed completely in an ultrasonically agitated bath of hot clean liquid solvent for at least 15 minutes, or until the item has reached the temperature of the bath, whichever is longer. The temperature should be the maximum specified by the *supplier* of the solvent.
2. Halogenated solvents are not permitted.

3. Suitable solvents need to be *accepted* by ITER before use. Isopropyl Alcohol, Ethyl Alcohol, Acetone, Axarel 9100™, Citrinox™, P3 Almeco™ P36 or T5161 are *accepted* for this purpose.
4. Where technically feasible, after the liquid immersion stage, the item should be immersed in the vapour of the solvent used for at least 15 minutes, or until the item has reached the temperature of the hot vapour, whichever is longer.
5. It must be ensured that all liquid residues have been drained off, paying particular attention to any trapped areas, blind holes etc.
6. The item is then be washed down with a high pressure hot (approx. 80°C) water jet, using clean demineralised water. Detergent must not be used at this stage.
7. The item is dried in an air oven at approx 100°C or with an air blower using clean, dry, hot air.
8. If the item is too large to be cleaned by immersion the item may be cleaned by washing it down with a high pressure jet of P3 Almeco™ P36 or T5161.
9. The item is cooled to room temperature in a dry, dust free area conforming clean conditions as defined in ITER Vacuum Handbook .
10. The item is inspected for signs of contamination, faulty cleaning or damage.
11. The item is baked to a temperature of 300°C or whatever other temperature has been specified for a minimum period of 24 hours at temperature in accordance with the ITER Vacuum Handbook Appendix 15
12. The item is packed and protected as in 13.11 above.

13.15 Chemical Clean for Stainless Steel or similar Items for use on VQC 2, 3 & 4 components

All items may be cleaned to the specification for items in Class VQC 1

It is also be permissible to use halogenated hydrocarbon solvents for cleaning items in these classes by analogy with 13.13 and 13.14.

For items for Class VQC 2, 3 and 4, baking will not normally be necessary with the exception of items specifically listed in the Vacuum Handbook.

13.16 Chemical Clean for Copper and Copper Alloys

Items manufactured from copper or copper alloys may be cleaned using the procedures for stainless steel, except that in this case Almeco P3-36™ is not acceptable.

Copper surfaces may alternatively be cleaned using a light chromic acid or citric acid etch, followed by thorough washing in hot, clean demineralised water.

13.17 Cleaning Ceramics

Ceramics such as alumina and beryllium oxide may be cleaned using the process described here. Other ceramics may not be able to withstand the high temperature air bake, so manufacturers specifications' must be checked.

Beryllium oxide must in no circumstances be ground or scraped except in specialist facilities.

1. Any surface contamination is removed by wet slurry blasting with alumina powder, or by hand polishing with fine-mesh alumina or diamond powder in an acetone, ethanol or isopropyl alcohol carrier.
2. Components are baked at 1000°C in atmosphere for 24 hours in accordance with Appendix 15. The maximum baking temperature may be limited by the system component materials.
3. Items are wrapped in clean aluminium foil and sealed under dry nitrogen in a sealed polyethylene bag

13.18 Cleaning of Aluminium

1. Components are sprayed with high pressure jets at 60 °C with a 2% solution of Almeco 29™ (an alkaline detergent).
2. This is be repeated with a 2 % solution of Amklene D Forte™.
3. Components are rinsed thoroughly with a jet of hot demineralised water.
4. Components are dried with hot air at 80 °C.

Alternatively,

5. Components are immersed in Sodium Hydroxide (45 g l^{-1} of solution) at 45 °C for 1 - 2 minutes.
6. Components are rinsed thoroughly in hot demineralised water.
7. Components are immersed in an acid bath containing Nitric acid (50% v/v) and Hydrofluoric acid (3% v/v).
8. Components are rinsed thoroughly in hot demineralised water.
9. Components are dried in warm air.

13.19 Air Baking

Items manufactured from stainless steel and the like may be air baked to provide a low hydrogen outgassing surface.

Note that this procedure is not suitable for materials that form a loose oxide, e.g. copper.

Items should be chemically cleaned using the procedures of 13.13 above

Items should then be heated in air at a temperature of 450 °C for a period of 24 hours in accordance with Appendix 15.

13.20 "Snow" Cleaning

A final clean after assembly of components into a large vacuum system may be achieved by the use of "snow" cleaning.

Snow cleaning uses a high velocity stream of soft microscopic particles of solid CO_2 to wash the surface and is effective for removing particulates and some organic contamination from surfaces.

Operatives undertaking this procedure must wear suitable protective clothing and personal safety equipment

The procedures used will be as specified by the *supplier*s of the equipment.

Snow cleaning will normally only be used for items to Class VQC 1, but may be used on all vacuum components.

13.21 Cleaning Procedures for Vacuum Bellows

13.21.1 General

Great care has to be exercised when cleaning thin walled metal bellows, particularly those of edge-welded, nested construction. If any cleaning residues are trapped between the convolutions, either inside or outside, these can result in corrosion which can rapidly cause leaks to develop. Similarly, if any particulates are deposited in the convolutions, mechanical puncturing can take place. Alkaline degreasing solutions such as Almeco are prone to particulate precipitation and therefore must not be used for bellows assemblies.

13.21.2 Procedure for Bellows for Class VQC 1 use

The bellows must be fixed in an extended position if possible.

1. Any traces of visible, loose contamination are removed with a gentle jet of clean, dry air or nitrogen.
2. The bellows are immersed in an ultrasonically agitated bath of isopropyl alcohol (IPA) or ethyl alcohol (ethanol).
3. The bellows should be vapour washed immediately in isopropyl alcohol or ethanol vapour.
4. The bellows, including the interspace where appropriate, must be thoroughly dried inside and out using a gentle jet of clean, dry, particulate free air or nitrogen.
5. The bellows should be placed in a dry air oven at 100 °C for at least 1 hour.
6. The bellows should be baked in a vacuum oven, for 24 hours at 250 °C with the bellows interspace pumped.
7. The bellows should be sealed under dry nitrogen in a polyethylene bag.

This procedure can be used for bellows used on VQC 2, 3 & 4 systems with the vacuum bake requirement waived.

13.22 Cleanliness

13.22.1 Wipe Test for Cleanliness

Gross contamination of a vacuum component may be assessed by means of a wipe test. This may be carried out "dry" or "wet".

Gross contamination may also manifest itself as an "oily" or "solvent-like" smell.

Note that these tests are of a somewhat subjective nature and may not be conclusive and therefore should only be used as a guide to cleanliness and as a marker for subsequent cleaning operations should the tests result in a failure of cleanliness.

13.22.1.1 Dry test

The surface of the component is wiped gently with a clean lint free cloth.

If there is any evidence of a deposit on the cloth (i.e. a stain or a change in colour) then the item should be regarded as unclean.

Similarly if the surface of the component which has been wiped shows any evidence of a change in colour or reflectivity of light, then the item should be regarded as unclean.

13.22.1.2 "Wet" test

This uses a clean lint free cloth dipped in a solvent which evaporates at room temperature, such as isopropanol, ethanol or acetone.

Appropriate safety precautions against fire hazard, breathing in of solvent fumes, eye and skin protection must be taken.

1. The cloth is dipped in the solvent which is then be allowed to evaporate in a safe manner. There should be no change in the appearance of the surface of the dry cloth.
2. The cloth is dipped in the solvent and the surface of the component is wiped gently while the cloth is still wet.
3. The solvent is allowed to evaporate from the cloth and the surface of the component until they are dry.
4. If there is any evidence of a deposit on the cloth (i.e. a stain or a change in colour) then the item should be regarded as unclean.
5. Similarly if the surface of the component which has been wiped shows any evidence of a change in colour or reflectivity of light, then the item should be regarded as unclean.

If required, the deposit on the cloth may be analysed by a suitable means to determine the chemical nature of the contamination.

13.22.2 General Test for Cleanliness

An item shall be deemed to be clean for the purposes of this Appendix provided that it meets the following criteria.

Cleanliness is defined to mean that the concentrations of "contaminants" (i.e. unwanted gas species) in the residual gas spectrum of the item are less than the specified values.

The concentration of a species is defined as the fractional intensity of its measured partial pressure components related to that species defined in a particular way to the total pressure in the system expressed as a percentage.

The partial pressures of species in the vacuum system or related to the component being measured should be obtained using the equipment and procedures defined in Appendix 17 of the Vacuum Handbook.

The residual gas spectrum will have been recorded over 1 –200 amu

The spectrum will have been corrected for sampling error, mass discrimination and species relative sensitivities.

The definition of "general contaminants" is the sum of the partial pressures of all peaks present in the residual gas spectrum of mass to charge ratio (amu) equal to 39, 41-43 and 45 and above (*excluding* any above 45 specifically listed in the table below). Also to be excluded from this summation are any peaks related to the rare gases xenon (i.e. 132, 129, 131) and krypton (i.e. 84, 86, 83)

Table 13-1 Allowed concentrations of contaminants pertaining to VQC

Vacuum Class	General Contaminants	Perfluoropolyphenylethers Sum of (peak at 69 and 77 amu)	Chorinated species (Sum of peaks at 35 and 37 amu)	Comment
VQC 4	5	1	1	Excluding water (sum of 17 and 18 amu) from the total pressure
VQC 3	2	0.5	0.5	
VQC 2	1	0.1	0.1	If unbaked, excluding water as above
VQC 1	0.1	0.01	0.01	After bake

This general test for cleanliness can be carried out as part of the verification of component outgassing in accordance with Appendix 17

13.23 Definition of Terms

For the purposes of this specification, the words or terms listed in Table 13-2 below are taken to have the stated meanings.

Table 13-2 Definitions of terms used

Term	Definition
Contaminant	Any unwanted substance present on a surface
Brushing	Using a fibre glass or wire brush to gently remove loosely adhered matter (e.g. dust) from a surface
Swabbing	Vigorous rubbing with a lint free cloth or rag
Wiping	Gentle rubbing with a lint free cloth or rag, either dry or soaked in a liquid
Washing	Cleaning an item by total immersion in a liquid or by pouring or spraying a liquid over it
Dipping	Immersing an item in a liquid and removing it relatively quickly
Rinsing	Using copious quantities of a liquid to remove traces of a contaminant or other material from an item, usually by repeated dipping or pouring the liquid over the item
Scraping	Using a hand tool of a material harder that the item being scraped to gently remove a thin layer from a surface
Grinding	Using a wheel or stone to remove a substantial amount of material from a surface
Scribing	Marking a surface with a clean metal point, vibrating engraver or laser engraving device, usually for identification or marking out purposes
Sand or shot blasting	Using a stream of abrasive particles e.g. silica or alumina to remove a surface layer. The medium may be a gas or a liquid.
Polishing or burnishing	Using a paste of fine particles, e.g. diamond or alumina, or a dry tool to produce a smooth surface
Solvent	A material which removes a contaminant from an item by dissolving it to form a solution
Detergent	A material which removes a contaminant from an item by acting as a surfactant i.e. by hydrophobic or hydrophilic action. Often used interchangeably (but incorrectly) with the term soap.
Etching	Removing a surface layer by chemical action
Pickling	Stripping of the oxide layer from a surface by use of acids
Passivation	Modifying a surface so that it is left in an inactive state, usually by leaving a uniform oxide film on the surface
Electropolishing	Removal of the surface layers of a metal by immersing the surface in a buffered acid solution and applying an electrical potential.
Ultrasonic cleaning	Immersion of a component in a bath of liquid with ultrasonic agitation

Vapour washing	Immersion of a component in a hot vapour such that the vapour condenses on the item and runs off by gravitation, carrying any contaminant in solution or suspension
Glow discharge	An electrical discharge set up in a low pressure gas. Discharges may use dc or radio frequency potential (voltage) sources
Clean surface	A surface with the desired properties e.g. outgassing.

IDM UID
2F457S

VERSION CREATED ON / VERSION / STATUS
02 Sep 2009 / 1.2 / Approved

EXTERNAL REFERENCE / VERSION

Guideline (not under Configuration Control)

Appendix 14 Passivation and Pickling

Approval Process			
	Name	*Action*	*Affiliation*
Author	**Worth L.**	**02 Sep 2009:signed**	**IO/DG/COO/PED/FCED/VS**
Co-Authors			
Reviewers			
Approver	**Pearce R.**	**09 Sep 2009:approved**	**IO/DG/COO/PED/FCED/VS**
Document Security: Internal Use *RO: Chiocchio Stefano*			
Read Access	**GG: MAC Members and Experts, GG: STAC Members & Experts, AD: ITER, AD: External Collaborators, AD: IO_Director-General, AD: EMAB, AD: Auditors, AD: ITER Management Assessor, project administrator, RO, LG: [CCS] CCS-All for Ext AM, LG: [CCS] CCS-Section Leaders, LG: [CCS] JACOBS, LG: [CCS] CCS-Doc Co...**		

Change Log			
Appendix 14 Passivation and Pickling (2F457S)			
Version	***Latest Status***	***Issue Date***	***Description of Change***
v1.0	In Work	27 Aug 2008	
v1.1	Signed	12 Jan 2009	
v1.2	Approved	02 Sep 2009	Minor textual changes for consistency with Vacuum Handbook

ITER Vacuum Handbook
Appendix 14

Guide to Passivation & Pickling for the ITER Project

	Name	Affiliation
Author/Editor	Liam Worth	Vacuum Group - CEP
Vacuum Responsible Officer	Robert Pearce	Vacuum Group - CEP

14 Guide for the Pickling/passivation of Steels and Copper for the ITER Project

1.1 Scope of this Appendix

This Appendix specifies typical procedures and processes to be used when materials used for vacuum components for the ITER project need to be passivated.

It is intended that the *suppliers* using such processes should follow the guidance in this Appendix to achieve the requirements of the ITER Vacuum Handbook.

The *supplier* is at liberty to utilise other techniques not described in this Appendix provided that the components supplied comply with the requirements of the ITER Vacuum Handbook.

1.2 General Comments

Pickling is most frequently used to remove heavy scale from steels or a heavy, loose oxide layer from copper (or aluminium).

Pickling is rarely specified for vacuum components, normally only for those to be used in rough vacuum, since the process attacks the metal surface and the oxide layer, tending to leave residues which are difficult to remove.

Heavy scale on steel is best avoided by specifying that the plate produced in a rolling mill or a hot-forged blank is stripped with an air knife while still hot.

Light scale on steel may be removed with a wire brush. Loose oxide on a copper surface can also be brushed off.

Pickling often leaves the surface in an etched state with a matt finish, which may or may not be desirable.

Dimensional stability cannot be guaranteed during the pickling process, so it should normally be carried out on the material before manufacture.

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

Pickling and passivation must always be followed immediately by an appropriate cleaning process, relevant to the Vacuum Classification of the component. (Refer to Appendix 13)

Pickling should always be followed by passivation. This is best carried out chemically, although native oxide layers can reform on exposure to atmosphere.

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 may require additional baking to achieve the outgassing requirements of the ITER Vacuum Handbook.

1.3 Pickling and Passivation of Steels.

Steel manufacturers/suppliers will often have their own preferred method of pickling/passivation and may be unwilling to use any other method. Expert advice from both a metallurgical and vacuum point of view shall be sought in this case. The vacuum person in this case will be the ITER Vacuum RO.

In no case, however, shall the use of glue in the pickling solution be permitted.

Note that the chemicals used in these processes are hazardous and all appropriate safety procedures must be followed

Table 14-1 below lists some of the acceptable pickling solutions for steels.

Material	Solution	Concentration	Temperature (°C)	Comment
Iron and steel	Sulphuric acid (SG 1.84)	10% solution	50-80	Until Scale visually removed
	Hydrochloric acid (SG 1.19)	10-20% solution	50-80	As above
Stainless steel	Nitric acid (SG 1.4) Hydrofluoric acid (52%)	$200gl^{-1}$ $40gl^{-1}$	55-65	As above
	Sulphuric acid (SG 1.84) Hydrofluoric acid (52%) Chromic acid - 60	$60gl^{-1}$ $60gl^{-1}$ $60gl^{-1}$	Room	As above
	Hydrochloric acid (SG 1.19) Nitric acid (SG 1.4)	$250gl^{-1}$ $22gl^{-1}$	60-70	Bright Finish

Table 14-1 – Pickling solutions for steels

Unless the pickling/passivation process is carried out on the raw material as part of the production process at the steel mill, the process to be used will typically be as follows -

- Gross contamination is removed by washing the material in a jet of hot (80°C) water.
- The material is allowed to dry.
- The material is thoroughly degreased using one of the methods specified in Appendix 13 of the ITER Vacuum Handbook
- The pickling baths should be checked visually to ensure that there are no visible signs of contamination, e.g. oils or greases floating on the surface. Ideally, clean pickling solutions in clean baths should be used.
- The material is lowered into the pickling solution for the specified time or until the process is complete.
- The material is washed in a jet of hot (80°C) water.
- The surface of the material is then passivated by lowering into a bath of dilute nitric or citric acid.

- The material is washed in a jet of hot (80°C) water and allowed to dry.

Note that there are alternative methods of pickling and passivation using spray and gel techniques. The use of such techniques is not prohibited but should only be used following *acceptance* of the proposal by the ITER Vacuum RO

1.4 Pickling and Passivation of Copper and Copper Alloys

The generalities and procedures of Section 1.3 above apply except where noted otherwise.

Pickling solutions for copper and copper alloys are given in Table 14-2 below

Material	Solution	Concentration	Temperature (°C)	Comment
Copper and copper alloys	Sulphuric acid (SG 1.84)	20% aqueous solution	65-75	
	Sulphuric acid (SG 1.84). Sodium dichromate	20% aqueous solution $75gl^{-1}$	20-75	
	Citric acid	1% aqueous solution	Ambient	Also passivates the surface

Table 14-2 – Pickling solutions for copper

Following pickling, copper parts must be passivated immediately by dipping in a 1% aqueous solution of citric acid.

1.5 Standards

The following standard procedures may be used to inform the processes described in this Appendix

EN 2516:1997 – Passivation of corrosion resistant steels and decontamination of nickel bas alloys

ASTMA380 – Practice for Cleaning, Descaling and Passivation of Stainless Steel Parts, Equipment and Systems

ASTM A967 – Specification for Chemical Passivation Treatments for Stainless Steel Parts

IDM UID
2DU65F
VERSION CREATED ON / VERSION / STATUS
02 Sep 2009 / 1.3 / Approved
EXTERNAL REFERENCE / VERSION

Guideline (not under Configuration Control)

Appendix 15 Vacuum Baking

Approval Process			
	Name	*Action*	*Affiliation*
Author	**Worth L.**	**02 Sep 2009:signed**	**IO/DG/COO/PED/FCED/VS**
Co-Authors			
Reviewers			
Approver	**Pearce R.**	**09 Sep 2009:approved**	**IO/DG/COO/PED/FCED/VS**
Document Security: Internal Use *RO: Chiocchio Stefano*			
Read Access	**GG: MAC Members and Experts, GG: STAC Members & Experts, AD: ITER, AD: External Collaborators, AD: IO_Director-General, AD: EMAB, AD: Auditors, AD: ITER Management Assessor, project administrator, RO, LG: [CCS] CCS-All for Ext AM, LG: [CCS] CCS-Section Leaders, LG: [CCS] JACOBS, LG: [CCS] CCS-Doc Co...**		

Change Log			
Appendix 15 Vacuum Baking (2DU65F)			
Version	***Latest Status***	***Issue Date***	***Description of Change***
v1.0	In Work	27 Aug 2008	
v1.1	In Work	12 Jan 2009	
v1.2	In Work	12 Jan 2009	
v1.3	Approved	02 Sep 2009	Minor textual changes for consistency with Vacuum Handbook

ITER Vacuum Handbook
Appendix 15

Guide to the Vacuum Baking of Components for the ITER Project

	Name	Affiliation
Author/Editor	Liam Worth	Vacuum Group - CEP
Vacuum Responsible Officer	Robert Pearce	Vacuum Group - CEP

15 Guide for Vacuum Baking

15.1 Scope

This Appendix specifies typical procedures and processes which may be used when vacuum components and materials used for vacuum components for the ITER project are required to be baked.

It is intended that the *suppliers* using such processes should follow the guidance in this Appendix to achieve the requirements of the ITER Vacuum Handbook.

The *supplier* is at liberty to utilise other techniques not described in this Appendix provided that the components supplied comply with the requirements of the ITER Vacuum Handbook.

15.2 General Comments

Vacuum components for the various classifications may require to be baked to ensure satisfactory vacuum performance. Baking can be included as in the component leak testing procedure (Appendix 12) and/or the component cleaning procedure (Appendix 13). 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 and durations listed in Table 15-1 should be used.

Vacuum baking has three functions, *viz.*, (a) the removal of contaminants which can break down to volatile components under the application of temperature (b) reducing the outgassing rate of the surface by accelerating the thermal desorption of molecular species (most often water) and (c) opening up incipient leaks, particularly porosity, where the leak path has been blocked by, for example, a carbon inclusion.

In order that the objectives of this Appendix are achieved, the times and temperatures specified for vacuum bakes have been based on considerable experience of using the processes.

In the following sections, the term “vacuum item” shall be taken to refer to an individual vacuum component, a sub-assembly or complete assembly as appropriate. It may also refer to material, e.g. steel sheet, being processed prior to manufacture.

Where the temperature is too high for a composite assembly the component part requiring higher temperature baking should 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 should be *accepted* in advance of baking operations.

Where the manufacturer is unable to carry out a bake procedure, either to the standard conditions in Table 15-1 or as otherwise specified, then any variation shall be *accepted* by ITER before proceeding.

Table 15-1Standard Temperatures and Durations for Vacuum Baking

Vacuum Classification	Temperature (°C)	Time (hr)	Comment
VQC 1	240	24	
VQC 1*	350	24	Stainless steel and beryllium
	450 - 2000	24	Carbon composites (see Appendix 16)
	250	24	Precipitation-hardened copper alloys
	350	24	Tungsten

* For vacuum items in line vicinity of plasma

15.3 General Procedures for Baking of Vacuum Items

15.3.1 Preliminary

Prior to baking, the vacuum item will have been thoroughly cleaned in accordance with the procedure of Appendix 13 of the ITER Vacuum Handbook.

If the vacuum item is not capable of being vacuum sealed and pumped down (e.g. it may be a batch of material or a part-finished vessel), then the vacuum item should be subjected to a total immersion bake (see 15.5.1 below)

All vacuum flanges should be sealed with a blank flange of material and thickness similar to that on the main vacuum item, using gaskets of the type to be used when the vacuum item is in service and fasteners of the appropriate strength.

Where a copper gasket is to be used and the bake temperature is greater than 100°C, then the gasket should be silver plated to avoid the formation of a loose oxide on the atmospheric side of the joint.

The vacuum item should be placed in or on a suitable bakeout stand which can safely support the vacuum item at the maximum temperature of the bake procedure. Any fixings should take into account the thermal expansion of the vacuum item and stand.

The vacuum item should be pumped down to an appropriate vacuum level and thoroughly leak tested to the appropriate specification in accordance with Appendix 12 of the ITER Vacuum Handbook prior to starting any baking process.

15.3.2 Vacuum Pumps and Gauges

Vacuum Pumps of the appropriate pumping speed and base pressure specification should be used in these processes.

Vacuum pumps used for these processes should be inherently clean (e.g. turbomolecular pumps with magnetic or greased bearings, dry backing/roughing pumps, cryosorption pumps or sputter ion pumps). Otherwise, the supplier needs to satisfy ITER that a suitable failsafe trapping system has been implemented to protect against back-streaming and/or pump failure.

Vacuum gauges (total and partial) with suitable measurement ranges and with appropriate calibration certificates should be fitted as required to monitor satisfactorily the progress of the bakeout process.

The manufacturer should provide ITER with complete details of all such equipment (including manufacturer, age, calibration certificates and history).

No bake procedure should be started before ITER has *accepted* the use of this equipment.

ITER will have the right to request documentary proof of the performance of the pumping equipment in the form of blank pump down characteristics and/or residual gas scans of the pumping equipment.

15.3.3 Temperature Monitoring and Control

The manufacturer should implement a suitable system to monitor, control and record the temperature of the baked vacuum item throughout the procedure.

It is important that the rate of rise and fall of temperature is controlled to within the *accepted* specification as detailed in the *accepted* baking procedure.

Full details of this system should be supplied to ITER.

No bake procedure may be started before ITER has *accepted* the use of this equipment.

15.3.4 Completing the Bake Process

When the temperature of the vacuum item has fallen to room temperature, the vacuum item should be leak tested thoroughly to the appropriate specification in accordance with Appendix 12 of the ITER Vacuum Handbook.

The vacuum item should be vented to dry nitrogen (dew point –50 °C), removed from the bakeout stand and suitably packed and protected for transport or storage.

15.4 Control of the Bake Process

To avoid undue stress on the vacuum item being baked, the temperature should be controlled such that it is uniform to within ±20 °C at all points on the surface of the vacuum item, unless otherwise *accepted* by ITER.

The temperature differential across a metal sealed vacuum flange pair of greater that 200 mm diameter should be less than 10 °C at all times.

The rate of rise and fall of the temperature of the vacuum item should be held within specified limits and, unless otherwise *accepted* by ITER, should be no greater than 10 °C per hour.

When the temperature is falling, it is normally permissible to switch off the temperature control when the temperature falls below 50 °C and let the vacuum item cool naturally to room temperature.

Thus for a 200 °C bake, the rise time will normally be 18 hours, the dwell time 24 hours and the fall time 15 hours plus the natural final cooling time.

At no time during the bake process should the pressure within the vacuum item being baked exceed 10^{-3} Pa. If it should approach this level, the temperature must be held until the pressure falls again as the outgassing rate decreases.

The use of a residual gas analyser to monitor the bake process is strongly advised. This can indicate possible leaks opening up during the process. It can also be used for “end point” detection – e.g. when the water peak falls to below a specified partial pressure.

15.5 Types of Bake Procedure

15.5.1 Total Immersion Bake

In this procedure, the vacuum item is totally immersed in the vacuum environment of a vacuum furnace which is capable of reaching the required temperature and maintaining a pressure less than 10^{-3} Pa at the maximum temperature used.

The manufacturer should, before the start of any baking process, demonstrate to ITER, by the provision of residual gas analysis spectra of the furnace during a blank run at the temperature to be used for the bake procedure, that the vacuum level and the cleanliness of the furnace at the temperature at which the bake is to be performed is satisfactory for the purpose . This requirement may be waived by agreement with ITER where the furnace has not been used for any other purpose between two successive bake processes for the ITER organisation.

Any vacuum joints on the vacuum item to be baked shall be left open.

The vacuum item is placed in the furnace, which is sealed and pumped down to the starting pressure with equipment conforming to the requirements of Section 15.3.2 above.

The furnace is checked for leaks.

The appropriate time/temperature bake cycle is carried out.

15.5.2 Oven Bake

The vacuum item, which will be a sealed vacuum vessel or assembly, is placed inside a suitable insulated enclosure and connected by a suitable pumping manifold to a vacuum pumping system conforming to the requirements of Section 15.3.2 above.

The arrangement shall be *accepted* by ITER before use.

Wherever possible, a suitable vacuum gauge or gauges capable of being operated at the maximum temperature of the bake cycle should be attached directly to the vessel or assembly being baked. Pressure readings on these gauges should be scaled to room temperature values by the appropriate temperature correction factor.

The insulated enclosure may be heated by convection heaters, radiant heaters or hot gas. It is recommended that some form of circulation of the air inside the enclosure be used to assist temperature uniformity.

A suitable number of temperature monitors should be fixed to the vacuum item so that the temperature distribution may be adequately monitored to ensure that the appropriate limits are not exceeded (15.4 above).

If any glass or similar viewports or accessories are fitted, they should be covered in triple thickness aluminium foil for thermal protection and fitted with suitable mechanical protection against impact or implosion.

The assembly should be leak tested to the appropriate specification.

The appropriate time/temperature bake cycle is carried out

15.5.3 "Tape" Bake

In this procedure, the sealed vacuum item is wrapped with heater tapes. Rod heaters, heater plates or flange band heaters may also be used.

A suitable number of temperature monitors is fixed to the vacuum item so that the temperature distribution may be adequately monitored to ensure that the appropriate limits are not exceeded (15.4 above). In this case, it is very important to monitor the temperature on each side of every large (i.e. greater than 200mm diameter) flange pair. Temperature measurement sensors will normally be located close to the heating device (i.e. in the location of highest expected temperature)

Wherever possible a suitable vacuum gauge or gauges capable of being operated at the maximum temperature of the bake cycle are attached directly to the vessel or assembly being baked. Pressure readings on these gauges should be scaled to room temperature values by the appropriate temperature correction factor.

The vacuum item is connected by a suitable pumping manifold to a vacuum pumping system conforming to the requirements of Section 15.3.2 above.

The assembly shall be leak tested to the appropriate specification in accordance with Appendix 12 of the ITER Vacuum Handbook.

The vacuum item may then be wrapped in aluminium foil to assist in uniformity of the temperature distribution, taking care around electrical connections.

If there are glass or similar viewports or accessories fitted, they must be covered in triple thickness aluminium foil for thermal protection and fitted with suitable mechanical protection against impact or implosion.

The vacuum item is then covered with suitable thermal insulation, preferably a ceramic fibre filled flexible jacket or blanket.

The appropriate time/temperature bake cycle is carried out.

15.5.4 Air Bake

Where an air bake is specified for any item, the general procedures are as specified in this Appendix for the particular type of bake (Immersion, Oven or Tape) except that in this case all sections referring to pumping are ignored and all surfaces (interior and exterior) of the item shall be exposed to normal atmospheric air during the bake process.

Vacuum equipment conforming to the above requirements may still be required where a leak test and/or outgassing test has been specified as part of the bake process either before or after such a process.

15.6 Documentation to be Supplied

For each vacuum item, the following certificates and records will normally be supplied:

- If requested by ITER a record of the performance of the pumping equipment
- A certificate of the initial leak rate
- A certificate of the final leak rate
- A record of the temperature distribution for the item and pressure within the vacuum item against time for the full duration of the bakeout process
- If agreed between the manufacturer and ITER, a full record of any residual gas scans taken with appropriate time markers which identify the scans to the position on the component bakeout cycle
- Full documentation regarding any leaks or other problems which occurred during the tests and any remedial action taken

IDM UID
27YH3U

VERSION CREATED ON / VERSION / STATUS
02 Sep 2009 / 1.2 / Approved

EXTERNAL REFERENCE / VERSION

Guideline (not under Configuration Control)

Appendix 16 Conditioning of Carbon Composites

Approval Process			
	Name	*Action*	*Affiliation*
Author	**Worth L.**	**02 Sep 2009:signed**	**IO/DG/COO/PED/FCED/VS**
Co-Authors			
Reviewers			
Approver	**Pearce R.**	**09 Sep 2009:approved**	**IO/DG/COO/PED/FCED/VS**
Document Security: Internal Use *RO: Chiocchio Stefano*			
Read Access	**GG: MAC Members and Experts, GG: STAC Members & Experts, AD: ITER, AD: External Collaborators, AD: IO_Director-General, AD: EMAB, AD: Auditors, AD: ITER Management Assessor, project administrator, RO, LG: [CCS] CCS-All for Ext AM, LG: [CCS] CCS-Section Leaders, LG: [CCS] JACOBS, LG: [CCS] CCS-Doc Co...**		

Change Log			
Appendix 16 Conditioning of Carbon Composites (27YH3U)			
Version	***Latest Status***	***Issue Date***	***Description of Change***
v1.0	In Work	27 Aug 2008	
v1.1	In Work	13 Jan 2009	
v1.2	Approved	02 Sep 2009	Minor textual changes for consistency with Vacuum Handbook

ITER Vacuum Handbook
Appendix 16

Guide to the Conditioning Carbon Composites for the ITER Project

	Name	Affiliation
Author/Editor	Liam Worth	Vacuum Group - CEP
Vacuum Responsible Officer	Robert Pearce	Vacuum Group - CEP

16 Vacuum Conditioning of Graphite and Carbon Composites

16.1 Scope

In order to remove absorbed impurities from graphite or carbon fibre composite materials it may be necessary to vacuum bake the raw material in a suitable vacuum furnace.

This Appendix outlines a process which may be used when graphite and carbon composites which are used on the ITER project are required to be baked.

It is intended that the *suppliers* using such processes should follow the guidance in this Appendix to achieve the requirements of the ITER Vacuum Handbook.

The *supplier* is at liberty to utilise other techniques not described in this Appendix provided that the components supplied comply with the requirements of the ITER Vacuum Handbook.

16.2 Procedures

The supplier shall perform a degassing cycle on components after machining to a procedure *accepted* by the ITER Vacuum Responsible Officer in accordance with Appendix 15 of the ITER Vacuum Handbook .

The temperature of the bakeout cycle will depend on the base pressure achievable in the vacuum furnace.

Leak tests of the vacuum furnace should be carried out in accordance with the ITER Vacuum Handbook.

16.2.1 Procedure for high temperature baking

The preferred outline procedure is as follows.

1. Condition the furnace.
2. Load the component parts.
3. Achieve a vacuum pressure of < 10 Pa.
4. Perform a leak test of the furnace. The acceptance leak rate will normally be $< 10^{-6}$ $Pa.m^3.s^{-1}$
5. Increase the temperature of the furnace to 2000 °C, maintaining the pressure at < 10 Pa
6. Hold at 2000 °C for 24 hours maintaining the pressure at < 10 Pa.
7. Cool under vacuum to 400 °C.
8. Back fill the furnace with pure (UHP grade) Nitrogen to ~30 kPa.
9. Cool to room temperature.
10. Vent the furnace to atmospheric pressure with Nitrogen (zero grade).
11. Package the parts in *accepted* packaging and atmosphere.

16.2.2 Procedure for lower temperature baking

In order to maintain the furnace base pressure < 10^{-3} Pa the baking temperature may be lowered as follows:

1. Condition the furnace.
2. Load the component parts.
3. Achieve a vacuum of < 10^{-3} Pa.
4. Perform a leak test of the furnace. The acceptance leak rate will normally be < 10^{-6} $Pa.m^3.s^{-1}$
5. Increase the temperature of the furnace to 450 °C, maintaining the pressure < 10^{-3} Pa.
6. Hold at 450 °C for 24 hours maintaining the pressure at < 10^{-3} Pa.
7. Cool under vacuum to 400 °C.
8. Back fill the furnace with pure (UHP grade) Nitrogen to ~30 kPa.
9. Cool to room temperature.
10. Vent the furnace to atmospheric pressure with Nitrogen (zero grade).
11. Package the parts in *accepted* packaging and atmosphere.

IDM UID
2EXDST

VERSION CREATED ON / VERSION / STATUS
08 Sep 2009 / 2.2 / Approved

EXTERNAL REFERENCE / VERSION

Guideline (not under Configuration Control)

Appendix 17 Guide to Outgassing Rates and their Measurment

Approval Process			
	Name	*Action*	*Affiliation*
Author	**Worth L.**	**08 Sep 2009:signed**	**IO/DG/COO/PED/FCED/VS**
Co-Authors			
Reviewers			
Approver	**Pearce R.**	**08 Sep 2009:approved**	**IO/DG/COO/PED/FCED/VS**
Document Security: Internal Use			
RO: Chiocchio Stefano			
Read Access	**GG: MAC Members and Experts, GG: STAC Members & Experts, AD: ITER, AD: External Collaborators, AD: IO_Director-General, AD: EMAB, AD: Auditors, AD: ITER Management Assessor, project administrator, RO, LG: [CCS] CCS-All for Ext AM, LG: [CCS] CCS-Section Leaders, LG: [CCS] JACOBS, LG: [CCS] CCS-Doc Co...**		

Change Log			
Appendix 17 Guide to Outgassing Rates and their Measurment (2EXDST)			
Version	***Latest Status***	***Issue Date***	***Description of Change***
v1.0	In Work	27 Aug 2008	
v1.1	In Work	15 Jan 2009	
v1.2	In Work	15 Jan 2009	
v2.0	Signed	17 Feb 2009	
v2.1	Signed	02 Sep 2009	Minor textual changes for consistency with Vacuum Handbook. Refference added. Corrections to outgassing rate tables
v2.2	Approved	08 Sep 2009	Correction to cryostat outgassing figures

ITER Vacuum Handbook
Appendix 17
Guide to Outgassing Rates and their Measurement

	Name	Affiliation
Author/Editor	Liam Worth	Vacuum Group - CEP
Vacuum Responsible Officer	Robert Pearce	Vacuum Group - CEP

17.1 Scope

This Appendix is intended as a guide to the measurement of the total and partial thermal outgassing rates of materials, vacuum vessels, components and assemblies for the requirements of the ITER Project. It is intended that the guide be used to assist *suppliers* in producing outgassing test procedures to comply with the mandatory requirements of the ITER Vacuum Handbook. It also gives details on how the outgassing requirements for ITER systems have been derived.

It is envisaged that outgassing tests will normally be performed on components, parts of the component or “coupons” which have been subjected to the complete manufacturing process. Manufacturing operations which have been applied, including baking and cleaning operations, should be recorded and traceable to the coupon (where used) or to the manufactured component.

17.2 Limitations

This Appendix describes a set of procedures for the measurement of thermal outgassing from a vacuum item when used as part of the vacuum quality assurance procedures for the ITER Project. This Appendix describes the recommended procedures of the most widely used methods of measuring the outgassing rates; it does not consider all available methods. Despite this limitation, the techniques are more widely applicable and form a basis for more general good practice.

The supplier is at liberty to propose other methods of thermal outgassing measurement not described in this Appendix.

When this set of procedures is used to measure the outgassing from a component or coupon placed within a vacuum chamber, the outgassing of the chamber walls cannot usually be neglected and must be subtracted from the measured value to obtain that from the coupon. For this, an independent measurement of the wall outgassing from the empty chamber will be required – often referred to as a *blank run*.

Unless otherwise specifically indicated, outgassing measurements using these procedures will be carried out with the component under test at 100 °C

In these procedures the term *outgassing* shall be taken to mean *thermal outgassing* unless otherwise indicated.

The methods of measuring outgassing rates described in these procedures yield an average value of the outgassing rate for each surface exposed to the vacuum measurement system.

17.3 Specific Outgassing Rate

Outgassing is described in terms of the rate of desorption of gas from a vacuum surface.

The measured (or net) outgassing rate is the difference between the intrinsic outgassing rate (of the component) and the rate of re-adsorption on the surfaces of the test chamber.

The specific outgassing rate defined as the total gas load generated per unit time due to gas desorbing from a vacuum surface due to the temperature of the surface per unit area of desorbing surface. It is represented here by q_{th}. Units are $Pam^3s^{-1}m^{-2}$

Clearly,

$$Q_{th} = q_{th} \cdot A$$

Where:

Q_{th} is the total outgassing rate ($Pa.m^3.s^{-1}$)

A is the area of the desorbing surface (m^2)

17.4 Generic Methods of Measuring Outgassing Rates

17.4.1 Rate of Rise of Pressure Method

This method of measuring outgassing rates is in principle very simple, but there are a number of considerations that need to be taken into account if the measurements are to be meaningful.

The principle of the method is that if one has a volume evacuated to a given pressure p_0 and then isolated from the vacuum pump, the specific thermal outgassing rate q_{th} is given by

$$q_{th} = \frac{V}{A} \cdot \frac{(p_t - p_0)}{t}$$

where V is the containing vessel volume

A is the total internal surface area of the desorbing surface

p_t is the pressure after a time interval t

provided that the outgassing rate is reasonably constant with both pressure (over the range $p_t \rightarrow p_0$) and the time interval t and that the temperature of the outgassing surfaces is constant.

Partial (i.e. species dependent) outgassing rates may be determined by using a calibrated gas analyser to measure the rate of rise of the partial pressure of a particular species.

What is actually measured using the rate of rise technique when the pressure remains in the high vacuum region or below, is the increase in number density of gas molecules entering the measurement volume of the “pressure” sensor. This increase can be affected by various processes, which can be classified as being either gas sources or gas sinks. A gas source is something which releases gas molecules into the interior of the vessel, and hence eventually into the measurement volume. A gas sink is something which adsorbs or absorbs a gas molecule which strikes it, i.e. it acts as a pump. This is further discussed later.

This method is quite simple to implement and requires the minimum of equipment. Since, during the measurement time the vacuum pump is valved off, there is no need to know the pumping speed (especially where the speed may be species dependent). Only one vacuum gauge is required. For absolute measurements, the gauge needs to be calibrated for the outgassing species. Where only *relative* measurements of outgassing are required (e.g. before and after a process such as baking), provided the gauge is known to be reasonably stable in sensitivity, calibration may not be required.

No vacuum parameters of the system need to be calculated or measured, apart from the pressure.

This method works best for relatively low outgassing rates, where measurements can be take over a long time period. For high outgassing rates, the rise in pressure can be quite rapid, making time and/or pressure dependent measurements difficult.

The volume of the vessel (and all appendages) needs to be measured or calculated to a reasonable degree of accuracy.

This method is more suitable for the measurement of outgassing from vessels or assemblies rather than coupon samples, unless either the intrinsic outgassing rate of the coupon is very much higher than that of the containing vessel or the surface area of the sample is much higher than that of the vessel or both.

17.4.2 Dynamic Flow (Conductance) Method

In this method, the item being measured is pumped through a known conductance and the pressure difference across this conductance is measured. The specific thermal outgassing rate q_{th} is then given by

$$q_{th} = C \cdot \frac{\Delta p}{A}$$

where:

C is the conductance

Δp is the pressure difference across the conductance

A is the area of the desorbing surface

Partial (i.e. species dependent) outgassing rates may be determined by using calibrated gas analysers to measure the differences in partial pressure of the particular species.

The method is suitable for all but the lowest values of outgassing, since the value of the conductance can be chosen to give a sensible pressure difference. Variation in outgassing rate with time can readily be measured even when the outgassing rate is quite high or is varying relatively rapidly and the volume of the vessel is not required.

The method requires two vacuum gauges which must both be calibrated for the desorbing species for the most accurate results. Both must remain stable across the full range of measurement for the duration of the test. If partial outgassing rates are required, then two calibrated residual gas analysers (RGAs) should be fitted.

It requires the use of a pump whose speed is much larger than the conductance for all gas species.

The conductance, which is gas species dependent, must be measured or calculated to a reasonable degree of accuracy.

When measuring outgassing from coupon samples, the outgassing rate of the containment vessel must remain sufficiently stable for a blank run to yield a meaningful correction.

17.4.3 Variant Dynamic Flow Methods

One variant of this method assumes that the pressure on the pump side of the conductance is very much less than that on the sample side and so can be ignored. In this case only one calibrated gauge and one RGA is required, both situated upstream of the conductance. Good practice would require a total pressure gauge also to be fitted downstream of the conductance to ensure that the pressure conditions were being met, but this gauge need not be calibrated.

A second variant uses an arrangement of valves so that a single calibrated gauge can alternatively be exposed to either side of the conductance. This requires good linearity in the gauge and an outgassing rate which is stable over the time of measurement.

17.4.4 Weight Loss Method

The method of weight loss measurement can be used to measure outgassing rates from materials with high outgassing rates, for example organic materials.

The test consists of measuring the weight loss of a sample which has been subject to a defined thermal cycle under vacuum. The sample is placed in an effusion cell and heated. The outgassing flux is condensed on temperature controlled collectors which are placed in front of the sample. From the mass deposit on the collector the total mass loss (TML) and hence outgassing rate are derived, as function of time, and is usually expressed as %TML

The setup and procedure are described in the ASTM E595-93 standard and are widely used in characterisation of materials for use in space applications.

17.5 Sources of Errors in Measuring Outgassing

All methods of measuring outgassing are susceptible to errors which may yield misleading results. Detailed consideration should always be given to this.

17.5.1 System Effects

17.5.1.1 Vacuum Vessels and Conductance's

Either the internal volume of the outgassing measurement chamber, or the conductance between this and the pump, must be known to a reasonable degree of accuracy, dependent on the technique employed. Volumes are notoriously difficult to measure or calculate to high accuracies and are temperature dependent. In some cases (e.g. where bellows are present) they may also be dependent on the atmospheric pressure in the laboratory. Volumes will change if there are movable items present, e.g. vacuum valves.

The value of a conductance element is also temperature dependent and, more importantly, dependent on the mass of the gas species traversing the conductance. To some extent the transmission probability of gas molecules through a conductance is dependent on the size and shape of the vacuum chamber at each end.

It is usually assumed that in measuring outgassing, free molecular flow conditions prevail. This may or may not be the case and needs to be checked.

In the dynamic flow method, it is assumed that outgassing of the vacuum system downstream of the conductance does not influence what is happening in the measurement chamber upstream of the conductance.

17.5.1.2 Vacuum Gauges

The calibration of both total pressure and partial pressure gauges is non trivial and the stability of many gauges is not good. Clearly this may introduce significant measurement errors, especially in the two-gauge dynamic flow method.

17.5.1.3 Vacuum Pumps

Pumping speeds of vacuum pumps vary with the species being pumped, so for the dynamic flow method it is important to ensure that a sufficiently high pumping speed (i.e. compared to the conductance for the particular gas species) is maintained at all times.

17.5.1.4 Temperature

Some of the effects of temperature have been discussed above. However, outgassing is itself strongly dependent on temperature, so it is important that for the most accurate measurements, the entire apparatus is maintained at a constant temperature during the period in which measurements are being taken.

17.5.2 Gas Sources and Sinks

Errors in measured outgassing rates may be affected by sources of gas other than true outgassing entering the measuring volume of the gauge or gauges used. In this case an enhanced value will be measured. Likewise any pumping in the vessel for which outgassing is being measured will lead to an apparent value being measured which is lower than the true value. In extreme cases, negative values of apparent outgassing may be measured.

17.5.2.1 General Types of Gas Source or Sink

Possible sources of gas include:

- any surfaces exposed to the vacuum which release molecules by desorption other than thermal desorption or by permeation
- all joints, which tend to be areas of increased permeation
- leaks, real or virtual
- any gauge
- gas bursts from items moving in the vacuum system

Possible sinks for gas include:

- any surfaces exposed to the vacuum which can exhibit wall pumping, particularly "active" surfaces found in capture pumps even when switched off
- any gauge which can act as a pump

17.5.2.2 Surfaces as Sources

The point of the measurement is to measure thermal desorption from the surface of interest, i.e. gas molecules released by the absorption of phonons, so it is important that extraneous forms of desorption are minimised. Details are not discussed here, but it should be noted that the surfaces under investigation should not be exposed to significant fluxes of photons of wavelengths shorter than the short-wavelength end of visible or to electrons of energy greater than a few eV. It is also important that the temperature of the surfaces under test is kept constant as thermal desorption is an exponential function of temperature.

For metals at room temperature, permeation is only significant for hydrogen and even that would normally be very low unless very thin walls are present or when measuring very low outgassing rates. However it should be remembered that hydrogen is by far the dominant species in such cases and there is some debate as to whether hydrogen permeation is in fact the rate limiting step in outgassing from metals. The source of the hydrogen may be either dissolution from the bulk metal or passing from atmosphere on one side of the wall to the other. In practice, both will happen.

Glasses, plastics and elastomers may have quite large permeabilities for hydrogen, helium or water. Care must therefore be exercised when these are exposed to both atmosphere and vacuum.

A special case of thermal outgassing is evaporation or sublimation of the wall material (vapour pressure). For most normal vacuum materials, this is only a problem when measuring extremely low outgassing rates.

17.5.2.3 Surfaces as Sinks

When gas molecules strike a surface, in general they stick. They may stick for a short time before being re-emitted or they may stick for a long time. Here, the former process is ignored although it is important for the thermodynamics of the system. However, the latter process gives rise to the phenomenon known as wall pumping. In some cases this process can be enhanced by preparing a surface which is chemically active and deliberately used as a pump in, for example, a Titanium Sublimation Pump (TSP) or a Non-Evaporable Getter (NEG). A similar effect is seen when a surface is cooled to cryogenic temperatures. In normal circumstances the walls of a vacuum system are sufficiently inert that wall pumping is insignificant. However there are circumstances where this may not be the case. A surface which has been glow discharged will have had its chemistry altered somewhat and until a passivation film, usually an oxide, is formed may exhibit wall pumping. Similarly a surface where the gas concentration has been reduced by photon desorption, electron or ion desorption or high temperature thermal desorption may be sufficiently far from equilibrium to exhibit wall pumping.

It is very difficult to estimate what wall pumping speeds might be in such circumstances.

17.5.2.4 Joints

Vacuum joints can be regions of enhanced permeability, especially demountable joints using elastomer gaskets. However, welds and brazes may also be suspect. If components have been hydrogen brazed, then enhanced hydrogen outgassing may be experienced from all surfaces. Joints which have been welded using the Tungsten Inert Gas (TIG) process may exhibit enhanced outgassing of (usually) argon.

17.5.2.5 Leaks

Naturally, the presence of leaks can vitiate any sensible measurement of outgassing and so thorough leak checking of the test system is a necessity.

17.5.2.6 Moving items

When items move in a vacuum, gas molecules can be desorbed. The most common moving item in an outgassing measurement system will be a vacuum valve. These can generate significant gas bursts when moving. This can be minimised by operating them slowly and by thorough outgassing.

In practice, this is not usually very important in measuring outgassing rates. In the case of rate-of-rise measurements, the system is sealed and static. Any gas generated when the valve is closed at the start of measurement forms part of the base pressure. In the two gauge dynamic flow technique, valve states do not change during the measurement. In the variant of this technique where a single gauge is exposed successively to either side of the conductance to eliminate gauge errors, some care has to be exercised to minimise any such effects.

17.5.2.7 Gauges as Sources

Hot filament gauges are clearly potentially major sources of error in measurements of this type, since they not only run at high temperatures but will also cause local heating of the vacuum system. Enhanced outgassing will be experienced from the gauge and walls.

Cold cathode gauges are better than hot filament gauges in this respect since they operate at room temperature.

Ionisation gauges, hot or cold cathode, are also sources of x-rays, ions and electrons of sufficient energy to cause desorption when they strike surfaces. Cold cathode gauges may also generate energetic neutrals which may themselves cause desorption.

17.5.2.8 Gauges as Pumps

All ionisation gauges will act as pumps. Hot filament Bayard-Alpert Gauges typically exhibit pumping speeds of around 0.1 $l.sec^{-1}$ but this will normally be swamped by the outgassing.

Cold cathode gauges of the Penning or magnetron (whether inverted or not) type may well exhibit (net) pumping speeds of up to 1 $l.sec^{-1}$.

17.5.3 Some Practical Considerations

17.5.3.1 Minimising Errors

Clearly if one wishes to measure an outgassing rate, all of the above effects may play a part in introducing errors. Good vacuum practice will help in many cases to vitiate the worst of these. Leak testing should be carried out with a sensitivity of at least an order of magnitude better than the measured total outgassing rate. Permeation (but not of course bulk dissolution) can be reduced by surrounding the measurement chamber with a guard vacuum. Wall pumping may be reduced by waiting or by saturating the surface with an inert gas. This may of course make nonsense of what one is trying to do!

In practice, the bulk of the errors will come from the gauge. A hot cathode gauge should be mounted on a water-cooled side arm, preferably with a cooled baffle in the gauge throat. It should be well-degassed, and any pressure difference between the gauge and the measurement chamber carefully evaluated. If possible a cold cathode gauge should be used or a gauge specially designed to minimise outgassing.

The gauge head must be mounted out of line of sight of the surfaces being tested and tubulation to the gauge head should have as large a conductance as possible. As is so often the case, such requirements are to some extent contradictory so some compromise is necessary. There is not a lot one can do to eliminate the effects of gauge pumping. Recent developments using stable field ion emitters as the electron source for a Bayard-Alpert gauge may offer a good compromise for measuring low outgassing rates. The temperature effect is eliminated and gauge pumping is relatively low. Energetic electrons and X-rays are still produced however.

The most troublesome effect is gauge pumping. In many cases it is relatively easy to guess what the minimum outgassing rate to be expected from a sample might be. The surface area of the sample should then be such that the expected gas load generated is significantly greater than the gas load pumped by the measuring gauge. If this is not the case, then the measurement is not meaningful.

In some cases, where the measured pressures are within it's operating range, a suitable gauge is the spinning rotor gauge. Outgassing form this type of gauge is simply that of its rather small internal surface area and there is no pumping effect. It is best suited to rate of rise measurements.

Because not all sources of error can be eliminated, rate-of-rise measurements, for example, can only set a lower bound for the outgassing rate. It may be possible to estimate an upper bound by guessing the gauge pumping speed. If these two values are reasonably close, then the result may be meaningful. This assessment cannot be done unless a real effect, i.e. a measurable pressure rise, is obtained.

It will be apparent that in the rate of rise method, sufficient time must be allowed for the pressure to rise significantly. Initially after isolating the main pump, there will be a period when the system is not in a steady state as the various gas sources and sinks settle down, but in a well-behaved and well designed experiment, this should be relatively short and for a constant outgassing rate a log-log plot of pressure against time should yield a straight line of positive slope. For outgassing rates close to the pumping speed of the system sensible measurement times may well be of the order of hours, not minutes.

17.5.3.2 Time Zero for outgassing

As noted earlier, the outgassing rate measured is a function of the time that a surface has been exposed to vacuum (i.e. has been pumped), and an idealised characteristic is shown in Figure 17.5.3-1 (Note that no great significance should be attached to the actual values of outgassing rate shown in the figure.) It is clear that the measured value of outgassing will depend on when the measurement is made.

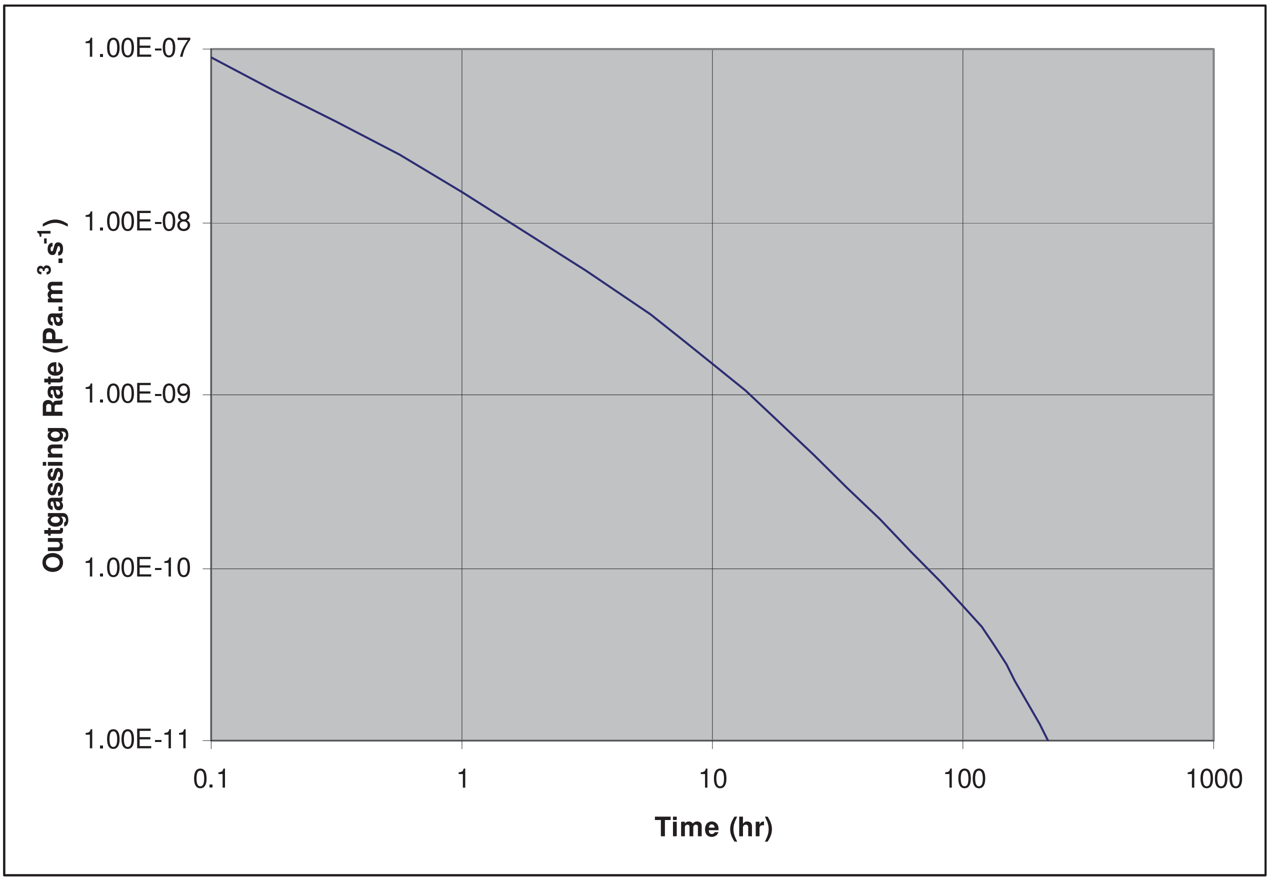


Figure 17.5.3-1 Idealised outgassing rate of a surface as a function of exposure time to vacuum

Because of the above, in order to achieve some sort of comparability, outgassing rates are often quoted as either 1 hour, 10 hour, 100 hour or “long term” rates. These are rates measured at these time intervals after time = 0. One matter of particular difficulty is determining just when time = 0 actually is. In a pump down, for example, when is the pressure determined by outgassing rather than removal of gas from the volume?

Since this set of procedures is intended for use in a quality assurance environment, this difficulty can be circumvented by careful specification of what should be done in individual cases.

17.5.4 Stating Outgassing Requirements

17.5.4.1 Vessel or Component Acceptance Tests as normally used in a Vacuum Quality Assurance Series of Procedures

In the specification for the vacuum item, if an outgassing test is required, then the specification should state the requirement in one of three alternative forms. These are as follows:

"*x* hours after the end of the procedure *y*, the specific outgassing rate shall be less than a value of *z* $Pa.m^3.sec^{-1}.m^{-2}$ using the measurement techniques described in the ITER Vacuum Handbook Appendix 17."

or

"m hours after the end of the procedure *n*, the total outgassing rate shall be less than a value of *r* $Pa.m^3.sec^{-1}$ using the measurement techniques described in the ITER Vacuum Handbook Appendix 17."

or

"k hours after the end of procedure g, the steady state specific outgassing rate shall be less than a value of *s* $Pa.m^3.sec^{-1}.m^{-2}$ using the measurement techniques described in the ITER Vacuum Handbook Appendix 17".

The steady state outgassing rate is defined at as the outgassing rate at the time when the rate of change of measured outgassing rate is less that 5 % over an elapsed time of 120 minutes.

That is to say:

$$\frac{q_t - q_{(t+120)}}{q_{(t+120)}} \leq 0.05$$

Where $q_{(t)}$ = specific outgassing rate at time *t* (minutes).

Procedures y, n and g will have been defined earlier in the specification and, unless there are good reasons otherwise, x and m will normally be 10 hours.

17.5.4.2 Testing items, materials or procedures for acceptability for more general use

Such tests are of a more generic nature and so some standardisation of results is necessary. There are two particular cases to be considered (a) where there is no form of processing and (b) where there is a processing stage included e.g. a bake.

Where no processing is involved outgassing measurements should be taken at intervals of 1 hour, 10 hours and (optionally) 100 hours after the start of pump down of the vacuum item. It should be noted that such results may be influenced by the pumping speed applied, so this should always be quoted.

Following a process stage, outgassing measurements should be taken at intervals of 1 hour, 10 hours and (optionally) 100 hours after the end of the process. In the case of a bakeout, the end of the process may be defined as when the system returns to room temperature, unless a particular specification states otherwise. It should be noted that results may be influenced by the pumping speed applied, so this should always be quoted.

17.6 Procedures

17.6.1 General

17.6.1.1 Start Time

In the following procedures, it is assumed that the appropriate starting time for measurements has been set according to the considerations discussed earlier. This is referred to below simply as the start time.

17.6.1.2 Pump Set Conditioning

Before the start time, all pump sets will have been conditioned and proved to be leak tight and clean.

17.6.1.3 Vacuum Vessel Outgassing Measurements

The vessel should be assembled into the appropriate apparatus using flanges and gaskets appropriate to the vacuum regime for which the vessel is designed.

In the case of the measurement of outgassing of a vacuum chamber whilst being pumped from atmospheric pressure, a preliminary pump down should be made and the vessel and its appendages proved leak tight. Following this leak test, the vessel should be vented to either clean dry nitrogen (dew point < $-50^{o}C$) or normal atmosphere as specified in the test documentation. If nothing is so specified, then clean dry nitrogen is recommended.

In the (usually rare) circumstances of an outgassing measurement being required for a vessel in “as received” condition, then leak tests should be carried prior to the completion of the outgassing measurements to ensure that the results are not dominated by any leak being present. Clearly, great care must be taken during assembly to minimise the possibility of such leaks. If such a leak is detected, the originator of the request for test must be consulted before any further work is carried out.

17.6.1.4 Vacuum Component or Sample Outgassing Measurements

The component or sample should be inserted into a vacuum chamber for which the outgassing characteristics have been established in a blank run immediately prior to the tests.

For a meaningful measurement of outgassing, the expected outgassing load of the component or sample must be at least 10 times greater than that of the empty chamber.

The procedure to be followed will be the same as that for a vessel as specified in the request for test.

17.6.2 Rate of Pressure Rise Method

17.6.2.1 Equipment

The equipment used will typically take the form shown in Figure 17.6.2-1.

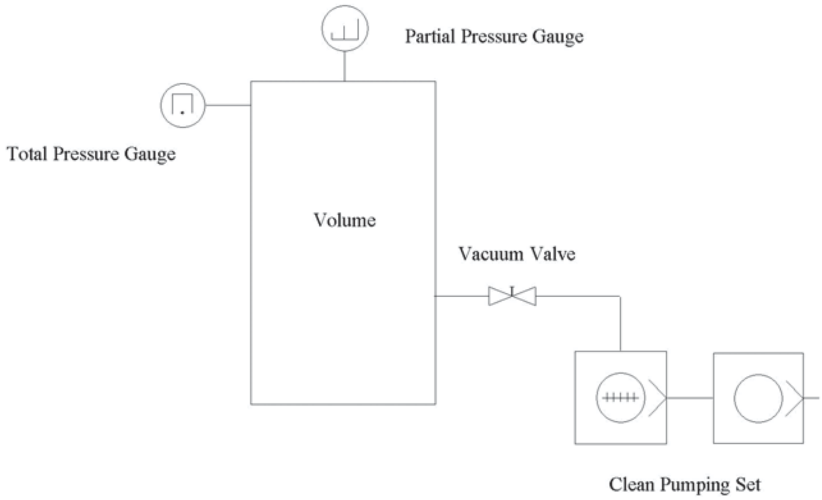


Figure 17.6.2-1 of outgassing - pressure rise technique.

The choice of pumping set and the type of total pressure gauge to be used will depend on the maximum total pressure expected during the measurements. The gauge is shown as a cold cathode device, but need not be. There are distinct advantages to using a Spinning Rotor Gauge if the pressures measured lie within its range of operation.

The use of a partial pressure gauge will normally mean that the total pressure should not normally rise above about 10^{-3} Pa during measurements unless some sort of sampling stage is used. The pump set should be chosen so that the volume may be evacuated through the valve to a reasonable pressure in a reasonable time. What “reasonable” means must be assessed on a case-by-case basis, but must be short compared to the time at which the first outgassing result is required.

17.6.2.2 Procedure

With the pump set under vacuum at or close to its ultimate, the vacuum valve is opened carefully and the volume evacuated to its base pressure or for the time at which an outgassing measurement is required, whichever is less.

Any processes specified (e.g. a bake cycle) are completed.

If the pressure achieved is below about 10^{-6} Pa, then any hot filament measuring devices should be thoroughly outgassed and the outgassing products pumped away.

The vacuum valve is closed and the pressure or partial pressure of the species of interest recorded at frequent intervals until a pressure rise of at least one decade is obtained. The times of recording each pressure should be noted. The use of a continuous record as on a chart recorder or a data logger is to be preferred.

If outgassing measurements are required at a number of values of pumping time, then the valve should be opened and the process repeated at the appropriate time.

The outgassing rate(s) are then calculated using the above formula.

17.6.3 Dynamic Flow Method

Note that only the two-gauge method is described here.

17.6.3.1 Equipment

The equipment used will typically take either of the forms shown in Figure 17.6.3-1. That on the left is more suited to measurements on vessels or assemblies, that on the right to coupon samples.

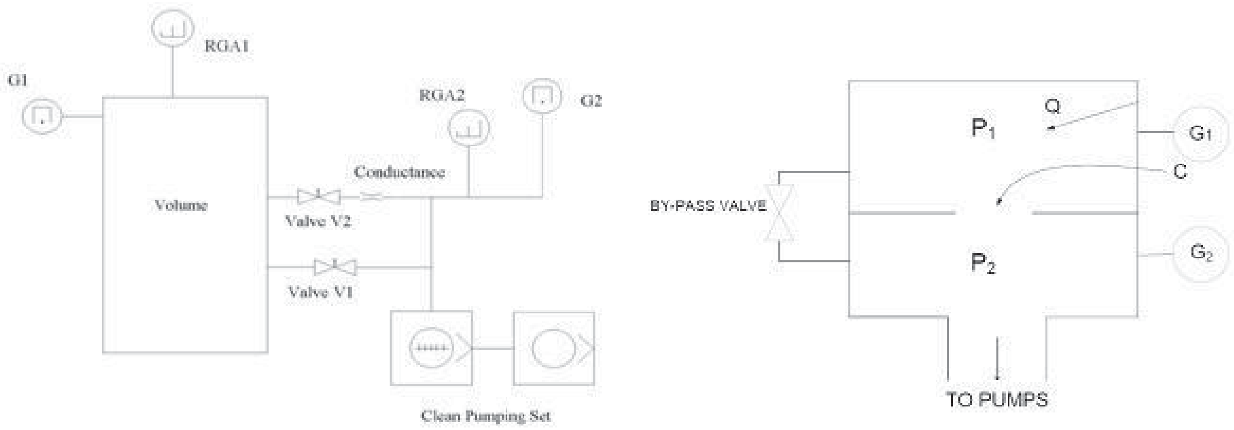


Figure 17.6.3-1 Equipment for the measurement of outgassing - dynamic flow technique.

The choice of pumping set and the types of total pressure gauges to be used will depend on the maximum total pressure expected during the measurements. The gauges shown are cold cathode devices, but need not be. The use of partial pressure gauges will normally mean that the total pressure should not normally rise above about 10^{-3} Pa at the gauge during measurements, unless some sort of sampling stage is used. The pump set should be chosen so that the volume may be evacuated to a reasonable pressure in a reasonable time. What "reasonable" means must be assessed on a case-by-case basis, but must be short compared to the time at which the first outgassing result is required.

The value of the conductance should be chosen so that a reasonable pressure differential is obtained.

17.6.3.2 Procedures

17.6.3.2.1 Outgassing measurements on a vessel

Here, the equipment shown on the left of Figure 17.6.3-1is the more suitable.

With the pump set under vacuum at or near its ultimate, vacuum valves V1 and V2 are opened carefully and the volume evacuated to its base pressure or for the time at which an outgassing measurement is required, whichever is less.

Any processes specified (e.g. a bake cycle) are completed.

If the pressure achieved is below about 10^{-6} Pa, then any hot filament measuring devices should be thoroughly outgassed and the outgassing products pumped away.

The vacuum valve V1 is closed and the pressures on either side of the conductance monitored until the values have stabilised over a period of about 15 minutes.

If quasi-continuous measurements of outgassing as a function of time are required, then sets of readings shall be taken at appropriate time intervals.

If outgassing measurements are required at a number of discrete values of pumping time, then the valve V1 is opened after a set of readings is complete and closed shortly before the next set is due, allowing sufficient time for the system to stabilise before each set of readings.

The outgassing rate(s) are then be calculated using the formula above.

17.6.3.2.2 Outgassing measurements on coupon samples

In this case, the equipment shown on the right of Figure 17.6.3-1 is the more suitable.

To be meaningful, the following procedure should be carried out first with the upper (test) chamber empty, then vented to clean, dry (dew point <-50°C) nitrogen and the sample inserted. The sequence is then repeated, the sample removed and, ideally, a final sequence carried out on the empty system. The two blank (i.e. empty chamber) runs should give consistent results. The measured pressure in the upper chamber with the sample inserted must be significantly higher than the blank runs if a meaningful value of outgassing is to be calculated.

With the pump set under vacuum at or near its ultimate, the valve to the pumping set (not shown) and the by-pass valve are opened and the volume evacuated to its base pressure or for the time at which an outgassing measurement is required, whichever is less. The by-pass valve should be of sufficient size that adequate pumping speed is achieved above the conductance.

Any processes specified (e.g. a bake cycle) are completed.

If the pressure achieved is below about 10^{-6} Pa, then any hot filament measuring devices should be thoroughly outgassed and the outgassing products pumped away.

The by-pass valve should be closed and the pressures on either side of the conductance monitored until the values have stabilised over a period of about 15 minutes.

If quasi-continuous measurements of outgassing as a function of time are required, then sets of readings should be taken at appropriate time intervals.

If outgassing measurements are required at a number of discrete values of pumping time, then the by-pass valve should be opened after a set of readings is complete and closed shortly before the next set is due, allowing sufficient time for the system to stabilise before each set of readings.

The outgassing rate(s) are then calculated using the formula above.

17.7 Presentation of Results

On completion of outgassing tests a report should be issued recording:

- full details of the apparatus used (including volumes where appropriate)
- copies of calibration certificates for all gauges used
- details of the calculation of the value of the conductance (where appropriate)
- results of system leak tests
- proof of cleanliness of the pump set
- tabulated measurements of pressure with times at which readings were taken or copies of recorder traces as appropriate
- tabulated values of calculated total and partial outgassing rates as appropriate

17.8 Derivation of the ITER Outgassing Rate Requirements

The limits of outgassing rates for materials for use in ITER vacuum systems are given Table 17.8-1, which is Table 5-1 of the ITER Vacuum Handbook and the values are therefore mandatory.

These limits have been produced by taking into account the total surface area expected, available pumping speed, the desired pressure, and post assembly conditioning time, with due consideration of what is reasonably achievable.

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

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

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

+ For CFC, refer to the ITER Vacuum Handbook Section 26.7

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

Table 17.8-1 – Outgassing rates pertaining to VQC

17.8.1 Vacuum Vessel

In calculating the maximum outgassing rates specified for the Vacuum Vessel (VQC 1) the following assumptions and calculations have been used.

The approximate total surface area of vacuum vessel is 20000 m^2 and is calculated as the sum of the following:

- vacuum vessel+ports ≈ 3000 m^2
- port plugs ≈ 4000 m^2
- blankets ≈ 5000 m^2
- divertor ≈ 2000 m^2
- piping ≈ 1000 m^2
- in-vessel cabling ≈ 2500 m^2
- fixtures and fittings ≈ 2500 m^2

The ITER Project Integration Document (PID) specifies the vacuum vessel base pressure to be < 10^{-5} Pa for hydrogen and <10^{-7} Pa for impurities prior to ITER operations at the operating temperature of 100 °C.

Using a conservative estimate of the vacuum vessel pumping speed of 20 $m^3.s^{-1}$ yields a derived maximum hydrogen throughput of 2 x 10^{-4} $Pa.m^3.s^{-1}$

Thus, the maximum allowable outgassing rate of hydrogen prior to pulsing is calculated as,

$$q = \frac{Q}{A} = \frac{2.0x10^{-4}}{20000} = 1x10^{-8}\,\mathrm{Pa.m^3.s^{-1}.m^{-2}}$$

It is expected that a factor 10 decrease in the outgassing rate for hydrogen can be achieved by baking the vessel to 200 °C and hence the maximum outgassing rates for VQC 1 components has been defined in Table 17.8-1 as:

- $1x10^{-7}$ $Pa.m^3.s^{-1}.m^{-2}$ for hydrogen at 100 °C
- $1x10^{-9}$ $Pa.m^3.s^{-1}.m^{-2}$ for impurities at 100 °C

17.8.2 Cryostat

The outgassing requirement for VQC2 is derived from the need to manage three areas:-

1) To be able to pump down the cryostat initially in a reasonable time with limited pumping and conditioning capacity and to achieve a level of vacuum suitable for an insulation vacuum.
2) To avoid poisoning of the activated charcoal in the reference cryostat cryo-pumps with heavy hydrocarbons.
3) To ensure that over time, the build up impurities on the cold thermal shields does not adversely affect their emissivity and hence the heat load on the superconducting coils and the cryo-plant.

The specified outgasing limit for VQC 2 excludes water because it is considered that it will not be possible during the cryostat construction to avoid surfaces becoming water contaminated.

It is the case that for item 3 above water ice is likely to be the dominant issue. However other gasses which are condensable at 80K can also present a similar problem and these can be more difficult to condition once the cryostat is complete. To quantify an acceptable outgassing rate, water is used below, as there is a better database available for the relevant emissivity change.

In calculating the maximum outgassing rates specified for the ITER cryostat (VQC 2) the following assumptions and calculations have been used.

Source[27]	A (m^2)[27]	qH_2O($Pa.m^3.s^{-1}.m^{-2}$)+	QH_2O_{tot} ($Pa.m^3.s^{-1}$)	Pressure in cryostat (H_20,Pa)‡
Metallic surface	2.5×10^4	1×10^{-7}	2.5×10^{-3}	5.0×10^{-5}
Vacuum facing epoxy	1.3×10^3	1×10^{-5}	1.3×10^{-2}	2.6×10^{-4}
‡Assumes 50 m^3s^{-1} H_2O cryostat pumping speed.[27] +Values from Table 17.8-1 & equation Section 17.8.1 after 100 hours.				

Table 17.8-2- Assumed cryostat areas and calculated H_2O outgassing rates

Using the figures from Table 17.8-1 the calculated partial pressure of water vapour in the cryostat prior to the cool down of the magnets is approximately 2.6×10^{-4} Pa.

The 2007 ITER PID value for partial pressure of H_2O before cool-down is quoted as ≤ 2×10^{-7} Pa. This figure is considered to be unachievable and the basis can not be found.

Assuming the cryostat thermal shield does not cool uniformly, residual water will initially condense on cold spots covering an estimated 10% of the thermal shield surface area with an equivalent thickness of 0.02 monolayers.

After baking the vacuum vessel and cooling the magnet structures and thermal shields, the remaining source of condensable water will be from the cryostat walls and internal components which are at ambient (or elevated) temperature, having an estimated total surface area of 3000 m^2.

Assuming a steady state outgassing rate of 1×10^{-7} (H_2O) $Pa.m^3.s^{-1}.m^{-2}$, the load to the thermal shield remains unchanged for 3 years. Over approximately 8 years a coverage of H_2O of 2000 monolayers (1μ thickness) will form on the cryostat-facing thermal shield. The change in emissivity of the thermal shield due to formation of this water layer results in a calculated increase in heat load to the cryo-plant of approximately 50% [28].

The ice crystal size significantly affects the infra-red absorption and consequently the emissivity of a panel: the larger the crystals, the higher is the emissivity; therefore the morphology of the ice formation significantly effects the change in emissivity.

In this estimation, it is assumed that the water forms a uniform layer of ice over the thermal shield with the coverage rate constant over the time period considered. If the coverage rate is not constant, and it is assumed water condenses on the thermal shield in batches as "snow", the time taken for a similar change in emissivity decreases to approximately 3 years.

The effect on emissivity due to the build up of ice can be seen in Figure 17.8.2-1[28] and the effect on the additional load to the cryo-plant due to water condensing on the cryostat-facing thermal shield is shown in Figure 17.8.2-2[28].

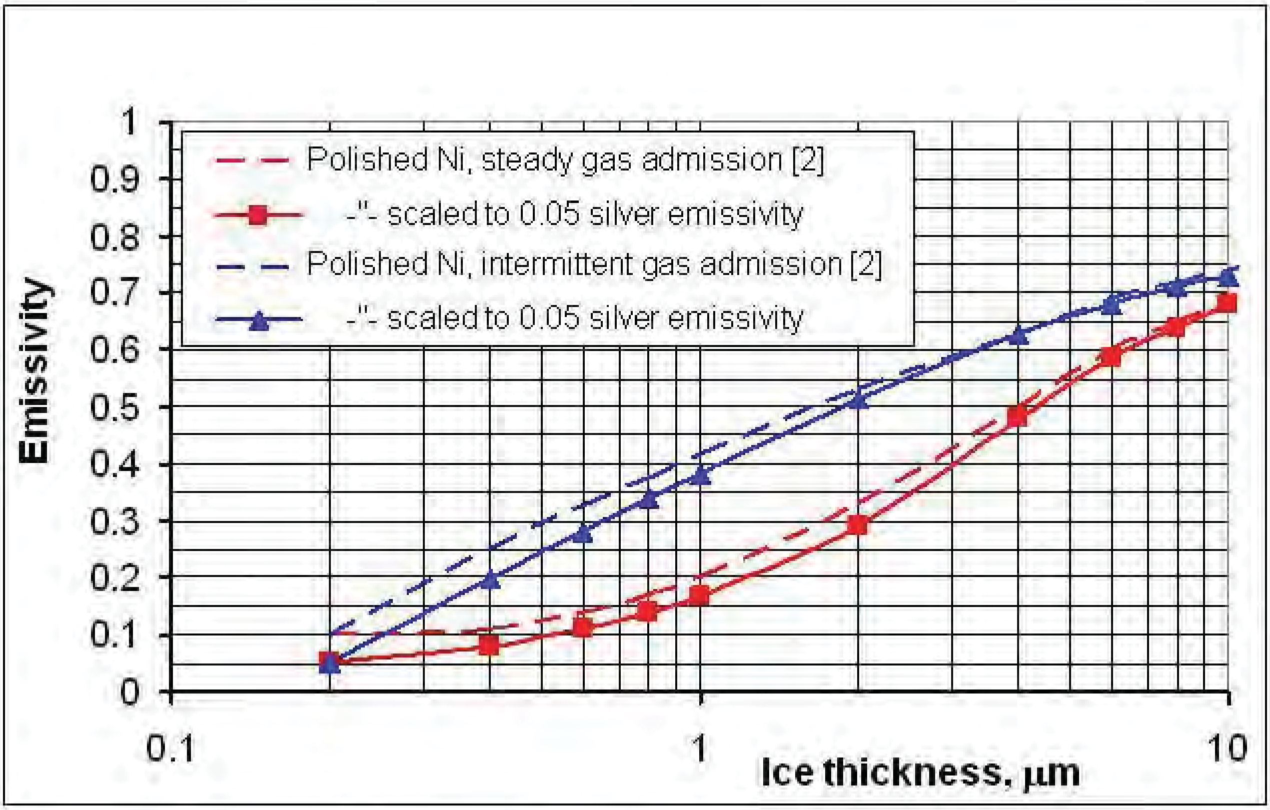


Figure 17.8.2-1 Effect on emissivity due to ice layer formation

It is considered that the effect on the emissivity of the cryostat thermal shields will be greater due the condensation of hydrocarbons outgassing from the cryostat internal components. Hence the maximum outgassing rate from cryostat vacuum-facing surfaces is defined in Table 17.8-1 to be1 x 10^{-7} Pa.m^3.s^{-1}.m^{-2} (excluding water and hydrogen) at ambient temperature

In order to reduce the steady state outgassing rate of water from the cryostat internal surfaces, a method of purging the cryostat with dry nitrogen prior to cool down of the magnet structures and thermal shields is being studied. The order in which the cryostat cryogenic surfaces are cooled, and the resulting effect on the emissivity of the cryostat cold surfaces due to condensed gas, is also to be studied. (See [28] for further recommendations)

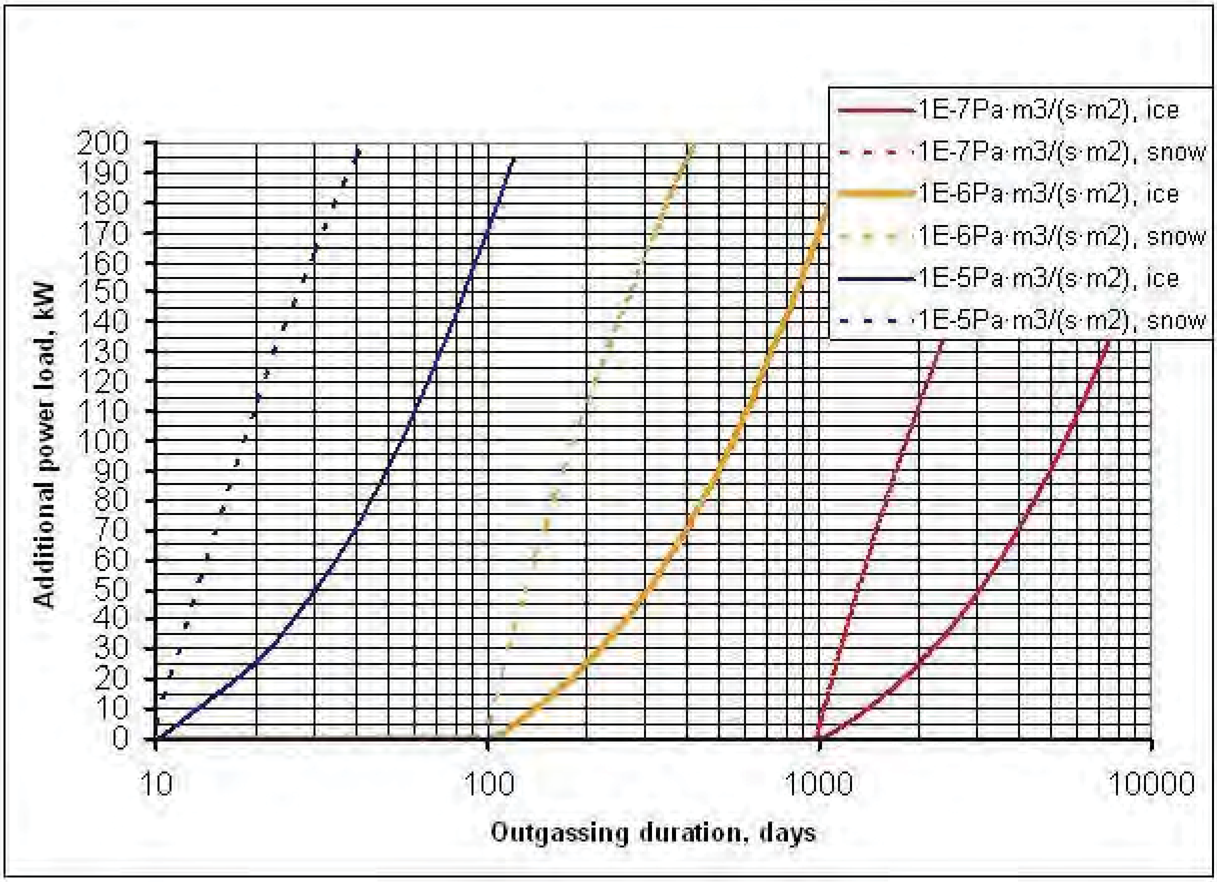


Figure 17.8.2-2 Additional power load on thermal shield coolant due to H_2O Outgassing

17.9 Outgassing Rates Review

The purpose of this section of the Appendix is to outline the methodology used in the assessment of outgassing rates from published data and to establish the relationship between common parameters which influence material outgassing rates

17.9.1 Material thermal outgassing

Thermal outgassing from material surfaces is time and temperature dependant and it can be shown that the measured outgassing rate from a metallic surface will increase by factor of about 10 by increasing the sample temperature from ambient to 100 ºC, and increases by a further decade by raising the sample temperature from100 to 250 ºC.[5]

The medium term (1 to 100h) outgassing from a surface can be described by a power law of the form:

$$Q = Q_0 . t^{-\alpha}$$

Where, α (the outgassing decay index) is typically near unity for metallic surfaces and 0.5 for epoxies and *t* is the time in hours [21].

The outgassing rate of a surface is also dependant on the surface condition. Factors affecting the outgassing rate include:

- chemical composition
- the presence of oxide layer's
- surface finishing
- cleaning and other processes

References to published data, listing outgassing rates for materials after varying surface treatments, are to be found in Section 17.10.

While a large record of outgassing rates can be found in literature for vacuum compatible materials comparisons of the reported data are difficult as, in many cases, for the same material differing surface treatments and measurement techniques are reported, some important factors may not be reported at all.

17.9.2 Unbaked Stainless Steel

The rate of outgassing from unbaked stainless steel is dependant of the process to which the stainless steel surface has been subjected. Outgassing rates gathered from literature (see Section 17.10) for Stainless steel after surface treatments are summarised in Table 17.9-1.

SST treatment	q_{tot} (Pa.m^3.s^{-1}.m^{-2}) at 1h, 20ºC
As received/fresh	1×10^{-4}
Degreased	2×10^{-6}
Surface finished (machined)	2×10^{-7}

Table 17.9-1 Outgassing rates of stainless steel after surface processing

Generally water is the dominant species outgassed from unbaked stainless steel and will evolve at a rate dependant on the elapsed pumping time of the surface. Generally, for unbaked stainless steel surfaces, water will remain the dominant outgassing species at pumping times in excess of 100 h.

17.9.3 Baked Stainless Steel

Baking at 150 ºC for a minimum of 24 h can reduce the total outgassing rate by a factor of 100 as water is desorbed from the metal surface. After this time the predominant outgassing species from clean stainless steel is hydrogen [5]. A reduction in the hydrogen outgassing rate can be achieved by vacuum firing or air baking the material.

After baking, stainless steel will generally exhibit outgassing rates between 10^{-9} and 10^{-10} Pa.m^3.s^{-1}.m^{-2} (see Section 17.10.1)

17.9.4 Organic Material

For organic materials (epoxies etc), the method of weight loss measurement is usually used for the determination of outgassing rates with the outgassing rate quoted as a percentage of total weight loss, or gram/s.

Using the formula below the outgassing rate can be calculated from the total mass loss measurement

$$q = \frac{dM}{dt} \cdot \frac{RT}{M} \cdot 10^3$$

where:

q is the outgassing rate in Pa.m^3.s^{-1}.m^{-2}

R is the universal gas constant (83.14 mbar.l.mol^{-1}.K^{-1})

dM/dt is the mass loss per unit time (g.s^{-1})

T is the sample temperature (K)

M is the molecular mass of the outgassing species

Using the above formula it can be shown that for water outgassing from a surface at a rate of 1µg.s^{-1} the specific outgassing rate near room temperature will be approximately 1 Pa.m^3.s^{-1}.m^{-2}.

The outgassing rate of organic materials is also dependent on the fabrication process (curing temperature, chemical hardener, vacuum, inert gas process, etc.). There is a lack of published data on outgassing rates for material of the same composition which has undergone different fabrication processes, making comparisons difficult. Hence qualification of new organic materials for use on ITER will have to be performed using experimental data.

An analysis of weight loss measurements on epoxies shows that the ratio of water outgassing to impurity outgassing is approximately 100 to 1, so, assuming a well controlled fabrication process, a low outgassing epoxy should outgas at a rate in the range of 10^{-7} Pa.m^3.s^{-1}.m^{-2} (excluding water) after 100 h baking (see Section 17.10.2).

17.10 Outgassing Rates - Published Data

Outgassing rates quoted in referenced publications are summarized in the tables below.

17.10.1 Stainless Steel

Published data on the outgassing rates of stainless steel following various surface treatments is given in Table 17.10-1.

Treatment	Total outgassing rate ($Pa.m^3.s^{-1}.m^{-2}$)	Time meas. (hours)	Reference
None	$2x10^{-4}$	1h	2
None	$2x10^{-5}$	10h	2
Polished & vapor degreased	$1.4x10^{-6}$	10h	2
None	$1.1x10^{-7}$	100h	2
Degrease + water rinse	$4.0x10^{-8}$	40h	2
Degrease + water rinse, baked in vacuum 150ºC for 12h	$4.0x10^{-9}$	5h after bakeout	2
Baked 24h @ 200°C	$9.3x10^{-10}$	100h	2
Unbaked	$2x10^{-7}$	10h	1
Baked (150º C,24h)	$2x10^{-9}$		1
Std cleaning	10^{-6}	1h	3
Baked	10^{-8}	1h	3
Untreated	$7x10^{-5}$		4
Degreased	$1x10^{-6}$		4
Baked	$3x10^{-10}$		4
unbaked	$9x10^{-7}$	20h	5
Electrochemical buffing	$5x10^{-8}$	50h	8
Electrochemical buffing followed by baking(215 °C,23h) and air (10days)	$1x10^{-8}$	50h	8
Electropolished, baked, air oxidation	$1x10^{-11}$		9
Air exposure/baking cycles	$1x10^{-10}$		10
UT cleaning + bake 250C,24h	$3x10^{-10}$		12
Various treatments	$2x10^{-6}$	100h	13
Annealing+bake	$2x10^{-11}$		14
Air firing	$3x10^{-11}$		15
Pre-baking+baking	$4x10^{-10}$		16
Chemical cleaning	$4x10^{-9}$		17
	$1x10^{-6}$	1h	18
Cleaned With bakeout	$8x10^{-7}$ $2x10^{-9}$		19
	$2x10^{-6}$	4h	20

Table 17.10-1 Outgassing rates for stainless steel – published data

17.10.2 Epoxies

Published data on the outgassing rates of various epoxies and resins is given in Table 17.10-2

Material	Outgassing rate (Pa.m3.s-1.m-2)	Outgassing rate % Total Mass Loss (TML)	Reference

Material	Outgassing rate (Pa.m3.s-1.m-2)	Outgassing rate % Total Mass Loss (TML)	Reference
RF4000 EV Roberts (baked)	$5x10^{-6}$ (10h)		22
ERL4221 union carbide (baked)	$1x10^{-5}$(10h)		
CY179 Ciba Geigy (baked)	$3x10^{-6}$(10h)		
1138 Ciba-Geigy (baked)	$2x10^{-6}$(10h)		
828 Shell chemical (baked)	$1x10^{-5}$(10h)		
DGEBA, + ≠ materials	10^{-3} -10^{-4}(10h)		23
Stycast	$4x10^{-5}$ (72h)	0.87	24
Redux 312UL	$7x10^{-6}$(72h)	0.40	25
Ablebond Ablestik		0.2	ESA database
Araldite resin	10^{-3}-10^{-4}(10h)		1
Polymers	10^{-5}(10h)		26

Table 17.10-2 Outgassing rates for epoxies and resins – published data

17.11 References

[1]: P Chiggiato, Outgassing, CAS 2006

[2] M Wong, review of outgassing rates, Mar 2002 http://home.fnal.gov/~mlwong/outgas_rev.htm#clean

[3] P Monneau, SDMS, Le dégazage, Dec 1992

[4] VARIAN, UHV course

[5] JH Craig, JVSTA vol. 18(3), Apr 1981

[6] HY Shin, Vacuum vol. 47(6-8), 1996

[7] M Suemitsu, JVSTA vol. 13(3), May 1992

[8] Y Saito, vacuum 73 (2004)

[9] K Okada, Vacuum/vol. 47/1996

[10] K Okada, JVSTA vol. 5(5), Oct 1987

[11] JP Bacher, CERN, JVSTA vol. 21(1), Jan 2003

[12] JD Herbert,JVSTA vol 12(4), Jul 1994

[13] HF Dylla, JVSTA vol 11(5), Sep 1993

[14] Y Ishikawa, vacuum 69(2003)

[15] V Brisson, Vacuum 60(2001)

[16] Y Ishikawa, JVSTA vol 9(2), Mar 1991

[17] KJ Middleman, Vacuum 81(2007)

[18] A Roth, vacuum technology, third edition

[19] JM Lafferty, vacuum science and technology

[20] N Harris, modern vacuum practice

[21] M Li and HF Dylla, JSTVA vol 12(4), Jul/Aug 1994

[22] S Rosenblum, JSTVA vol 4(1),Jan/Feb 1886

[23]S Muralithar, Triumph report, Dec 1986

[24] OSI report, Nov 2002

[25] OSI report, Oct 2002

[26] A Berman ,vacuum calculations

[27]M Wykes et .al. "Design Status of the ITER cryostat High Vacuum Pumping System" Proceedings SOFT 24

[28] A Antipenkov Memo "Thermoshield Icing " IDM Ref. 2E96YC

IDM UID
2F2PYS

VERSION CREATED ON / VERSION / STATUS
07 Feb 2011 / 2.0 / Approved

EXTERNAL REFERENCE / VERSION

Guideline (not under Configuration Control)

Appendix 18 Vacuum Reliability Data

Source document for reference

Approval Process			
	Name	*Action*	*Affiliation*
Author	**Worth L.**	**07 Feb 2011:signed**	**IO/DG/COO/PED/FCED/VS**
Co-Authors			
Reviewers	**Pearce R.**	**29 Mar 2011:recommended**	**IO/DG/COO/PED/FCED/VS**
Approver	**Kim Y.- H.**	**05 May 2011:approved**	
Document Security: Internal Use *RO: Chiocchio Stefano*			
Read Access	**GG: MAC Members and Experts, GG: STAC Members & Experts, AD: ITER, AD: External Collaborators, AD: IO_Director-General, AD: EMAB, AD: Auditors, AD: ITER Management Assessor, project administrator, RO, LG: [CCS] CCS-All for Ext AM, LG: [CCS] CCS-Section Leaders, LG: [CCS] JACOBS, LG: [CCS] CCS-Doc Co...**		

Change Log			
Appendix 18 Vacuum Reliability Data (2F2PYS)			
Version	***Latest Status***	***Issue Date***	***Description of Change***
v1.0	In Work	27 Aug 2008	
v1.1	In Work	13 Dec 2010	New document created
v2.0	Approved	07 Feb 2011	New data added

ITER Vacuum Handbook
Appendix 18

Vacuum component reliability data

	Name	Affiliation
Author/Editor	Liam Worth	Vacuum Group - CEP
Vacuum Responsible Officer	Robert Pearce	Vacuum Group - CEP

CONTENTS

18 Vacuum component reliability data

18.1 Scope

This document is a summary compilation of reliability data of vacuum components culled from a variety of sources (See Section 18.2). All failure rate data quoted is average value and is presented as frequency per annum. All mtbf (mean time before failure) values are in years.

By the very nature of such data this summary cannot be fully comprehensive, given the large variety of vacuum components and materials which are available from a diverse number of manufacturers. In addition, although there is a vast quantity of components in use around the world, there is little systematic gathering of data on failure modes and failure rates. One assumes that individual manufacturers collect such data for their own components (and maybe that of their competitors) but little is published and the remainder is generally inaccessible to users.

Anecdotal data, based mainly on experience in the world of accelerators, suggests that an ordered listing of vacuum component failures causing leaks would look something like (worst to best): -

- damaged or improperly made demountable vacuum seals
- edge-welded bellows leaks
- valve seat leaks
- ceramic or glass component shock damage
- ceramic or glass to metal seal failure (corrosion or otherwise)
- brazed coolant feedthrough seal corrosion
- hydroformed or rolled bellows failure
- weld leaks
- metal porosity.

It is difficult to draw systematic conclusions from the data presented, perhaps casting some doubt on its statistical significance. It is important when making any assessment of such data to ensure that one is comparing like for like. All data quoted in this appendix is believed to be inherently comparable, coming from the fusion and accelerator communities, where the vacuum atmosphere is relatively non-aggressive, as opposed to the semiconductor industry for example, where chemical corrosion is a major problem.

18.2 Source data

Title	Author	Date	Reference	Cited as
Vacuum System Operating Experience Review for Fusion Applications	L.C. Cadwallader	1994	EGG-FSP-11037 ITER/US/93/TE/SA-18	LCC-1
In-Vessel ITER Tubing Failure Rates for Selected Materials and Coolants	T D Marshall and L C	1994	EGG-FSP-10928	TDM

	Cadwallader			
Selected Component Failure rate values from Fusion Safety Assessment Tasks	L.C. Cadwallader	1998	INEEL/EXT-98-00892	LCC-2
Fusion Component Failure Rate Database	T. Pinna	2001	FUS-TN-SA-SE-R-43 http://spx595.frascati.enea.it:8080/homepage.nsf*	TP-1
Collection and analysis of data related to fusion machines	T. Pinna *et al*	2005	Fusion Engineering and Design **75-79** (2005) 1199	TP-2
Failure Rate Estimate for Stainless Steel Piping used in ITER Vacuum System	L.C. Cadwallader	2010		LCC-3
Vacuum Bellows. Vacuum Piping, Cryogenic Break and Copper Joint Failure Rate Estimates for ITER Design Use	L.C. Cadwallader	2010	INL/EXT-10-18973	LCC-4

** Page unavailable in Sept 2010*

In reality, the information in the paper by Pinna (TP-1) – which is a description of the database rather than digested information contained therein – is very limited and repeats that in LCC-2 so is of little additional value in this context. As noted above, the actual database is no longer accessible at the url cited (or indeed the alternative cited in *Fusion Engineering and Design*, **51-52**, November 2000, 579-585).

The data listed in LCC-1 and LCC-2 is derived from a range of operating facilities – fusion machines, accelerators, space simulators and industrial vacuum furnaces. The data in TP-2 derives from experience at JET and TLK. Note that this paper does not cite error factors.

LCC-4 is an attempt to draw together as much relevant data as is available in order to provide a reasonable estimate of the likely reliability of the ITER vacuum system.

18.3 Failure rates for major vacuum components

The following sections provide a digest of the failure rates for major types of vacuum components from the sources cited. The figures will be averages and need to be treated with some care – one would expect there to be some variance between specific models of each type of component, especially when these are available from different manufacturers. This is probably the reason why there is considerable variability in the figures quoted – there is insufficient information cited to clarify this aspect.

For simplicity, values are quoted in two different formats – in terms of failure rates per year and MTBF (mean time before failure) in years. The quoted error factor is a measure of the reliability of the data – the lower the better. This will be related of course in some way to both the number of data points available and their spread. It is not clear how this figure is derived and it is not available for some of the data.

It should be noted that the figures quoted are derived on the assumption that distribution of failures in time follows the "bathtub" curve and that these lie on the part of the curve where failure rates are nearly constant.

18.3.1 Failure rates for vacuum pumps

Type of Pump	Failure mode	Failure rate per year	MTBF (yr)	Error factor	Source
Rough Pumps	Failure to operate	0.13	7.6	1.2	LCC-2
	External leak	$5.0X10^{-3}$	200.0	10	LCC-2
Turbo Pump	Bearing failure	$7.9X10^{-2}$	12.7	3	LCC-1
	Housing Leak	$5.0X10^{-3}$	200.0	10	LCC-1
Cryosorption pump	Housing Leak	$5.0X10^{-3}$	200.0	10	LCC-1
Cryopumps	Failure to operate	$1.8X10^{-2}$	57.1	10	LCC-2
	Leak into vacuum chamber	0.18	5.7	1.7	LCC-2
TSP	Filament o/c	$1.8X10^{-2}$	57.1	1.7	LCC-1
	Feedthrough leak	0.65	1.5	1.4	LCC-1
	Housing Leak	$3.0X10^{-5}$	33333.3	10	LCC-1
NEG (Cartridge)	Failure to operate	$7.9X10^{-3}$	126.8		LCC-1
	Housing Leak	$3.0X10^{-5}$	33333.3	10	LCC-1
Ion Pump	Failure to operate	0.18	5.7	3	LCC-1
	Housing Leak	$3.0X10^{-5}$	33333.3	10	LCC-1
	Feedthrough leak	13	0.8	1.4	LCC-1

18.3.2 Failure rates for vacuum gauges

Type of gauge	Failure mode	Failure rate per year	MTBF (yr)	Error factor	Source
Rough Vacuum Gauges	Failure to operate	0.88	1.1	10	LCC-2
	Leak	$1.0X10^{-3}$	1000.0	3	LCC-2
Pirani gauge	Failure to operate	0.26	3.8	10	LCC-1
	Leak	$6.0X10^{-3}$	166.7	2.2	LCC-1
High Vacuum Gauges	All modes	$6.0X10^{-3}$	166.7	2.2	LCC-2
Penning gauge	All modes	$6.0X10^{-3}$	166.7		LCC-1
BAG	All modes	$6.0X10^{-3}$	166.7	2.2	LCC-1
Not specified	Leak	$2.5X10^{-2}$	39.4		TP-2

18.3.3 Failure rates for vacuum gate valves

Type (where known)	Failure mode	Failure rate per year	MTBF (yr)	Error factor	Source
	Failure to operate	0.88	1.1	2	LCC-1
	Failure to operate	$4.4X10^{+2}$	0.0	2	LCC-2
	Failure to operate	$9.6X10^{-4}$	1037.8		TP-2
	Spurious open or close	$2.6X10^{-2}$	38.1	10	LCC-2
Motorised	Spurious open or close	$4.4X10^{-4}$	2283.1	10	LCC-1
Pneumatic	Spurious open or close	$2.6X10^{-2}$	38.1	10	LCC-1
Solenoid	Spurious open or close	$4.4X10^{-3}$	228.3	10	LCC-1
	Housing Leak	$1.8X10^{-3}$	570.8	10	LCC-1
	Housing Leak	$1.8X10^{-3}$	570.8	10	LCC-2
	Housing Leak	$6.6X10^{-3}$	152.2		TP-2
	Seat leak	$2.6X10^{-2}$	38.1	30	LCC-1
	Seat leak	$2.6X10^{-2}$	38.1	30	LCC-2
	Seat leak	$4.6X10^{-2}$	21.5		TP-2

Vacuum gate valves can have one of two distinct types of actuator for the seal mechanism. The first uses a shaft sliding through a sealing bush or gland. In the second type, the motion is accommodated by means of a bellows, normally an edge welded bellows. Although it is not clear to which type the data in the table refers, it is most likely to be the latter which are more reliable. Bellows leaks are not specifically identified in the data but probably dominate the statistics quoted for housing leaks.

18.3.4 Failure rates for standard fittings

Group	Type	Failure mode	Failure rate per year	MTBF (yr)	Error factor	Source
Metal gasket flange	160-215mm	Leak	$1.0X10^{-3}$	1000.0	3	LCC-1
	295-360mm	Leak	$6.0X10^{-2}$	16.7	3	LCC-1
	>1m	Leak	0.5	2.0	10	LCC-1
	Bolt		$1.8X10^{-4}$	5707.8	10	LCC-1
Window		Leak	$1.2X10^{-2}$	81.5	1.8	LCC-1

18.4 Failure rates for bellows.

Vacuum bellows are used in vacuum systems to facilitate motion, to take up expansion and contraction and to compensate for construction inaccuracies. There are two major families, *edge welded* bellows which are fabricated from stacks of thin annuli welded alternately on the outer and inner diameters, and *formed* bellows which are rolled or moulded from thin seam welded sheet or thin wall drawn tube. Edge welded bellows are very flexible and can accommodate large extensions and contractions, so are useful for long throw linear motions for example, but are relatively fragile. Formed bellows are more rigid, are less flexible, and are less vulnerable.

Available reliability data does not distinguish between failure rates for these two families, but the data appears to be dominated by formed bellows. The failure rates for edge welded bellows will be inherently higher than those for formed bellows. However, because of the different characteristics of these two types of bellows, it is much more likely that edge welded bellows will be used in motion actuators rather than in the relatively static applications for which formed bellows are more suitable. Lifetimes for edge welded bellows will therefore tend to be dominated by duty cycle rather than mtbf. It may be noted that for edge welded stainless steel bellows, manufacturers will typically quote lifetimes of 10,000 cycles.

LCC-4 provides an extensive discussion of bellows failures based almost entirely on data from LEP at CERN, as is that in LCC-1. The TP-2 data derives from JET. The LCC-1 data is derived from 3 bellows failures during a vacuum bake in the early conditioning phase of LEP and are included in the early service leak data in LCC-4. The values of failure rates from CERN are based on assumptions about the time in service of bellows units which do not appear to take into account duty cycles. This however, would not explain the discrepancies in the values.

Failure data is summarised in the table below.

Type	Failure mode	Failure rate per year	MTBF (yr)	Error factor	Source
Metal Bellows	Leak	70.1	0.14	1.6	LCC-1
	Leak	$1.66x10^{-2}$	60.1		TP-2

Early service leak	$7.01x10^{-2}$	14.3	LCC-4
Small leak (10^{-8} Pam^3s^{-1})	$7.0X10^{-4}$	1430	LCC-4
Large leak	$8.8X10^{-5}$	11400	LCC-4

Based on the derived operational data from LEP, LCC-4 calculates anticipated lifetimes for the double bellows configuration anticipated for ITER. The values are, for small leaks, a failure rate of $7x10^{-6}$ per annum (mtbf $1.4x10^5$ yrs) and for large leaks, $8.8x10^{-7}$ and $1.1x10^6$ respectively.

18.5 Failure rates for metallic tubing and pipework

Determining failure rates for metallic tubing and pipework is a very complex business since there are many variables to be taken into account. TDM, LCC-3 and LCC-4 go into this in considerable detail for many of the potential situations relevant for ITER.

For the purposes of the Appendix, we shall note that there are three distinct categories of pipe and tubing – those forming a boundary between atmosphere or other gas and vacuum; those immersed in vacuum and containing water as a coolant; those immersed in vacuum and carrying a cryogenic fluid. In all cases, the inherent reliability of the system will most likely be dominated by joints rather than the metal itself.

The data in TDM, LCC-3 and LCC-4 is derived mainly from fission reactor data with pipes carrying liquid coolant, so will be particularly relevant to water coolant lines in ITER. Values for stainless steel pipe type 304L when scaled to ITER conditions are given below. The reliability of vacuum lines will be dominated by joints – seam welds, joining welds/brazes, etc., and should be comparable to any other vacuum envelope.

	Failure rate per year per m
Schedule 20 pipe	$1.2x10^{-7}$
Schedule 10 pipe	$2.4x10^{-7}$

It may be of interest to note that the failure rates quoted above for vacuum pump housings for ion pumps, TSPs and NEG pumps which are basically simple stainless steel vacuum vessels of characteristic dimension somewhat less than 1 m, are about two orders of magnitude higher. Whilst it is true that the wall thickness will be less than schedule 10, it is difficult to account for this difference if it is statistically significant.

TDM lists data for a number of different materials. It shows copper water cooing tubing to have failure rates rather more than two orders of magnitude worse than for stainless steel type 316L. It may be relevant to comment here that accelerator experience shows enhanced corrosion rates for copper in the presence of X-ray flux.

18.6 Other References

L.C. Cadwallader and T. Pinna*, Progress Toward a Component Failure Rate Data Bank for Magnetic Fusion Safety*

L.C. Cadwallader, *Failure Rate Data Analysis for High Technology Components,* INL/CON-07-12265

These references discuss methodology rather than providing data.

IDM UID
2DMNNR

VERSION CREATED ON / VERSION / STATUS
02 Sep 2009 / 1.4 / Approved

EXTERNAL REFERENCE / VERSION

Guideline (not under Configuration Control)

Appendix 19 Documentation and QA

Approval Process			
	Name	*Action*	*Affiliation*
Author	**Worth L.**	**02 Sep 2009:signed**	**IO/DG/COO/PED/FCED/VS**
Co-Authors			
Reviewers			
Approver	**Pearce R.**	**09 Sep 2009:approved**	**IO/DG/COO/PED/FCED/VS**
Document Security: Internal Use *RO: Chiocchio Stefano*			
Read Access	**GG: MAC Members and Experts, GG: STAC Members & Experts, AD: ITER, AD: External Collaborators, AD: IO_Director-General, AD: EMAB, AD: Auditors, AD: ITER Management Assessor, project administrator, RO, LG: [CCS] CCS-All for Ext AM, LG: [CCS] CCS-Section Leaders, LG: [CCS] JACOBS, LG: [CCS] CCS-Doc Co...**		

Change Log			
Appendix 19 Documentation and QA (2DMNNR)			
Version	***Latest Status***	***Issue Date***	***Description of Change***
v1.0	In Work	27 Aug 2008	
v1.1	In Work	10 Sep 2008	
v1.2	In Work	13 Jan 2009	
v1.3	In Work	13 Jan 2009	
v1.4	Approved	02 Sep 2009	Minor textual changes for consistency with Vacuum Handbook

ITER Vacuum Handbook
Appendix 19

Guide to Documentation and QA for Vacuum components for use on the ITER Project

	Name	Affiliation
Author/Editor	Liam Worth	Vacuum Group - CEP
Vacuum Responsible Officer	Robert Pearce	Vacuum Group - CEP

19 Documentation and Vacuum Quality Assurance

19.1 Scope of this Appendix

This Appendix describes typical documentation which should normally be produced to assure adherence to the Quality Assessment (QA) system for vacuum items for use in the ITER Project.

Suppliers who follow the guidelines contained in this Appendix will provide suitable documentation which will meet the requirements of the ITER Vacuum Handbook. Other forms of documentation which satisfy these requirements may be *accepted*.

This Appendix does not specify a Quality *Control* System for vacuum items for the ITER Project. This will be specified elsewhere to conform to the necessary international standards.

This document does not specify the technical requirements for, or specifications of, any individual vacuum item. Such information will be found in general form elsewhere in the ITER Vacuum Handbook and in detail in the specification and/or drawings issued by ITER for any particular tender or contract.

In any dispute over QA related to vacuum procedures applied to or vacuum performance of any item, the decision of the ITER Vacuum Responsible Officer (RO) will normally be taken as authoratative.

19.2 Areas to which Vacuum QA Applies

- Materials
- Satisfactory procedures for cleaning and processing
- Assessment of cleanliness
- Leak tightness
- Outgassing performance
- Baking

19.3 *Supplier's* QA System

It is to be expected that the *supplier* will have experience in operating a quality assurance system to the relevant national or international standards, e.g. ISO 9001 or equivalent. Evidence of this would normally be supplied with the tender or quotation process.

19.4 Certificates

Except where the ITER Project has issued a specific pro-forma certificate pertaining to any requirement, the *supplier* should use a suitable certificate of the *supplier's* devising. Draft versions of such certificates should be submitted as part of the tender or quotation process to be *accepted* before use. Certification should conform to EN 10204 2.2, 3.1 or 3.2

19.5 Materials Used

19.5.1 Information Normally Required Prior to Manufacture

- The *supplier* should supply typical certificates of chemical analysis for each batch of material called in the specifications and/or drawings, based on the *supplier's* previous experience of such materials. If the *supplier* has no previous experience of using such materials, a statement of this fact should be supplied.
- The *supplier* should normally supply certificates and/or samples of capability of carrying out welding or other jointing techniques called in the specifications and/or drawings for the materials to be used.

19.5.2 Normal Post Manufacture Certification

- The *supplier* should issue a certificate that all materials used conform to the specification and/or drawings, drawing attention to any discrepancies.
- Unless otherwise specified, certificates of chemical analysis of each batch of material used (e.g. ladle or ingot samples) are normally required.
- Forged stainless steels for use on VQC 1A components should be supplied with certificates of inclusion counts conforming to ASTM E-45 method D or equivalent.

19.6 Cleaning and Processing

19.6.1 Information Normally Required Prior to Manufacture

- The *supplier* should provide details of the cleaning processes to be used in the form of a job flow check sheet or diagram, together with a list of the chemicals used.
- The *supplier* should provide details of all equipment to be used for cleaning or processing, including sizes, *supplier* and approximate date of manufacture. Details of all vacuum pumps and gauges which may be used in any process are to be included. Where any equipment cannot meet the requirements of the specification this must be clearly indicated.
- The *supplier* should provide details of any subcontractor to be used for cleaning and/or processing.

19.6.2 Normal Post Manufacture Certification:

- The *supplier* should deliver a certificate for each item supplied showing compliance with the appropriate specification. This will clearly identify the item and record all significant parameters (e.g. time and temperature) of the major stages of the processes applied and all equipment used.
- A non-conformance report should be provided for each item where any deviation from the *accepted* procedures has occurred.

19.7 Assessment of Cleanliness

19.7.1 Information Normally Required Prior to Manufacture

- The *supplier* should provide details of the method or methods to be used to assess cleanliness of the items.
- The *supplier* should provide full details of all equipment to be used for assessing cleanliness including specification, supplier and approximate date of manufacture. Details of all vacuum pumps and gauges to be used in any testing are to be included. Where any equipment cannot meet the requirements of the specification this must be clearly indicated.
- The *supplier* should provide details of any subcontractor to be used for assessing cleanliness.

19.7.2 Normal Post Manufacture Certification

- The *supplier* should deliver a certificate for each item supplied showing compliance with the appropriate specification. This will clearly identify the item and all equipment used. Included will be a record of all significant parameters of the major stages of the procedures used to carry out these tests and calibration certificates for vacuum gauges and gas analysers used. Results of any chemical analyses or residual gas spectra will be supplied in full.
- A non-conformance report should be provided for each item where any deviation from the performance specification has occurred.

19.8 Leak Tightness

19.8.1 Information Normally Required Prior to Manufacture

- The *supplier* should provide details of the method or methods to be used to leak test the items in accordance with the ITER Vacuum Handbook.
- The *supplier* should provide full details of all equipment to be used for leak testing including specification, supplier and approximate date of manufacture. Details of all vacuum pumps and gauges, including dates of calibration, to be used are to be included. Where any equipment cannot meet the requirements of the specification this must be clearly indicated.
- The *supplier* should provide details of any subcontractor to be used for leak testing

19.8.2 Normal Post Manufacture Certification

- The *supplier* should deliver a certificate for each item supplied showing compliance with the appropriate specification. This will clearly identify the item and all equipment used in these tests. Included will be a record of all significant parameters of the major stages of the procedures used and calibration certificates for leak detection equipment and standard leaks used.
- A non-conformance report should be provided for each item where any deviation from the performance specification has occurred.

- The *supplier* should report details of all leaks found during the manufacturing phase and details of remedial action taken to minimise the size of any identified leaks.

19.9 Outgassing Performance

19.9.1 Information Normally Required Prior to Manufacture

- The *supplier* should provide details of the method or methods to be used for measuring outgassing in accordance with the ITER Vacuum handbook Appendix 17, where this is called for in the specification and/or drawings
- The *supplier* should provide full details of all equipment to be used for measuring outgassing including specification, supplier and approximate date of manufacture. Details of all vacuum pumps and gauges, including dates of calibration, to be used are to be included. Where any equipment cannot meet the requirements of the specification this must be clearly indicated.
- The *supplier* should provide details of any subcontractor to be used for measuring outgassing.

19.9.2 Normal Post Manufacture Certification

- The *supplier* should deliver a certificate for each item supplied showing compliance with the appropriate specification. This will clearly identify the item and all equipment used for these measurements. Included will be a record of all significant parameters of the major stages of the procedures used and calibration certificates for vacuum gauges and gas analysers used.
- A non-conformance report should be provided for each item where any deviation from the performance specification has occurred.

19.10 Baking

19.10.1 Information Normally Required Prior to Manufacture

- The *supplier* should provide details of the method or methods to be used for Baking in accordance with the ITER Vacuum Handbook where this is called for in the specification and/or drawings
- The *supplier* should provide full details of all equipment to be used for baking including specification, supplier and approximate date of manufacture. Details of all vacuum pumps and gauges, including dates of calibration, to be used are to be included. Where any equipment cannot meet the requirements of the specification this must be clearly indicated.
- The *supplier* should provide details of any subcontractor to be used for baking.

19.10.2 Normal Post Manufacture Certification

- The *supplier* should deliver a certificate for each item supplied showing compliance with the appropriate specification. This will clearly identify the item and all equipment used for these measurements. Included will be a record of all significant parameters of the major stages of the procedures used and calibration certificates for vacuum gauges and gas analysers used.

- A non-conformance report should be provided for each item where any deviation from the performance specification has occurred.

IDM UID
2F9QWX

VERSION CREATED ON / VERSION / STATUS
27 Aug 2008 / 1.0 / In Work

EXTERNAL REFERENCE / VERSION

Guideline (not under Configuration Control)

Appendix 20 Standard Components

Approval Process			
	Name	*Action*	*Affiliation*
Author	**Pearce R.**		**IO/DG/COO/PED/FCED/VS**
Co-Authors			
Reviewers			
Approver			
Document Security: Internal Use *RO: Chiocchio Stefano*			
Read Access	**GG: MAC Members and Experts, GG: STAC Members & Experts, AD: ITER, AD: External Collaborators, AD: IO_Director-General, AD: EMAB, AD: Auditors, AD: ITER Management Assessor, project administrator, RO, LG: [CCS] CCS-All for Ext AM, LG: [CCS] CCS-Section Leaders, LG: [CCS] JACOBS, LG: [CCS] CCS-Doc Co...**		

Standard Components TBD

Type	Name / type	Applicable to Vacuum Quality Classification							
		1A	1B	2A	2B	3A	3B	4A	4B
Valves Vacuum Fittings	Double bellows VAT series 10	✓	✓	✓	✓	✓	✓	✓	✓
	VCR, *all sizes*	✓	✓	✓	✓	✓	✓	✓	✓

KEY: ✓ = approved for use. × = not approved for use. ✝ = restricted use

Type	Name / type	Applicable to Vacuum Quality Classification							
		1A	1B	2A	2B	3A	3B	4A	4B

KEY: ✓ = approved for use. × = not approved for use. ✝ = restricted use

Type	Name / type	Applicable to Vacuum Quality Classification							
		1A	1B	2A	2B	3A	3B	4A	4B

KEY: ✓ = approved for use. × = not approved for use. ✝ = restricted use

Type	Name / type	Applicable to Vacuum Quality Classification							
		1A	1B	2A	2B	3A	3B	4A	4B

KEY: ✓ = approved for use. ✗ = not approved for use. ✝ = restricted use

Type	Name / type	Applicable to Vacuum Quality Classification							
		1A	1B	2A	2B	3A	3B	4A	4B

KEY: ✓ = approved for use. ✗ = not approved for use. ✝ = restricted use

IDM UID
2F94QX
VERSION CREATED ON / VERSION / STATUS
18 Mar 2011 / 1.2 / Approved
EXTERNAL REFERENCE / VERSION

Baseline Report (not under Configuration Control)

Appendix_21_Glossary_2F94QX

Glossary of vacuum terms relevant to ITER

Approval Process			
	Name	*Action*	*Affiliation*
Author	**Worth L.**	**18 Mar 2011:signed**	**IO/DG/COO/PED/FCED/VS**
Co-Authors			
Reviewers			
Approver	**Pearce R.**	**29 Mar 2011:approved**	**IO/DG/COO/PED/FCED/VS**
Document Security: Internal Use *RO: Chiocchio Stefano*			
Read Access	**GG: MAC Members and Experts, GG: STAC Members & Experts, AD: ITER, AD: External Collaborators, AD: IO_Director-General, AD: EMAB, AD: Auditors, AD: ITER Management Assessor, project administrator, RO, LG: Section Scheduling, AD: OBS - Vacuum Section (VS) - EXT, AD: OBS - Vacuum Section (VS)**		

Change Log			
Appendix_21_Glossary_2F94QX (2F94QX)			
Version	***Latest Status***	***Issue Date***	***Description of Change***
v1.0	In Work	09 Dec 2008	
v1.1	Approved	13 Jan 2009	
v1.2	Approved	18 Mar 2011	definition of seamless added

ITER Vacuum Handbook
Appendix 21

Glossary of vacuum terms relevant to ITER

	Name	Affiliation
Author/Editor	Liam Worth	Vacuum Group - CEP
Vacuum Responsible Officer	Robert Pearce	Vacuum Group - CEP
Reviewed by		
Approved by		

Note that common standard vacuum terms related to gas flow, vacuum pumps or pressure measurement are not included as they may be found in any standard textbook on the subject.

Back-filling	Raising the pressure of a vacuum space by admission of a defined gas.
Baking or bakeout	Heating of a vacuum component to remove adsorbed gas (usually water) from the surface.
Bellows (*incorrectly* bellow)	A section of a vacuum envelope which permits movement of one part of the vacuum envelope with respect to another part.
Blow hole	A surface hole in a material which has solidified from a liquid and which may join onto a void within the material, especially in a weld melt zone or in a braze fill.
Bonding	In this context, the joining of two materials or vacuum items to form a permanent, leak tight joint.
Brazing	A technique for joining two items by filling the interspace between them with another material, usually an alloy, which melts at a temperature lower than that of the items and which wets the surface of each of the items, filling gaps between workpieces by capillary action.
Clean	A vacuum item is clean when it is in a state such that it emits no undesirable species into the vacuum space or does not adversely affect any desired process in the vacuum.
Clean work plan	A documented set of procedures by means of which a vacuum item shall be transformed into a clean state and by means of which it shall be maintained in that state during all subsequent operations or procedures.
Cleaning	The process of transforming a vacuum item from a contaminated state to a clean state.
Coating	Covering the surface of a material with a conformal layer of another material.
Cold welding	A process by which two clean metal surfaces held in physical contact become permanently bonded without the action of heat.
Component	*See* Vacuum component
Contaminant	A substance on the surface or in the bulk of a vacuum item which can interfere with any process intended to be carried out on that item or which can desorb to give an undesirable species in the residual gas of the vacuum.
Cross contamination	Where a contaminant present on the surface or in the bulk of one vacuum item is transferred onto or into another vacuum item.

Cryopumping	Removal of a gas from the vacuum space by condensing it onto a cold surface
Cryosorption	Removal of a gas from the vacuum space by adsorbing it onto a cold porous material e.g. charcoal or zeolite.
Cutting fluid	A fluid used for cooling and/or lubricating a cutting device, e.g. a milling head.
CVD (Chemical vapour deposition)	Deposition of a coating onto a substrate by chemical reaction in or from the gas phase, usually at an elevated temperature.
DA	Domestic Agency
Degassing	Removal of gas dissolved in a material, usually by heating the material to a high temperature in a vacuum.
Desorption	The release of a substance from a surface into the vacuum space. (*Note: the related verb form is desorb*)
Diffusion	In this context, the transmission of gas atoms or molecules from one side of a vacuum barrier to the other by direct migration through the solid or glassy phase or along the grain boundaries of the material.
Diffusion bonding	A technique for joining two items by filling the interspace between them with a material or materials which can diffuse into the surface layers of the host material of each item under the action of heat and/or pressure thereby forming a bond between them.
Dry lubricant	In this context, a solid state material which when deposited between two surfaces in vacuum reduces the coefficient of friction significantly or prevents cold welding. Examples would be MoS_2, WS_2 or WSe_2.
Edge welded bellows	Bellows which are formed from a number of thin annuli by welding around the circumference of alternately the inner and outer diameters of the annuli. Such bellows can provide great flexibility longitudinally and significant flexibility in the transverse direction.
Electrical break	A device which permits two parts of the envelope of a vacuum system to operate at different electrical potentials whilst maintaining gas flow continuity between the two parts of the vacuum envelope.
Explosion bonding	A technique for joining two items, usually in the form of sheet metal, by generating a high pressure at the interface by means of an explosion. There will not normally be any filler material between the items.
Feedthrough	A device by means of which electrical potential or current can cross the boundary of a vacuum space or by means of which a pipe carrying a fluid can cross the boundary of a vacuum space.

Formed bellows	Bellows formed from a thin sheet or cylinder of metal in which convolutions are manufactured by rolling or by hydrostatic pressing against a former. Such bellows allow limited flexibility in any direction.
Friction bonding	A technique for joining two dissimilar materials by using friction heating to liquefy the interface.
Full penetration welding	Welding where the heat is applied to one side of a prepared joint such that the melt zone extends through the whole thickness of the material.
Gasket	A mechanical seal that fills the space between two objects.
Getter	A material which acts as a vacuum pump by trapping residual gas atoms by chemically bonding them to the atoms of the getter material or by dissolving them.
Helium bombing	A technique by which a nominally hermetically sealed component is subjected to an overpressure of helium so that, on subsequent exposure of the component to a vacuum, helium desorption into that vacuum indicates that a leak or porosity may be present which allowed helium to enter the component.
Helium leak detection	Using the transmission of helium gas through a leak path from the higher pressure side of a vacuum barrier to the lower pressure side and detecting the passage of the helium by means of a suitable mass sensitive device e.g. a mass spectrometer.
High vacuum (HV)	Pressures between 10^{-3} Pa and 10^{-7} Pa.
Hipping	Material forming by applying a high pressure to a powder at a high temperature but below its melting point so that the particles stick together to form a relatively dense and non-porous solid.
Inclusion	A particle embedded in a material that is chemically or structurally different from the host material.
ITER Vacuum Responsible Officer (RO)	A person nominated by ITER as the arbitrator on matters pertaining to vacuum.
Leak rate	The volumetric flow of gas through a vacuum barrier.
Leak tight	Not exhibiting a leak rate great than the minimum detectable leak.
Liquid dye penetrant	A liquid of low viscosity which is used to penetrate small voids or porosity in a material and which evaporates to leave a coloured dye in the voids thus revealing their presence.
Medium vacuum	Pressures between 0.1 Pa and 10^{-3} Pa.
Minimum detectable leak	Smallest value of leak rate which can be detected by the apparatus being used, usually at a signal to noise ratio of 2.
Outgassing	Gas desorbed from a vacuum surface due to the temperature of the surface. Such gas will normally derive from the surface or immediate sub-surface layers of the material.

Permeation	Diffusion or porosity.
Porosity	Transmission of a gas through a solid due to linked small voids in the solid.
Purge gas	A gas flowing through a vacuum system, usually in turbulent flow mode, so as to remove a contaminant such as water.
PVD (Physical Vapour Deposition)	Deposition of a coating onto a substrate from the gas phase, by a means such as evaporation, sublimation or sputtering.
Residual gas	Those atomic or molecular species contributing to the pressure inside a vacuum envelope.
Residual gas scan	A mass spectrometric analysis of the residual gas in a vacuum space.
Rough vacuum	Pressures between atmosphere and 0.1 Pa.
Scale	Poorly adhered oxide clumps on a metal, particularly steel, caused when the metal cools from high temperature to room temperature in atmosphere e.g. after hot rolling of sheet steel or welding.
Sealing surface or seal face	A surface of a vacuum item which is used to form a leak tight joint by means of a vacuum seal being pressed against it.
Seamless pipe	Pipe (or tube) formed without longitudinal weld
Sintering	Material formed by heating a powder to a high temperature, but below its melting point, so that the particles stick together.
Sputtering	A process by which sufficient energy is transferred to the atoms of a target material so that they escape into the vacuum space. The energy transfer may be effected by an electron beam or by ions generated in the gas phase by a gas discharge for example.
Supplier	Any legal entity providing items or services in accordance with a contractual document. An all-inclusive term used in place of any of the following third parties DA's, vendor, seller, contractor, subcontractor, fabricator, consultant, and their sub-tier levels).
Trapped volume	In this context either (i) a void within a material with a small passage opening to the vacuum space (the passage will have a transverse dimension smaller than that of the void.) (ii) a space between two surfaces in contact which is not well vented to the vacuum space.
Ultrahigh vacuum (UHV)	Pressures < 10^{-7} Pa.
Undetectable leaks	Leaks with a value below the sensitivity (minimal detectable leak rate) of the equipment being used to try to find them.
Vacuum arc	A vacuum discharge which carries sufficient current to melt the surface of the material into which it comes into contact.

Vacuum baking	Baking a vacuum item which is totally immersed in a vacuum.
Vacuum barrier	A boundary between a vacuum space and another space.
Vacuum component or item	Any item with one or more surfaces exposed to vacuum. The term includes individual components (like a fixing screw for example), a sub assembly (like a pumping port) or a complete assembly (like the whole vacuum vessel).
Vacuum discharge	A mechanism whereby the residual gas inside a vacuum system becomes ionised and hence electrically conducting.
Vacuum flange	A demountable vacuum joint, normally used in pairs.
Vacuum seal	In this context, a gasket trapped between two vacuum flanges to create a leak tight joint.
Vacuum space	A bounded system held at sub-atmospheric pressure.
Vacuum Specialist	A person nominated by the ITER Vacuum Responsible Officer as an expert in a particular field of vacuum science or technology.
Vacuum system	Any assemblage of vacuum items forming a discrete, independent vacuum space, comprising at the minimum a vacuum envelope, pumping and pressure measurement.
Vacuum valve	A mechanical device which can be used to isolate or link two individual vacuum spaces, depending on its state.
Venting	Opening a vacuum space to another space.
Welding	A technique for joining two items by melting the interface region, with or without the use of a filler material.

Standards.
EN 10204 Metallic products. Types of inspection documents

IDM UID
2FMM4B
VERSION CREATED ON / VERSION / STATUS
10 Apr 2009 / 1.2 / Approved
EXTERNAL REFERENCE / VERSION

Baseline Report (not under Configuration Control)

Attachment 1 Welding

This Attachment relates to welding of vacuum boundaries and outlines the procedures for documentation, qualification, approval and testing.

Approval Process			
	Name	*Action*	*Affiliation*
Author	**Pearce R.**	**14 Apr 2009:signed**	**IO/DG/COO/PED/FCED/VS**
Co-Authors			
Reviewers	**Kim Y.- H.** **Sands D.**	**13 Jun 2009:recommended** **15 Jun 2009:recommended**	**ITER Organization (IO)**
Approver	**Holtkamp N.**	**16 Jun 2009:approved**	**SLAC - National Accelerator Laboratory (US)**
Document Security: Internal Use *RO: Chiocchio Stefano*			
Read Access	**GG: MAC Members and Experts, GG: STAC Members & Experts, AD: ITER, AD: External Collaborators, AD: IO_Director-General, AD: EMAB, AD: Auditors, AD: ITER Management Assessor, project administrator, RO, LG: Section Scheduling, AD: OBS - Vacuum Section (VS) - EXT, AD: OBS - Vacuum Section (VS)**		

Change Log			
Attachment 1 Welding (2FMM4B)			
Version	***Latest Status***	***Issue Date***	***Description of Change***
v1.0	Signed	17 Dec 2008	
v1.1	Signed	26 Jan 2009	
v1.2	Approved	10 Apr 2009	

ITER Vacuum Handbook

Attachment 1
Inspection and Qualification of Welded Joints

	Name	Affiliation
Author/Editor	Liam Worth	Vacuum Group - CEP
Vacuum Responsible Officer	Robert Pearce	Vacuum Group - CEP
Reviewed by	D Sands Y-H Kim	MQP Working Group DDG - CEP
Approved by	N Holtkamp	PDDG

1 Scope

This Attachment relates to welding of vacuum boundaries and outlines the procedures for documentation, qualification, approval and testing.

Whilst this Attachment is based on the international standards ISO 9606, EN 287-1, ISO 15614 and ISO 15609, additional requirements are specified to achieve the high integrity and reliability of the vacuum systems to ensure the required ITER machine reliability. Specifically this Attachment is more stringent in places than the standards in the range of approval for joint types, mechanical testing and acceptance criteria.

The requirements are designed to complement codes which may be used. Where requirements differ in general the more stringent standard should be applied or advice sort from ITER.

2 The Welding and Inspection Plan

Before fabrication can commence the *supplier* shall prepare for approval a weld plan. The weld plan is a drawing which cross references each welded joint to a supporting Welding Procedure Specification (WPS).

3 Welder and operator Qualification

The welder qualification is intended to show the competence of the welder/operator for implementing the specified WPS.
Welder qualification shall be in accordance with EN 287-1, ISO 9606 or equivalent standards agreed in advance. For welding operators ISO 1418 shall be used.
Other standards may be approved by ITER on submission of documentation detailing the equivalence between the proposed standards and the standards quoted herein. All standards and documentation pertaining to equivalence shall be submitted in English and must be agreed in advance of welding operations.

The *supplier* shall establish and maintain a list of qualified welders and operators. This list shall include their individual identification and range of welds for which they are qualified.

4 Applicable Standards

The latest revisions of the standards listed in Table 4-1 shall be applied in the procedure, qualification, and acceptance testing etc. of any welding process and form, where applicable, part of this attachment. Alternative national standards may be submitted for approval but they must meet the minimum technical requirements of this Attachment. Alternatives must be formally accepted through written communication before welding can commence.
Where this attachment is more stringent than the standards, this document takes precedence. Where specified in this document, additional requirements to or requirements differing from the quoted international standards have been highlighted ***in bold italics.***

ISO 15607	Specification for the qualification of welding procedures for metallic materials – general rules
ISO 15614 – 1, 2, 5 ,6, 8, 11:2004	Specification and qualification of welding procedures for metallic materials-welding procedure test
ISO 15609	Specification and qualification of welding procedures for metallic materials – Welding procedure specification
EN 970, ISO 17637	Non-destructive examination of fusion welds. Visual examination.
ISO 4063	Welding and allied processes – Nomenclature of processes and reference numbers.
EN 571 ,ISO 3452	Non destructive testing. Penetrant testing.
EN 1290, ISO 9934	Non-destructive examination of welds. Magnetic particle examination of welds
EN 1435, ISO 17636	Non-destructive examination of welds. Radiographic examination of welds.
EN 1714, ISO 17640	Non-destructive examination of welds. Ultrasonic Examination.
EN 287-1	Qualification test of welders – Fusion welding – Part 1: steels.
ISO 9606	Qualification test of welders – Fusion welding – Part 2: aluminium and aluminium alloys.
ISO 14344	Welding and allied processes – Flux and gas shielded electrical welding processes – Procurement guidelines for consumables.
ISO 5817	Fusion welded joints in steel, nickel, titanium and their alloys (beam welding excluded) – Quality levels for imperfections.
ISO 1418	Welding personnel. Approval testing of welding operators
EN 473 , ISO 9712	Non-destructive testing - Qualification and certification of NDT personnel - General principles
ISO 22825	Non-destructive testing of welds - Ultrasonic testing - Testing of welds in austenitic steels and nickel-based alloys
ISO 10380	Corrugated metal hoses and hose assemblies

Table 4-1 Standards relating to welding

5 Welding Procedure Specification

The Welding Procedure Specification (WPS) is a document which details all the variables which must be defined to produce a weld of acceptable quality. The qualification of the WPS shall be performed in accordance with this Attachment.

Each WPS shall detail each type of weld and shall include, but not be limited to, the following in accordance with ISO 15609:

- Identification of equipment manufacturer
- Equipment calibration records
- Examiner or test body
- WPS number

- Parent material(s), defining which joint element is comprised of a given material
- Filler material(s): classification, type, trade name, flux, diameter of electrode, rod, or wire
- Joint sketch and weld run sequence
- Range of qualified thicknesses and/or diameters
- Welding position
- Welding process (in accordance with ISO 4063)
- Welding technique (single, multipass etc)
- Groove or edge preparations (cleaning, degreasing, jigging etc)
- Shielding and backing gas (composition and flow rates)
- Welding equipment parameters which may include:-
    - AC or DC
    - Polarity
    - Current range
    - Voltage range
    - Pulsed welding parameters
    - Tungsten electrode diameter and type
    - Nozzle diameter
- Backing: method and type, materials and dimensions
- Back gouging: method
- Heating: pre-heat temperature, interpass temperature, post weld temperature
- Drying and preservation temperatures for covered electrodes (if applicable)

Additional Parameters for automatic welding may include:

- Welding equipment specification
- Tool and programme numbers (where applicable)
- Travel speed range
- Wire feed speed range
- Arc Voltage Control parameters

For special processes (remote welding etc) additional information may be required.

6 Welding Procedure Qualification Record

The Welding Procedure Qualification Record (WPQR) is used to record all the relevant data from the welding of test pieces in the qualification of the WPS.

- The qualification of the WPS provides proof that the defined welding process, will achieve a weld of acceptable quality. The welding and testing of this must be witnessed by an ITER recognised Independent Inspection Authority.

All welding data and results from the required non-destructive and destructive testing shall be documented using a Welding Procedure Qualification Record (WPQR). It can also be called Welding Procedure Approval Record (WPAR).

6.1 Qualification of the Welding Procedure Specification.

An existing Welding Procedure Qualification Record (WPQR or WPAR) is acceptable if the following conditions are met:

- The test must have been performed in the same environment as proposed for production, using the same welding technique, process, joint configuration and welding equipment (for mechanised welds)
- The allowable ranges are the same with regard to essential variables.
- The related Preliminary Welding Procedure Specification (pWPS) has been qualified in accordance with ISO 15614
- The test must have been witnessed by an ITER recognised Independent Inspection Authority

Weld produced for qualification must be performed by suitably qualified welders.

The *supplier* must also demonstrate that the welding equipment and plant use for qualification is properly maintained and calibrated in accordance with the relevant operation and maintenance schedules.

6.2 Extent of Approval

6.2.1 Material Groups

For differing grades of stainless steel (304, 304L, 316, 316L and 316LN-IG), cross qualification can be accepted for manual welds when 316L filler is used. Cross qualification is not acceptable for automatic welds. Transition welds joining dissimilar materials other than those listed above must have specific qualification tests performed.

6.2.2 Base Materials

Qualification on the production heat number is mandatory for special welding processes (e.g. electron beam welding, orbital, TIG etc). If this is not possible then the welding of a production proof sample (PPS) is required during production welding.

6.2.3 Thickness Range

6.2.3.1 Thickness Range for Welds Excluding Fillet and Branch

The qualification of a welding procedure test on thickness t shall include qualification for thickness in the ranges given in Table 6-1 in accordance with ISO 15614.

Thickness of test piece t (mm) (where t is the thickness of the thinner material)	**Range of approval[1,2] (Dimensions in mm)**	
	For single run or single run from both sides	**Multi-run**
$t \leq 3$	0.7t to 1.3t	0.7 t to 2 t
$3 < t \leq 12$	0.5 (3 min) t to 1.3 t	3 mm to 2 t
$12 \leq t \leq 100$	0.5 t to 1.1t	0.5 t to 2 t
$t > 100$	Not applicable	50 mm to 1.5 t
1) when impact requirements are specified the upper limit of qualification is 12 mm unless impact testing has been performed 2) The range of approval may have to be reduced in order to avoid hydrogen cracking		

Table 6-1 Range of Approval for material thickness and weld deposit thickness– all welds

6.2.3.2 Thickness Range for Fillet Welds

The qualification of a welding procedure test on thickness t shall include qualification for thickness in the ranges given in Table 6-2 in accordance with ISO 15614.

Thickness of test piece t (mm)	**Range of approval (Dimensions in mm)**		
	Material thickness	**Throat thickness**	
		Single run	**Multi-run**
$t \leq 3$	0.7t to 2 t	0.75 a to 1.5 a	No restriction
$3 < t < 30$	0.5t (3 min) t to 1.2 t	0.75 a to 1.5 a	No restriction
$t \geq 30$	≥ 5	†	No restriction
Note 1a is the throat thickness of the test piece ***Note 2 Fillet welds cannot be qualified by Butt welds*** † For special applications only. Each throat thickness has to be proofed separately by a welding procedure test			

Table 6-2 Range of qualification for material thickness and throat thickness of fillet welds

6.2.3.3 Thickness Range for Branch Pipes (Diameter Range)

The qualification of a welding procedure test on diameter D shall include qualification for diameters in the following ranges give in Table 6-3 in accordance with ISO 15614.

Diameter of test piece D[1,2] (in mm)	Range of approval
D ≤ 25	0.5 D to 2 D
D > 25	≥ 0.5 D up to plates (25 mm min)

1) D is the outside diameter of the pipe or the outside diameter of the set-on branch pipe
2) Approval given for plates also covers pipes when outside diameter is > 500 mm

Table 6-3 Range of approval for pipe and branch connections

6.2.4 Range of Approval of Welded Joints

Lip weld and Automatic socket welds shall be qualified on actual size within nominal material specification tolerances. Pre-weld /socket/spigot gap shall be adequate to preclude post-weld abutment contact and minimise weld stress. The range of approval for other types of joint is given in Table 6-4.

6.2.5 Range of Approval Welding Consumables

All consumables shall be certified to a standard acceptable to the ITER IO (e.g. ISO 14344). In the case of manual welding processes the approval range of filler materials covers other filler metals as long as they are in the same range and chemical composition.

In the case of automatic and semi automatic welding processes the welding consumables used for qualification shall be the same batch as those used for production welds. Following any change during production, weld samples shall be welded and examined prior to the continuation of production with the new batch of consumables. Qualification using filler does not qualify autogenous (fusion welding with out filler material) welds or vice versa.

6.2.6 Welding Processes

In all cases, any change in the welding process will require a requalification of the process. In addition, in the case of automatic welding any change to the welding equipment will require requalification.

6.2.7 Welding Position

Welds for qualification shall be done in local conditions similar to the local conditions where the production weld will be made. Local access to the test piece (in terms of welder access) and the orientation of the test piece (relative to the welder) shall be similar to those for the production weld for which they qualify.

Type of Joint in Approval Test Piece			Range of Approval											
			Butt welds on plate				T Butt welds on plate		Fillet weld on plate	Butt welds on pipe		Fillet weld on pipe	Branch welds on pipe	
			Welded from one side		Welded from both sides		Welded from one side	Welded from both sides		Welded from one side			Set on	Set through
			With backing	No backing	With gouging	No gouging				With backing	No backing			
Butt weld on plate	Welded from one side	With Backing	✓	×	Δ	Δ	×	×	×	×	×	×	×	×
		No Backing	Δ	✓	Δ	Δ	×	×	×	×	×	×	×	×
	Welded from both sides	With gouging	×	×	✓	Δ	×	×	×	×	×	×	×	×
		No gouging	×	×	×	✓	×	×	×	×	×	×	×	×
Butt weld on pipe	Welded from one side	With backing	Δ	×	Δ	Δ	×	Δ	×	✓	×	×	×	×
		No backing	Δ	Δ	Δ	Δ	Δ	Δ	×	Δ	✓	×	×	×
T Butt weld on plate	Welded from one side		×	×	×	×	×	Δ	×	×	×	×	×	×
	Welded from both sides		×	×	×	×	×	✓	×	×	×	×	×	×
Fillet weld	Plate		×	×	×	×	×	×	✓	×	×	×	×	×
	Pipe		×	×	×	×	×	×	Δ	×	×	✓	×	×
Branch weld in pipe	Set on		×	×	×	×	×	×	×	×	×	×	✓	×
	Set through		×	×	×	×	×	×	×	×	×	×		✓

Key:
✓ Indicates the weld for which the WPS is approved in the approval test
Δ Indicates those welds for which the WPS is also approved
× Indicates those welds for which the WPS in not approved

Table 6-4 Range of approval for type of joint

6.3 Non –Destructive Examination

Supplier's inspectors shall be competent in accordance with ISO 9712.

6.3.1 Examination

After post weld heat treatment and prior to destructive testing, test pieces shall be examined by the following:

- Visual examination (in accordance with ISO 17637)
- Dye Penetrant testing (in accordance with ISO 3452) or Magnetic particle testing (in accordance with ISO 9934)

  Inspection using Photothermal camera is permitted in the case where the manufacturer has qualified the method/acceptance criteria prior to the weld qualification
- Radiographic examination (in accordance with ISO 17636)

  and/or
- Ultrasonic examination (in accordance with ISO 17640 and ISO 22825 for austenitic steels and nickel alloys)

For a pipe or plate of 2 mm (or less) wall thickness, the method of examination shall be agreed prior to examination.

6.3.2 Acceptance Criteria

Defects which are detected by the relevant non-destructive examination method shall be assessed in accordance with ISO 5817 level B. In particular acceptance criteria are detailed in Table 6-5. Table 6-5 is in accordance with ISO 5817 however contains additional requirements for production vacuum boundary welds.

Defect Type		Permitted maximum
Planar Defects	Cracks or lamellar tears Lack of root fusion Lack of side fusion Lack of inter-run fusion Lack of root penetration	Not permitted
Solid inclusions	Slag inclusions - individual	20% of t or 2 mm, which ever is smaller
	Slag inclusions - Group	Aggregate length not to exceed t in a length of 12 t, except when the distance between successive indications exceeds 6L where L is the longest indication in the group
	Inclusions – ***Tungsten*** or Copper	Not permitted
Cavities	Isolated pores - round	Diameter <20% t or 2 mm, whichever is smaller
	Gas pore uniformly distributed porosity	1% for single layer (2% for multi-layer) by area where the area of the radiograph to be considered is the length of the weld affected by the porosity times the maximum thickness of the weld
	Elongated pores - wormholes	***Not permitted***
	Linear Porosity	***Not permitted***
Profile defects	***Under cut***	***Some intermittent undercut permitted. Depth not to exceed 0.5 mm for t > 3 mm or 10% for t < 3 mm. Under cut to blend smoothly with the parent material.***
	Incompletely filled groove, sagging. Root concavity, shrinkage groove	0.05 t or 0.5 mm, which ever is smaller. Weld thickness shall not be less than the parent plate thickness
	Excess penetration - pipe	Not greater than 5% of the pipe internal diameter up to 2 mm max.
	Excess penetration – plate	t = 0.5 to 3 mm: , h ≤1 mm+10% b t > 3mm: h ≤1 mm+20% b max 3mm. h=height of excess penetration on backside of plate and b the width
	Excess weld material	Not greater than 10% weld width
	Misalignment	Not greater than 10% of the parent material thickness

	Fillet leg length (asymmetry)	Unequal leg length should not exceed 20% of the fillet throat thickness
	Burn through	Not permitted
Other	Root oxidation	Not permitted where a backing purge gas is specified in the WPS

Table 6-5 Acceptance levels

6.4 Destructive Tests

6.4.1 Test Specimens

The number of test specimens that shall be subjected to destructive testing is given in Table 6-6 in accordance with ISO 15614.

TEST SPECIMEN	No of Tests
BUTT WELD	
Transverse Tensile (room temp.)	2
Root Bend (for t <12mm)	2
Face Bend (for t <12mm)	2
Side Bend (for t >12mm)	4
Transverse Tensile (design temp. if required by tech. spec.)	1
Impact test (for t ≥12 mm one set from weld metal and one set from HAZ if required by tech. spec).	2
Macro-examination (with photo)	1
Micro-examination x 200 (if required by tech spec.)	1
Hardness test survey	1
Burst test†	1
FILLET WELD	
Fracture Test	1
Macro-examination (with photos)	***4***
Micro-examination x 200 (if required by tech. spec.)	2
Hardness Survey	2
T-BUTT/BRANCH CONNECTION	
Macro-examination (with photos)	***4***
Micro-examination x 200 (if required by tech. spec.)	2
Hardness Survey	2
SOCKET/LIP WELD+	
Macro-examination (with photos)	4
Micro examination x 200 (if required by tech. spec.)	2
Hardness Survey	2
† Longitudinal butt weld on bellows (or flexible) tube to ISO 10380	

Table 6-6 Number of destructive test specimens

6.4.2 Test Results

Unless specified differently in Table 6-7 destructive testing and test results shall comply with ISO 15614.

Bend test (stainless steel and nickel alloy only)	***The bend angle shall be 180° round a former of diameter 2t, where t is the thickness of the specimen. The bend test specimen shall have no open defects exceeding 2 mm measured in any direction on the convex surface after bending.***
Micro - Examination	***In general micro-examination shall only be required for welds which form part of the vacuum boundary or are in contact with cryogenic liquids. If required micro-examination tests shall be specified in the technical specification.***
Macro Examination	***For lip welds, penetration shall be 0.7t where t is the thickness of the thinner material.***

Table 6-7 Acceptable test results

6.4.3 Qualification for Welds Under Stressed Applications.

Additional destructive tests to those listed in Table 6-6 to qualify welds under stressed applications may be required as defined in the technical specification.

7 Production Welds

Production welds shall be performed to qualified procedures by qualified welders.

The WPS shall be available for reference by welders or welding operators, by the responsible welding engineer and by the authorised inspector.

The contractor must also demonstrate that the welding equipment and plant is properly maintained and calibrated in accordance with the relevant operation and maintenance schedules.

7.1 Inspection of Fusion Welded Joints

After post weld heat treatment welds shall be subject to the following tests:

- Visual examination (in accordance with ISO 17637)
- Dye Penetrant testing (in accordance with ISO 3452) if permitted†. (Inspection using Photothermal camera is permitted in the case where the manufacturer has qualified the method/acceptance criteria prior to the weld)
- Radiographic examination (in accordance with ISO 17636)

  and / or
- Ultrasonic examination (in accordance with ISO 17640 and ISO 22825 for austenitic steels and nickel alloys)

† See ITER Vacuum Handbook Section 7.1.4.

The range of wall thickness and preferred volumetric examination method is given in Table 7-1 .

Defects which are detected by the relevant non-destructive examination method shall be assessed in accordance with Table 6-5.

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

For all other vacuum boundaries, volumetric examination of 10% of production welds shall be performed unless a method of pre-production proof sampling is approved. In the event of failures, this shall be increased to 100% examination of the batch, defined as same welder/same WPS/ same weld. ……. Acceptance criteria are specified in Table 6-5

On welds where it is specified that volumetric examination be performed and radiography or ultrasonic inspection is not possible, Production Proof Sampling is required.

Wall Thickness	Preferred Volumetric Examination Method
Wt < 12 mm	Radiography
12 mm > wt < 19 mm	Radiography & Ultrasonic
wt > 19 mm	Ultrasonic

Table 7-1 Range of wall thickness and preferred volumetric examination method

7.2 Production proof samples

Welds where radiography or Ultrasonic testing is impractical (e.g. welds that are not full penetration butt welds) must be covered by Production Proof Sampling (PPS). Each PPS will only represent a specific type of weld and must use the same materials, thickness and set-up as the production weld.

For VQC 1 and 2 vacuum boundary welds a PPS must be welded during the same shift as the production welds and by the same welder using the same equipment to be representative of the production welding.
If more than one welder welds the production welds, each must perform a PPS. PPS's are required each shift production welding is being performed to represent the welds performed on that shift.

For VQC 3 and 4 vacuum boundary welds a PPS shall be welded for each welder performing the production welds.

PPS's should be sectioned and macro examined in four places (including one stop/start area). Photographs of the macros giving the date the PPS was welded, the welder's identity and identifying the production welds it is covering must be included in the final documentation package.

An ITER representative will normally witness PPS welding and all PPS macros shall be reviewed. Operations with witness and hold points to facilitate this must be incorporated in the Work Schedule.

As the PPS is a representative sample, rejection of the macro will result in rejection of all welds covered by this PPS.

7.3 Helium Leak Testing of Production Welds

100% of vacuum sealing welds (VQC 1A, 2A, 3A, 4A) shall be subject to helium leak testing in accordance with the requirements and procedures of the ITER Vacuum Handbook.

7.4 Repair by welding of production welds

No weld repair shall be performed with out qualification of the welding procedure. Welding procedures used for welding repair shall be qualified in accordance with this document.

8 Documentation

All quality assurance documentation required by this procedure shall form part of the delivery to ITER, and shall include:

- Weld plans
- WPS's
- WPQR's and test reports
- Welder qualification's and test reports
- PPS test reports
- Production weld test reports
- Reports on weld repairs
- Non-Conformance Reports

IDM UID
MBXPP3

VERSION CREATED ON / VERSION / STATUS
13 Mar 2014 / 1.7 / Approved

EXTERNAL REFERENCE

Report

ITER Vacuum Handbook Attachment 2 - Cleanliness Requirements Relating to the Assembly of Vacuum Equipment

This Attachment sets out the requirements which must be satisfied when performing assembly work on, or in, the ITER vacuum systems.It coverspreliminary assembly work in assembly areas final assembly and integration work inside and outside the vacuum vessels

Approval Process			
	Name	*Action*	*Affiliation*
Author	**Worth L.**	**13 Mar 2014:signed**	**IO/DG/DIP/PSE/FCED/VS**
Co-Authors			
Reviewers	**Blackler K.** **Pearce R.** **Sands D.** **Shaw R.**	**14 Apr 2014:recommended** **01 Apr 2014:recommended** **17 Mar 2014:recommended** **14 Apr 2014:recommended**	**IO/DG/DIP/PCA/AOP** **IO/DG/DIP/PSE/FCED/VS** **IO/DG/SQS/QA** **IO/DG/DIP/PCA/AOP/MAI**
Approver	**Haange R.**	**16 Apr 2014:approved**	**IO/DG/DIP**
Document Security: level 1 (IO unclassified) *RO: Pearce Robert*			
Read Access	**RO, project administrator, AD: ITER, AD: External Collaborators, AD: IO_Director-General, AD: IC_OMPE_WG, AD: Section - Vacuum - EXT, AD: Section - Vacuum, AD: Auditors, AD: ITER Management Assessor**		

Change Log				
Title (Uid)	***Version***	***Latest Status***	***Issue Date***	***Description of Change***
ITER Vacuum Handbook Attachment 2 - Cleanliness Requirements Relating to the Assembly of Vacuum Equipment (MBXPP3_v1_7)	v1.7	Approved	13 Mar 2014	Construction Volume 13: Health, Safety and Environmental Management Plan (ITER_D_EC8ALD) removed and replaced with "ITER Health & Safety & Environment management plan" with out reference. Updated version numbers and date.
ITER Vacuum Handbook Attachment 2 - Cleanliness Requirements Relating to the Assembly of Vacuum Equipment (MBXPP3_v1_6)	v1.6	Signed	13 Mar 2014	version number!
ITER Vacuum Handbook Attachment 2 - Cleanliness Requirements Relating to the Assembly of Vacuum Equipment (MBXPP3_v1_5)	v1.5	Signed	13 Mar 2014	Reference list update
ITER Vacuum Handbook Attachment 2 - Cleanliness Requirements Relating to the Assembly of Vacuum Equipment (MBXPP3_v1_4)	v1.4	Signed	13 Mar 2014	Corrected the version number. All comments from reviews of the document have been taken into account in this final version. This version is ready for final review by the ITER Vacuum RO and subsequent approval.
ITER Vacuum Handbook Attachment 2 - Cleanliness Requirements Relating to the Assembly of Vacuum Equipment (MBXPP3_v1_3)	v1.3	Signed	13 Mar 2014	Removed reference to "Construction Volume 13: Health, Safety and Environmental Management Plan "
ITER Vacuum Handbook Attachment 2 - Cleanliness Requirements Relating to the Assembly of Vacuum Equipment (MBXPP3_v1_2)	v1.2	Signed	06 Feb 2014	All comments from all reviewers addressed.
ITER Vacuum Handbook Attachment 2 - Cleanliness Requirements Relating to	v1.1	Signed	04 Feb 2014	All comments received addressed. Track changes included in attachment.

the Assembly of Vacuum Equipment (MBXPP3_v1_1)				Requirements for atmospheric air included.
ITER Vacuum Handbook Attachment 2 - Cleanliness Requirements Relating to the Assembly of Vacuum Equipment (MBXPP3_v1_0)	v1.0	Signed	20 Dec 2013	Version 1.0
ITER Vacuum Handbook Attachment 2 - Cleanliness Requirements Relating to the Assembly of Vacuum Equipment (MBXPP3_v0_0)	v0.0	In Work	20 Dec 2013	

ITER Vacuum Handbook

Attachment 2
Cleanliness Requirements Relating to the Assembly of Vacuum Equipment

	Name	Affiliation
Author/Editor	Liam Worth	IO
Vacuum Responsible Officer	Robert Pearce	IO

Contents

1 Terminology

The following terms and acronyms listed in are used throughout this Attachment.

Term/acronym	Contextual meaning
Accepted	Accepted for use by the ITER Vacuum Responsible Officer
ALARA	As Low As Reasonably Achievable
Ex-vessel work	Work for which the operator(s) remains physically outside the vacuum system (e.g. assembly of a vacuum pipework run)
In-vessel work	Work for which the operator(s) must enter the vacuum system to perform (e.g. assembly in the main VV or cryostat)
Operator(s)	Person(s) performing the work
RA	Risk Assessment
UT	Ultrasonic Testing
VV	ITER main Vacuum Vessel
VQC	Vacuum Classification
WRO	Work Responsible Officer – Responsible for preparation of the RA and WI. The WRO is also responsible for ensuring that the work is performed to the WI and any safety requirements are satisfied
WI	Work Instruction – as part of the documentation package includes written procedures such as method statements

Table 1 Terms and acronyms with meaning in context of this document

2 Scope

This Attachment sets out the requirements which must be satisfied when performing assembly work on, or in, the ITER systems which have been assigned a VQC [1].This document is applicable for work performed at the ITER site.

It covers

- preliminary assembly work in assembly areas
- final assembly and integration work inside and outside the vacuum equipment.

3 Purpose

The purpose of the requirements described herein are to ensure that the overall contamination levels in the various vacuum equipment of the ITER machine when it is brought into operation are commensurate with the Vacuum Classification (VQC) of the pertinent vacuum equipment.

All procedures and processes used during assembly and testing work of ITER vacuum systems equipment shall comply with the requirements of the ITER Vacuum Handbook [1].

4 General Requirements

These requirements are applicable to all assembly work for all items with a VQC. Subsequent sections detail VQC specific requirements.

4.1 Management of Work

All work shall be performed in compliance with the ITER Health & Safety & Environment management plan which concerns the safety of work on the IO site. The basic requirements of the referenced document which must be satisfied are outlined below.

4.1.1 Risk Assessment

The risks associated with assembly and test of vacuum equipment shall be assessed prior to work commencing. The risk assessment shall be performed by a competent person and approved by the IO. Prior to work commencing all controls identified to lower the risks to a level commensurate with the principles of ALARA shall be in place.

4.1.2 Work Instruction

All assembly and test operations shall be performed to a Work Instruction (WI). The WI may take the form of, for example, a written procedure or method statement. The WI shall be approved by the IO and supported by a relevant Risk Assessment (RA).

The requirements for cleanliness and cleanliness control as described in this Attachment shall be stated in the WI as shall the processes to achieve the requirements as stated herein.

4.1.2.1 Deviations from the WI

During the execution of the tasks as defined in the WI it may be necessary to deviate from the WI. All deviations from the WI shall be agreed with the WRO prior to execution. The WRO shall update the WI accordingly to account for the deviation. Any unauthorised deviation from the WI shall be reported to the WRO.

4.1.3 Personnel

No work shall be performed except by competent personnel trained to perform the work to be carried out.

4.2 Area Designation

The area in which the work shall be performed shall be designated according to the VQC of the system being worked upon. All general and any specific requirements pertaining to the work being performed in the area shall be clearly displayed in the working area preferably with the WI and RA.

4.3 Operator Attire

All operators performing work on vacuum equipment with any VQC where there is a risk of the operator coming into physical contact with the vacuum facing surfaces shall wear suitable attire. The exact nature of the attire to be adorned shall be specified in the WI and displayed on the area designation (section 4.2).

4.3.1 Personnel Protective Equipment

The operators shall adorn PPE as defined as a result of the Risk Assessment. All PPE shall be clean and free from surface contamination such as grease and oil.

4.3.2 Ex-vessel work

As a minimum and in addition to the requirements of 4.3.1 the operator shall wear the following when assembling vacuum equipment ex-vessel;

- Clean powder free latex or nitrile outer gloves
- Clean lint free overalls

4.3.3 In-vessel work

In addition to the requirements of 4.3.2 the operator shall also adorn the following garments when performing work in-vessel;

- Clean plastic overshoes
- Hair nets or caps and beard covers where appropriate
- Clean plastic helmet cover

4.4 Tools

4.4.1 General

All tools shall be fit for purpose and shall be specified in the WI.

Prior to use all tools shall be cleaned by wiping with a clean lint free cloth dampened with isopropyl alcohol (IPA) or laboratory grade ethanol.

4.4.2 Tools for use in-vessel

All tools for use in-vessel shall come from a dedicated set of tools which are new or have only been used for in-vessel work.

Tools shall be logged into and out of the working area.

After each assembly stage a check shall be made to ensure all tools have been removed from the work area.

4.4.2.1 Hand Tools

Hand tools shall be stored in a clean tool container which may be transported into the working area. The tool container shall also include an inventory list of tools contained therein. Prior to removal from the work area the inventory of tools shall be checked against the inventory list. Any discrepancy between the tools in the container and the inventory list shall be reported to the Work Responsible Officer (WRO).

4.4.2.2 Power Tools

The use of power tools in-vessel shall be specified in the WI.

Prior to the use of power tools adjacent parts of the work area shall be screened off by the use of clean polyethylene sheeting, aluminium foil or the like to catch swarf, debris, etc. and to minimise its spread to other parts of the job.

Following each stage of such work, swarf, debris, etc., shall be cleaned up by vacuuming and surfaces wiped down with clean lint-free rags dampened with IPA or laboratory grade ethanol.

4.4.2.3 Welding/ Brazing Equipment

Welding and/ or brazing equipment shall be used only as specified in the WI. All operations of this type shall be supported by the relevant paper work (such as hot work permit) which shall be attached to the WI.

Prior to starting any such operation, surfaces to be worked on shall be cleaned by swabbing with an IPA or laboratory grade ethanol on clean lint-free rags.

Adjacent parts of the work piece shall be screened off by the use of clean polythethylene sheeting, aluminium foil or the like to catch weld spatter etc.

PPE such as welding screens shall be clean and new, or clean and dedicated for in-vessel work.

4.4.2.4 Tools Containing Fluids

The use of tools containing fluids, such as hydraulic jacks, shall be avoided where possible. Where the use of a tool containing fluid cannot be avoided then the following requirements must be satisfied.

The working fluid shall normally be air or glycol based.

The use of hydraulic tools containing oils as the working fluid is prohibited unless *accepted* by the ITER Vacuum Responsible Officer.

The area surrounding to tool shall be protected, with plastic sheeting, from the possible release of the fluid.

As far as is practical the tool shall be wrapped in plastic sheet to prevent the possible spread of contamination from leaking fluid.

The WI shall include measures which must be taken in the event of loss of fluid from the tool into the work area.

4.4.2.5 Equipment, trolleys, jigs, slings, etc.

All such equipment, etc., shall be maintained in a fully serviceable manner.

All such items shall be operated in a manner such that no oils, greases, etc., can be transferred to surfaces in the clean area or that debris including particulates can be shed from the items.

4.4.2.6 Vacuum Pumps

All vacuum pumps for use in-vessel shall be dry (oil free) type.

4.4.2.7 Specialised Tools

The use of specialised equipment shall be by prior agreement with the WRO and only to the procedures as specified in the WI.

4.5 Materials

4.5.1 Marking

Indelible inks and paint used for temporary mark shall only be *accepted* for use under the following conditions:

The marking can be completely removed without residue

All markers shall **not** contain any contaminates as described below:

- Ferrite steel
- Chlorine content greater 0,25%
- Sulphur and sulphur compounds
- Products which may release elements: Pb, Hg, P, Zn, Cd, Sn, Sb, Bi, As, Cu, rare earth elements.

4.5.2 Adhesive Tape and plastic coverings

Adhesive tapes, peel-off preservative varnishes and temporary plastic coverings, used for austenitic stainless steels shall meet the following requirements:

- halogen or sulphur content shall be less than 0,10% in weight
- less than 15 ppm of chloride and 10 ppm of fluoride shall be released through lixiviation.

4.5.3 Grinding and Cutting Wheels

Grinding and cutting wheels for use on vacuum equipment shall be alumina based and only used for austenitic stainless steel. Cutting wheels for use in vessel shall be *accepted* for use by the IO.

4.5.4 Products for Ultrasonic Testing (UT)

Only ITER approved [2] coupling fluids required for UT are accepted for use on vacuum equipment. Requirements pertaining to coupling fluids are detailed in the ITER Vacuum Handbook [1].

4.5.5 Products for Liquid Penetrant Examination

Only ITER approved liquid penetrant product families are *accepted* for use on vacuum equipment [2].

4.5.6 Machining Fluids

Only machining fluids *accepted* by the IO are acceptable for use on vacuum equipment [2].

4.5.7 Unacceptable Materials

It is prohibited for the materials listed in Table 2 to become in contact with the surface of vacuum equipment.

Metals	Plastics
Carbon steel	PVC
Zinc	
Lead	

Table 2 Prohibited materials

5 Performance of Work

5.1 In-Vessel Dressing Working Procedures

The following general clean area procedures shall be followed and combined with good judgment in order to produce and maintain vacuum.

1. Controlled clean dressing area at entrance and exit of vacuum vessel will be set up with appropriate notices posted.
2. No food, drink, chewing gum or ablutions allowed within the vacuum vessel.
3. Clean protective clothing must be worn when working in-vessel. Clean overalls/coats, gloves and overshoes will be put on when entering the vacuum vessel and taken off upon exit.
4. Hands should be washed before wearing clean gloves. This must be done especially if any lotions or creams have been used.
5. Change clean gloves if contamination is suspected.
6. Cover hair and arms if there is any possibility of them contacting a clean vacuum surface.
7. Equipment brought into the clean dressing area for entry into vacuum vessel must be clean. Carts, stands, tools and other equipment must not be oily or greasy and must be wiped down with appropriate cleaning solutions immediately prior to entering the clean area. Note that wheels on carts must also be cleaned.
8. Tools that are cleaned for in-vessel use must not leave the clean area until end of job.
9. Expendable tools (saw blades, files, cutters, stainless steel wire brushes, grinding wheels, etc.) used shall be new and cleaned to minimize the potential for contamination.

5.2 Cutting, Drilling, Grinding, Filing and Polishing

Such operations shall only be carried out when specified in the work instructions.

Cutting fluids, lubricants, polishing materials, etc., may only be selected from those which have been *accepted* by IO for the relevant VQC.

Prior to starting any such operation, surfaces to be worked on shall be cleaned by swabbing with IPA or laboratory grade ethanol on lint-free rags.

Adjacent parts of the work piece shall be screened off by the use of clean polyethylene sheeting, aluminium foil or the like to catch swarf, debris, etc. and minimise its spread to other parts of the job.

Following each stage of such work, swarf, debris, etc., shall be cleaned up with a vacuum cleaner and surfaces wiped down with an IPA or laboratory grade ethanol using clean lint free rags.

If grinding is essential, the grinding wheel shall be free of organic components and shall have been manufactured in an oil-free, clean environment. Grinding wheels shall be *accepted* by IO prior to use.

5.3 Welding, Brazing &Soldering

All welding shall be to the requirements of the ITER Vacuum Handbook Attachment 1 [3].

Such operations shall only be carried out when specified in the WI.

Only *accepted* weld fillers, brazing materials, solders and fluxes may be used.

Following each stage of such work, surfaces once cooled shall be wiped down with IPA or ethanol using clean lint-free rags and all traces of flux, etc., removed.

5.4 Mechanical Joining

Surfaces to be joined shall be cleaned by swabbing with IPA or laboratory grade ethanol on lint-free rags.

Only fasteners of the type specified in the WI and fabricated from *accepted* materials shall be used.

Unless specified in the WI, no lubricants, greases, thermal compounds, etc., shall be used on joints or fasteners.

5.5 Marking

Marking of any surface shall normally be carried out by scribing. The use of marker pens, ink, dyes, paint, etc., shall only be as specified in the WI. Only IO *accepted* marker pens, ink, dyes, paint, etc. shall be used.

6 Specific Requirements

To preserve cleanliness of the components and the area in which the components are assembled and/or integrated the requirements as specified in the following sections shall be satisfied. The requirements pertain to vacuum equipment after final cleaning.

6.1 Assembly and Integration

6.1.1 VQC 1 and 2 Demountable Joints

The making of demountable joints of flange class 1 [4] for use on VQC 1 equipment shall be under the supervision of the IO Vacuum Section. This requirement shall be stated in the WI. The ITER Vacuum Responsible Officer will nominate a representative of the IO Vacuum Section to supervise this activity.

6.1.2 Ex-Vessel

In the case where assembly operations are to be performed on a piece of vacuum equipment with exposed surfaces of different VQC (for e.g. VV sector) the more stringent requirements for cleanliness shall apply to the whole piece.

6.1.2.1 VQC 1

Areas for the assembly of VQC 1 equipment shall be physically segregated from other work areas in the vicinity unless those work areas are of the same cleanliness (i.e. the room in which the clean area is to be established meets the cleanliness requirements *per se).*

The suitability of the clean area shall be checked on a regular basis (daily) by monitoring the airborne particulate count, which should not exceed 5 x 10^6 Particles of size > 0.5 μm per m^3. Should the daily air check return a particle count not in compliance with these limits specified herein the WRO shall be informed as soon as possible.

6.1.2.2 VQC 2

Areas for the assembly of VQC 2 equipment shall be maintained clean by daily cleaning of the working areas, including the floors and surfaces.

6.1.2.3 VQC 3 and 4

Areas for the assembly of VQC 3 and 4 equipment shall be kept clean by daily cleaning of the general area.

6.2 In-vessel

6.2.1 General

Personnel entering the inner area shall wear clean room clothing, comprising clean white overalls; overshoes or clean job specific footwear; protective hair nets or caps and beard covers where appropriate; powder free latex or nitrile outer gloves as specified in Section 4.3.

Personnel entry shall be through a controlled temporary vestibule with curtains screening the vessel entry aperture and the outer access from general areas. This vestibule shall be constructed so that it can be maintained in a clean and controlled manner. The vestibule shall be divided into two areas with a step over barrier between them. Each area will have sticky mats on the floor. The outer area will be for changing into clean room clothing.

Dedicated clean tools and equipment shall be stored in the inner area. Positive air flow shall be maintained from the inner to the outer area.

Only authorised personnel shall be permitted to enter the inner area.

No work shall be carried out by personnel who have not been trained for such work.

Where possible when working in the vessel, personnel shall stand on suitably supported temporary flooring manufactured from stainless steel or aluminium sheet covered with clean aluminium foil. Such foil shall be replaced at frequent intervals.

6.2.2 VQC 1

The requirements for cleanliness pertaining to in-vessel VQC 1 work areas shall be compliant with section 6.1.2 of this Attachment with the exception that the vacuum containment boundary may be considered a barrier for work area segregation.

6.2.3 Ventilation

6.2.3.1 VQC 1 & 2 ventilation air flow rate

Vacuum enclosures shall be ventilated with atmospheric air at a flow rate sufficient to provide at least 10 air changes per hour. The flow rate shall be determined on a case by case basis depending on the volume to be ventilated.

6.2.3.2 VQC 1 and 2 ventilation air humidity

Air for the ventilation of VQC 1 and vacuum enclosures shall have a relative humidity not exceeding 70%

6.2.3.3 Particulate count

Air for ventilation of VQC 1 enclosures shall have a maximum particulate count which shall not exceed 5 x 10^6 Particles of size > 0.5 μm per m^3measured at the vessel air inlet.

6.3 Work Areas in the Vicinity of VQC 1 and 2 Systems

All vessel apertures open to VQC 1 and / or 2 vacuum areas which are not directly involved in the work being undertaken shall where practical be covered by clean polyethylene sheeting or clean aluminium foil.

The region of the machine being worked on shall be screened by a polythene tent or similar. All surfaces inside this area shall be cleaned off before and after the process by vacuuming and swabbing with IPA or laboratory grade ethanol using clean lint-free rags.

All equipment shall be protected in such a way that no contamination can be transferred to vacuum surfaces.

Care shall be taken to ensure that no oils or greases (including finger grease) are rubbed into any surface which forms a vacuum boundary.

7 References

[1] ITER Vacuum Handbook (ITER_D_2EZ9UM).

[2] Appendix 4 Accepted Fluids (ITER_D_2ELN8N).

[3] Attachment 1. Inspection and Qualification of Welded Joints (ITER_D_ 2FMM4B).

[4] ITER Vacuum Handbook Appendix 8 Flanges (ITER_D_2DJYQA).

IDM UID
46FN9B
VERSION CREATED ON / VERSION / STATUS
08 Mar 2012 / 2.1/ Approved
EXTERNAL REFERENCE

User Manual

ITER Dimensional Metrology Handbook

This Metrology Handbook outlines the mandatory requirements for dimensional control of the components, assemblies and systems for the ITER machine. In addition this handbook provides significant guidance and helpful information on best practise for large volume metrology applications which can be used in the production of procurement specifications. The handbook also provides information on the ITER metrology infrastructure and the provision of alignment and metrology services during assembly of ...

Approval Process			
	Name	*Action*	*Affiliation*
Author	**Wilson D.**	**08-Mar-2012:signed**	**IO/DG/DIP/CIE/AOP/MAI**
CoAuthor			
Reviewers	**Higuchi M.**	**08-Mar-2012:recommended**	**IO/DG/SQS/QA**
Previous Versions Reviews	**Blackler K.** **Kondoh M.** **Shaw R.**	**31-Jan-2012:recommended v2.0** **07-Mar-2012:recommended v2.0** **31-Jan-2012:recommended v2.0**	**IO/DG/DIP/CIE/AOP** **IO/DG/DIP/CIE** **IO/DG/DIP/CIE/AOP/MAI**
Approver	**Haange R.**	**08-Mar-2012:approved**	**IO/DG/DIP**
Document Security: level 1 (IO unclassified) *RO: Wilson David*			
Read Access	**LG: M&I ext, AD: Only-staff, AD: Division - Diagnostics - EXT, AD: Directorate - Central Integration and Engineering - EXT, AD: Division - Magnet - EXT, AD: DA-US, AD: DA-RF, AD: DA-KO, AD: DA-JA, AD: DA-IN, AD: DA-EU, AD: DA-CN, project administrator, RO**		

Change Log				
Title (Uid)	***Version***	***Latest Status***	***Issue Date***	***Description of Change***
ITER Dimensional Metrology Handbook (46FN9B_v2_1)	v2.1	Approved	08 Mar 2012	Reference to Design Authority Policy removed Hyperlink to SRD 62-13 corrected
ITER Dimensional Metrology Handbook (46FN9B_v2_0)	v2.0	Signed	25 Jan 2012	Version for senior management approval after internal review.
ITER Dimensional Metrology Handbook (46FN9B_v1_4)	v1.4	Signed	20 Jun 2011	M Kondoh and D Sands added as reviewers at the request of K Blackler
ITER Dimensional Metrology Handbook (46FN9B_v1_3)	v1.3	Signed	15 Jun 2011	Following technical review, document issue raised to add reviewers/approver for sign off Authority.
ITER Dimensional Metrology Handbook (46FN9B_v1_2)	v1.2	Signed	16 May 2011	references to Manual replaced with Handbook +/- 1mm value removed Reference to temperature control requirements added note on MQP requirements added
ITER Dimensional Metrology Handbook (46FN9B_v1_1)	v1.1	Signed	03 May 2011	Comments included following review
ITER Dimensional Metrology Handbook (46FN9B_v1_0)	v1.0	Signed	04 Mar 2011	

Table of Contents

1 Purpose

The purpose of this document is to supply information relating to dimensional metrology to all Departments of the ITER Organisation and Domestic Agencies. To define strategies and infrastructure provision, identify requirements and best practises and provide a standardised approach to dimensional control and alignment processes.

2 Scope

The Dimensional Metrology Handbook (DMH) outlines the mandatory requirements for dimensional control of the components, assemblies and systems for the ITER machine. In addition the handbook provides significant guidance and helpful information on best practise for large volume metrology applications. The handbook also provides information on the ITER metrology infrastructure and the provision of alignment and metrology services during assembly of the machine and its ancillary components and systems.

The DMH is issued as a supplement to project requirements documents, since it is necessary that the requirements contained in this handbook are followed by the ITER Organisation, the Domestic Agencies and industry to ensure the successful construction and operation of ITER.

3 Definitions

Abbreviations and Acronyms

3D	Three Dimensional
A&M	Alignment and Metrology
AIMS	Advanced Integrated Mathematical System
ASCII	American Standard Code for Information Exchange
CAD	Computer Aided Design
CBD	Cryostat Base Datum
CCL	Current Centreline
CCR	Corner Cube Reflector
DA	Domestic Agency
DCM	Design Compliance Matrix
DMH	Dimensional Metrology Handbook
DMIS	Dimensional Measurement Interface Standard
GD&T	Geometric Dimensioning and Tolerancing
GPS	Geometrical Product Specifications
ICD	Interface Control Document
IDM	ITER Document Management System
IGES	Initial Graphics Exchange Specification
IO	ITER Organisation
IS	Interface Sheet
LVM	Large Volume Metrology
MIP	Manufacturing Inspection Plan

MQP	Management and Quality Program
MRP	Mandatory Requirements for Procurement
NRK	New River Kinematics
PA	Procurement Arrangement
PF	Raw 3D Scan data Format
PIF	Parametric Image Format
PIT	Pit Datum
POL	InnovMetric's Binary Format
RO	Responsible Officer
SA	Spatial Analyzer
SAT	Standard ACIS Text
SMR	Spherically Mounted Reflector
SRD	System Requirements Document
STEP	Standardised Exchange of Product
TAD	Tokamak Assembly Datum
TRO	Technical Responsible Officer
TF	Toroidal Field
TFGS	Toroidal Field coil Gravity Support
TGCS	Tokamak Global Coordinate System
VVGS	Vacuum Vessel Gravity Support

4 Communications and acceptance

To satisfy the requirements of this handbook, processes and procedures relating to alignment and dimensional control must be clearly documented and where stated: approved or accepted by the Metrology RO or nominated representative.

Section 11 and its sub-sections "Process control and best practise" identify areas that will be reviewed prior, during and on completion of the activity and will require IO acceptance at predefined stages. *Acceptance/Approval* is to be a positive and recorded action, either by signature or by electronic means.

A possible route of communication and acceptance could be:-

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

5 Alignment and Metrology (A&M) Classifications

Machine components and plant systems requiring alignment and/or dimensional control shall be given an A&M classification by the applicable TRO. The classification shall reflect the importance placed on A&M for the system to function and the consequence of failure on the project. This classification shall be reviewed with the Metrology RO and accepted

Alignment & Metrology (A&M) Class 1

Components or assemblies requiring alignment and/or dimensional control, where failure to comply in these areas will significantly impair or prevent machine assembly and/or operation and could potentially cause schedule delay in excess of one month or cost risk in excess of 1M€.

A&M Class 2

Components or assemblies requiring alignment and/or dimensional control, where failure to comply in these areas will significantly impair or prevent machine assembly and/or operation and could potentially cause schedule delay in excess of one week or cost risk in excess of 0.1M€.

A&M Class 3

No dimensional control oversight by IO is required through the supply chain or on receipt at the ITER site. No component alignment requirements however; setting out points/lines will be required from the IO metrology team to facilitate the installation.

Unclassified

No IO infrastructure required or support from the ITER metrology team

Note: It is the responsibility of the Technical RO to make an assessment of the A&M requirements for his system following the processes in this document in order to determine the A&M class, which is be reviewed by the metrology RO.

6 Mandatory requirements for A&M Tasks

For the ITER machine to operate to specification it is essential that the supply of its constituent parts is controlled throughout their life cycle from raw material through manufacture, assembly commissioning and operation. From a metrology perspective this means that dimensional control processes must be qualified and traceable.

The Metrology RO shall be available to provide technical advice to system ROs during preparation of PAs and Technical Specifications, reviewing metrology related documentation and providing support where necessary during manufacture, assembly/installation and acceptance.

In the following sections, information is provided on best practise guidance for metrology related processes and will be used as the basis for reviewing process documentation relating to dimensional control activities.

Within this section are the mandatory requirements relating to A&M for the supply and assembly/installation of the systems for ITER. If an exceptions to a mandatory requirement is requested it must be agreed by the IO MAI section through a deviation request.

Mandatory requirements relating to A&M are dependent on the A&M classification applicable (section 5) to the component or assembly concerned. These requirements are detailed in the following sub-sections:

6.1 Mandatory Requirements for Site (MRS) based A&M Class 1 activities

A&M Class 1 activities are critical to the successful assembly/installation and operation of the ITER machine and as such require the highest level of qualification and control. Listed below are the mandatory requirements, as applicable for the system concerned, identifying responsibilities for their delivery and acceptance. The Metrology RO or his delegate shall review all key documents pertaining to A&M tasks within this classification.

[MRS1] The System Requirements Document (SRD), Interface Control Document (ICD) or other document, shall define the alignment and/or dimensional control requirements. These shall be included in the DCM and the methods to achieve them shall be reviewed and approved as part of the ITER Design Review Procedure with the Metrology RO accepting the process for the A&M tasks.

[MRS2] The ITER RO shall identify all A&M quality documentation that will form part of the supply for the applicable system. The dossier of documents shall be certified compliant with the requirements of the technical specification or shall be supported by a non-conformance report. This shall be in place prior to any A&M work commencing at the ITER site.

[MRS3] For items requiring goods inwards, in-process or final inspection, a list of key characteristics shall be compiled by the RO to identify the scope of the inspection. Datums and tolerances shall be identified in a drawing or other medium acceptable to the inspection team carrying out the task. A method statement or procedure shall be prepared by the party responsible for the inspection which shall be accepted by the Metrology RO or his delegate.

[MRS4] For items requiring setting out, pre-alignment and/or final alignment at the ITER site, a procedure shall be prepared detailing the requirements, process description, reference data, output data together with reporting and acceptance criteria. This procedure shall be accepted by the Metrology RO or his delegate prior to task commencement.

[MRS5] The coordinate/datum systems used during inspection and alignment tasks on the ITER site shall be clearly defined in the A&M procedure for the task and applicable drawings. Where datums evolve to reflect as-built variation in the assembly/installation process the logic shall be traceable back to the nominal requirement.

[MRS6] Inspection reports shall identify the nominal dimensions, applicable tolerances and the dimension achieved for the feature, with non-complying values flagged in red on the report. These features shall be the subject of rework or a non-conformance report.

[MRS7] All metrology equipment used for A&M tasks shall hold a current calibration certificate issued by an accredited laboratory (Reference standard BS EN ISO/IEC: 2005). The equipment selected by the supplier shall be fit for the requirements of the measurement process considering areas such as: measurement uncertainty, speed of data acquisition, measurement geometry, local environmental conditions etc.

[MRS8] Measurement uncertainty shall be calculated for all reported measurements at a confidence level of 2σ. As a general rule, the uncertainty value shall not exceed 20% of the tolerance applicable to the feature measured. Maintaining an uncertainty of 10% or less is recommended to optimise the available tolerance applicable to the feature concerned.

[MRS9] The IO drawings specify dimensions at the reference temperature of 20˚C. The environmental conditions for A&M will depend very much on the location in which the activity is to be carried out. The RO shall make an assessment of the impact of thermal expansion/contraction on the A&M task and specify controls to be put in place as necessary to compensate. Consideration shall be given to the thermal inertia of the components being measured, where necessary allowing sufficient soak time in the measurement environment to ensure thermal stabilisation. For critical items Temperature measurements (better than ± 1°C) shall be recorded throughout the measurement task of both the component and the environment, logged against time and saved with the measurement file. For large components, multiple measurements shall be required to enable the detection of thermal gradients.

[MRS10] For measurement surveys utilising multiple instrument stations, bundle adjustment algorithms shall be utilised to ensure error propagation, via multiple best-fit alignments, does not occur.

[MRS11] All "as-built" drawings/3D models/electronic data shall be supplied in a format agreed with the IO to demonstrate compliance with the design. The IO does not prescribe which software should be used however; it is critical that measurement data can be easily transferred been all parties requiring access to it.

[MRS12] All inspection/dimensional control and alignment reports shall include, as a minimum, the following information:

- Identification of measuring instruments used including calibration certificate number
- Identification of ancillary equipment, as applicable, used including type, make unique identifier and calibration certificate number i.e.
    - Test unit
    - Probes (dimensions, frequencies)
    - Targets and tooling

  - Scale bars
- Identification of the part examined
- Reference drawing or CAD model identification defining the tolerances, datum etc. which the part has been inspected to, including issue status
- Time and place of the inspection plus signature of the operator
- Name and qualification of the operator and his employer.
- Procedure followed and issue status
- Meteorological data (temperature, humidity, pressure)
- Identification of all computer files generated during the inspection, all raw and processed data must be in a format acceptable to the IO
- Written values tabulated to provide: nominal dimensions, applicable tolerances and the dimension achieved for the feature, with non-complying values flagged in red on the report. Graphical data may be used if agreed by IO.
- Interpretation of results, including an explanation for any readings considered invalid.
- Identification of any non-conformity reports raised.

[MRS13] All drawings and/or electronic data used for A&M activities shall be issued through the ITER document control process and certified at the status to which they shall be used.

6.2 Mandatory Requirements for Site (MRS) based A&M Class 2 activities

Components or assemblies with an A&M class 2 will require a significant amount of dimensional control on the IO site. They may need to go through a pre-alignment process to provide references (fiducials) for assembly/installation and may also need inspections during and on completion of assembly/installation.

A&M class 2 tasks however have a reduced impact on cost and schedule in the event of failure therefore requiring a reduced level of input by the Metrology RO.

The A&M class 1 mandatory requirements [MRS1] through to [MRS13] shall be maintained for this classification, as applicable to the task, but the requirement for review/approval by the Metrology RO is removed.

6.3 Mandatory Requirements for Site (MRS) based A&M Class 3 activities

A&M class 3 activities only require setting out points/lines to facilitate their installation therefore the mandatory requirements for these activities are [MRS4], [MRS7] and [MRS13].

6.4 Mandatory Requirements Procurement (MRP) for A&M Class 1 activities

A&M Class 1 activities are critical to the successful assembly/installation and operation of the ITER machine and as such require the highest level of qualification and control. Listed below are the mandatory requirements, as applicable for the system concerned, identifying responsibilities for their delivery and approval. The Metrology RO or his delegate shall be given the opportunity to review all key documents pertaining to A&M tasks within this classification.

[MRP1] The System Requirements Document (SRD), Interface Control Document (ICD) or other document, shall define the alignment and/or dimensional control requirements relating to the subject of the procurement. These shall be included in the DCM and shall be reviewed as part of the ITER Design Review Procedure.

[MRP2] The A&M requirements for the procurement shall be included within the Technical Specification (Annex B for PA's) with design drawings and associated design documents defining the fundamental design dimensions and tolerances. The supplier shall produce shop floor documentation that demonstrates how the manufacturing and/or assembly process shall be controlled throughout the production cycle. This shall include tolerance requirements for relevant stages of the manufacturing process that shall be agreed with the IO prior to commencement of manufacture.

[MRP3] Prior to contract commencement the supplier shall produce an implementation plan defining all quality related activities to be carried out during the contract. Elements relating to A&M shall include:

- Reference standards
- Design change control procedures – Drawings and CAD models
- Document control
- Instrument calibrations and test procedures
- Control of non-conformities
- Data management procedures
- Measurement procedures- data acquisition, post processing and validation
- Reporting procedures

The Metrology RO shall be given the opportunity to review the implementation plan and any documents referenced within it, prior to contract commencement.

[MRP4] Inspections shall be carried out at all crucial stages of the manufacturing process to guarantee adherence to final tolerances and set as early as possible corrective measures where necessary. The frequency and details of these inspections shall be defined by the supplier in the MIP for the procurement which the IO will be given the opportunity to witness at their discretion.

[MRP5] The coordinate/datum system used during inspection and dimensional control processes shall be as defined in the design drawings. Inspection reports shall identify the nominal dimensions, applicable tolerances and the dimension achieved for the feature with non-complying values flagged in red on the report.

[MRP6] All metrology equipment used for A&M tasks shall hold a current calibration certificate issued by an accredited laboratory (Reference standard BS EN ISO/IEC: 2005). The equipment selected by the supplier shall be fit for the requirements of the measurement process considering areas such as: measurement uncertainty, speed of data acquisition, measurement geometry, local environmental conditions etc.

[MRP7] The supplier shall draft a dimensional control plan (DCP) that shall include all inputs and outputs relating to the measurement process, see section 9. The DCP shall be supplied to the IO for acceptance, prior to commencement of manufacture.

[MRP8] Measurement uncertainty shall be calculated for all reported measurements at a confidence level of 2σ. As a general rule, the uncertainty value shall not exceed 20% of the tolerance applicable to the feature measured. Maintaining an uncertainty of 10% or less is recommended to optimise the available tolerance applicable to the feature concerned.

[MRP9] The IO drawings specify dimensions at the reference temperature of 20˚C. Dimensional control for factory acceptance shall be carried out in a controlled environment with a maximum temperature variation of ± 2˚C. Key dimensions shall be measured at the reference temperature or corrected to this temperature therefore temperature stability during the measurement process is critical. Raw measurement data and corrected values shall be made available to the IO. Consideration shall be given to the thermal inertia of the components being measured allowing sufficient soak time in the measurement environment to ensure thermal stabilisation. Temperature measurements (better than ± 1°C) shall be recorded throughout the measurement task of both the component and the environment, logged against time and saved with the measurement file. For large components, multiple measurements shall be required to enable the detection of thermal gradients.

[MRP10] For measurement surveys utilising multiple instrument stations, bundle adjustment algorithms shall be utilised to ensure error propagation, via multiple best-fit alignments, does not occur.

[MRP11] The supplier shall produce "as-built" drawings/3D models/electronic data, in a format agreed with the IO demonstrating compliance with the design. The IO does not prescribe which software should be used however; it is critical that measurement data can be easily transferred between the parties to the ITER agreement. During manufacture this data may be required to qualify measurement processes, address non-conformance issues, and consider concession requests. In addition, the data may be used to construct a configuration model representing the true geometry of the item concerned.

[MRP12] Deviations from the design requirements shall be the subject of a non-conformance (NCR) report with corrective measures involving geometric or material property changes requiring the prior approval of the IO. To enable a decision to be made the supplier shall furnish the IO with documents justifying their proposal delivered within the NCR system.

[MRP13] All inspection/dimensional control reports shall include, as a minimum, the following information:

- Identification of measuring instruments used including calibration certificate number
- Identification of ancillary equipment, as applicable, used including type, make unique identifier and calibration certificate number i.e.
    - Test unit
    - Probes (dimensions, frequencies)
    - Targets and tooling
    - Scale bars
- Identification of the part examined
- Reference drawing or CAD model identification defining the tolerances, datum etc. which the part has been inspected to, including issue status
- Time and place of the inspection plus signature of the operator
- Name and qualification of the operator and his employer.
- Procedure followed and issue status
- Meteorological data (temperature, humidity, pressure)
- Identification of all computer files generated during the inspection, all raw and processed data must be in a format acceptable to the IO
- Written values tabulated to provide: nominal dimensions, applicable tolerances and the dimension achieved for the feature, with non-complying values flagged in red on the report. Graphical data may be used if agreed by IO.
- Interpretation of results, including an explanation for any readings considered invalid.
- Identification of any non-conformity reports raised

In order to avoid unnecessary duplication, some of the information listed above can be provided in documents identified by the supplier and attached to the report.

6.5 Mandatory Requirements Procurement (MRP) for A&M Class 2 activities

Components or assemblies with an A&M class 2 for procurement will require a significant amount of dimensional control during manufacture, overseen by the IO. They may need to go through a pre-alignment process to provide references (fiducials) for assembly/installation at the ITER site and may also need some form of inspection during factory acceptance or on receipt by the RO.

The TRO for the system involved shall need to consider the level of control to be applied during the procurement process and identify the mandatory requirements in the technical specification applicable to the procurement.

As a minimum the following mandatory requirements from A&M class 1 shall be applied: [MRP1], [MRP2], [MRP3], [MRP4], [MRP5], [MRP6], [MRP7] and [MRP12]. Other requirements may be added at the discretion of the RO.

Note: Components of A&M Class 3 or below require no specific dimensional controls of alignment activities during the procurement process.

7 Standards

There are a large number of standards relating to dimensional metrology which can broadly be grouped under the scope of two Technical Committees within the International Standards Organisation (ISO) namely:

TC 213 - Dimensional and geometrical product specifications and verification

Standardisation in the field of geometrical product specifications (GPS), i.e. macro- and microgeometry specifications covering dimensional and geometrical tolerancing, surface properties and the related verification principles, measuring equipment and calibration requirements including the uncertainty of dimensional and geometrical measurement. The standardisation includes the basic layout and explanation of drawing indications (symbols).

TC 176 - Quality management and quality assurance

Standardization in the field of quality management (generic quality management systems and supporting technologies), as well as quality management standardization in specific sectors at the request of the affected sector and the ISO Technical Management Board.

Note:

ISO/TC 176 is also entrusted with an advisory function to all ISO and IEC technical committees to ensure the integrity of the generic quality system standards and the effective implementation of the ISO/IEC sector policy on quality management systems deliverables.

Non ISO standards useful for reference:

Guidelines for the Evaluation of Dimensional Measurement Uncertainty (Technical Report) (B89.7.3.2 - 2007)

Performance Evaluation of Laser-Based Spherical Coordinate Measurement Systems (B89.4.19 - 2006)

8 Infrastructure - Survey Networks and datums

All measurement tasks need a fixed reference base (the datum) from which measurements can be made and calculated. For large volume metrology (LVM) applications this reference typically takes the form of a survey network consisting of a collection of target nests and/or instrument stations of known geometry and computed uncertainty.

The accuracy and precision of the survey network(s) directly affects the measurement accuracy that can be achieved for subsequent alignment tasks. Accuracy and precision are terms that often get confused therefore for the purposes of this document their definitions are as follows:

Accuracy:	The degree of conformity of a measured or calculated quantity to its actual (true) value
Precision:	The degree of repeatability achieved when the same quantity is measured a number of times

The survey network design process starts with a specification detailing how the network will be utilised and defining the ultimate measurement tolerances to be achieved. A perfect measurement does not exist therefore it is important to be able to determine the measurement uncertainty for each stage of the measurement process and thus create a tolerance budget.

Measurement uncertainty:	The parameter, associated with the result of a measurement (e.g. a calibration or test) that defines the range of values that could reasonably be attributed to the measured quantity. When uncertainty is evaluated and reported in a specified way it indicates the level of confidence that the value actually lies within the range defined by the uncertainty interval.

The survey networks for ITER will cover the whole of the site, providing a global coordinate matrix for survey instruments to reference against. The accuracy requirements for each network will vary, dependent on the alignment tasks for which they are being supplied. As such, interface control documents need to clearly define the alignment requirements of ITER components, assemblies and systems.

8.1 Primary Survey Network

The first survey network installed was the Primary Survey network which defines the site reference system for buildings construction, provides the datum for monitoring stability and is the global datum for dedicated secondary networks installed throughout the site.

The network consists of a collection of geodetic pillars, spread around the site and tied into foundations designed to optimise stability. A common interface for force-centring survey instruments and survey targets is embedded in the top of each pillar.

The network was installed and measured in the summer of 2010. A least squares adjustment was made to optimise the network and determine the co-ordinate and uncertainty values for each survey monument. The measurement uncertainty for the network was calculated to be ~1mm when initially measured. The network will be periodically monitored for stability.

The coordinates of the primary survey network are reported within the Lambert III mapping projection with elevations relative to sea level. The Tokamak Global Coordinate System (TGCS) is an orthogonal system with the gravity vector defining the Z-axis at machine centre, the Y-axis points towards site north (37˚ counter-clockwise from geographic north) with the X-axis mutually perpendicular to Z & Y in an easterly direction. The origin of the coordinate system is at the nominal tokamak centre. For more information on ITER co-ordinate systems refer to document ITER_D_2A9PXZ.

8.2 Tokamak Pit Network

Machine assembly activities within the tokamak pit shall require accurate and precise alignment of components. The design specification for the network is to achieve an uncertainty no greater than ± 0.2 mm within a temperature controlled environment of ± 2˚C (ref. SRD 62-13), this requirement is achievable if the environment remains stable. However, it is clear that with the immense transfer of loads occurring during construction that the network will move and distort to a certain extent. This distortion will need to be monitored and modelled during machine assembly to ensure that the final machine is aligned to specification. Both dynamic and passive measurement systems are being considered to provide an efficient system for monitoring the network movement and thus enable adjustments to be calculated and employed.

The initial network shall consist of many targets, or target nests, distributed around the pit wall covering the full height of the pit and extending into the adjacent port cells. The best fit centre of the pit shall be derived from the pit wall targets defining the vertical datum axis for machine assembly. The datum for toroidal position and elevation will be derived from the best fit position of the port cells.

Once the lower cryostat cylinder is installed, lines of sight to the lower pit wall targets will be blocked however, lines of sight from the pit into the port cells and vice versa shall be maintained. The pit wall targets above the cryostat lower cylinder shall remain visible throughout the vacuum vessel construction, only becoming obscured when the cryostat upper cylinder is installed. The port cell targets are very important to the pit network as they provide the link to systems external to the pit within the adjacent galleries.

It is likely that a number of different instrument types will be used during the tokamak build process such as photogrammetry cameras, laser trackers and total stations. Laser trackers and total stations measure to similar spherically mounted reflectors called SMRs or corner cube reflectors CCRs, different names for the same item. Photogrammetry uses retroreflective however, common targeting mounts are readily available from suppliers such as Hubbs and Brunson enabling interchangeability of instruments utilising the network.

8.3 Tokamak Galleries Networks

Survey networks shall be installed external to the bio shield wall within the port cells and galleries. These multi-level networks shall provide the dimensional control for all systems external to the tokamak pit within the tokamak building and will be linked to the Tokamak Pit Network via the port cells. The network shall consist of a collection of wall and floor mounted target nests distributed throughout the galleries. These will be a standardised design as used for the pit network thus allowing flexibility of instrument selection for measurement tasks.

Provision shall be made to link the tokamak hall network to the primary network. This will be carried out with a total station and level and will be periodically checked for stability whist lines of sight remain available.

8.4 Generic Buildings Networks

There are various buildings around the site having different requirements for dimensional control. Users of these buildings need to consider their requirements at an early stage so that fit for purpose networks can be installed and measured in a timely manner.

Where required, building networks shall be linked to the primary survey network thus providing a global position for all setting out, alignment and measurement tasks. Where a local reference is required co-ordinate transformations into the building co-ordinate system can be made (ref. ITER_D_2A9PXZ).

8.5 Assembly Datums

During assembly of the ITER machine it will be necessary to adjust the build datum to optimise the assembly process with respect to the as-built geometry of key machine components. Each build datum shall define the position and orientation of a coordinate frame within which the coordinates of the targets/target nests of the Tokamak Pit Network shall be valued.

The pit datum (PIT) as described in section 8.2 will be the initial datum used to align the following components:

- Cryostat Column Baseplates
- Cryostat Columns
- Cryostat Base Section assembly

The as-built position of the cryostat base shall be used to define the cryostat base datum (CBD) this shall be used to align:

- Cryostat lower Cylinder
- TF Coils

The key characteristics on the cryostat base that are used to establish the CBD are the gravity support interfaces for both the TF coils (TFGS) and the vacuum vessel (VVGS).

The key characteristic of the coils to be aligned is the current centre line (CCL) of the winding back, its position defined with respect to fiducials on the coil case.

When the 18 TF Coils are in place, the Tokamak Assembly Datum (TAD) shall be established representing the Least Square best Fit of the 18 TF Coils. This datum shall be used for final alignment of the vacuum vessel, remaining magnet systems and the internal vacuum vessel components.

9 Survey and Alignment during buildings construction

During the construction phase of the ITER buildings there will be many requirements for accurate alignment. ROs need to carefully consider the alignment requirements of their systems especially in areas of restricted access where opportunities to define reference points may be limited.

The alignment path of systems that will ultimately be separated by physical barriers, such as concrete walls, may not be restricted at an early stage of the project. Providing the alignment references at this early stage may be the only opportunity to carry out the task and therefore guarantee the success of the installation.

Some large or heavy pieces of plant and equipment may have to be installed during the construction process if access to deliver such component will not be possible once construction is complete. In these instances, alignment references will need to be established in advance to facilitate the setting out and alignment as required.

Generally speaking; if a piece of equipment needs to be installed accurately to a global co-ordinate i.e. not positioned to local features like adjacent walls, building columns etc., then access to a survey network or pre-defined and established reference points will be required. Local alignment tasks need clear lines of sight or a network or dedicated reference points to facilitate the task.

The installation of the primary survey network is complete however the addition, pace and sequence of secondary networks will be driven by the requirements defined by the various system ROs on the project and should be clearly defined in the project schedule.

10 Design for Alignment and Metrology

The ITER machine is made up of many complex components and assemblies which need to interact in specific ways for the experiment to be successful. The design process will identify the optimum configuration for these systems identifying key characteristics to be focussed on with realistic parameters for manufacture and assembly, achieving a fit for purpose design.

From a metrology perspective, measurement uncertainty is a key contributor to the overall tolerance budget and as such needs to be carefully considered. For example; if a component can be manufactured to a perceived tolerance of +/- 1 mm but the measurement process can only deliver to +/- 2 mm then the overall process is clearly out of control.

It has already been identified that survey networks can be designed and installed to provide the datum for alignment activities. This however is only part of the requirement; the components themselves also need to be equipped with alignment features, designed to interface with the most appropriate measurement instruments and positioned to deliver the required alignment accuracy. In addition, the survey features need to be positioned with due consideration to the kinematics of the alignment system. There is no point in having an accurate and precise measurement system if the alignment mechanism cannot respond efficiently to the data provided by the measurement survey.

The list below identifies areas for consideration when designing components for alignment:

Alignment tolerances

- Position
- Elevation
- Angle: Roll, Pitch,
- Yaw

Datum references

- PIT
- CBD
- TAD
- Local to component

Alignment features

- Target nests
- Tooling Ball
- Retroreflective targets
- Scribed reference lines

Adjustment Mechanisms

- Screw threads
- Jacks
- Cams

Alignment Geometry

- Plane
- Line
- Centre of rotation
- Coupled or decoupled

Metrology Instruments

- Laser Trackers
- Total Stations
- Theodolites
- Articulated measurement arms
- Photogrammetry
- Laser Scanners
- Levels

During the design and planning stages for ITER and in support of the procurement arrangements (PAs), the Metrology RO is available to give advice on aspects relating to geometrical and dimensional control for the project. Inspection and alignment surveys can be simulated at the design stage enabling qualification of measurement processes and the determination of uncertainty values for measured points and features within the survey.

11 Process control and best practise

The control of dimensional measurement is an essential part of the supply chain for the ITER components and the subsequent assembly activities to be carried out at the ITER site. For all critical inspections/surveys the measurement process needs to be clearly defined, controlled and accepted by the IO.

Inputs to the process may include:

- design specifications, drawings, CAD models
- quality plans, procedures, method statements
- measuring instruments, calibrations, reference artefacts
- components and assemblies
- plant and equipment
- personnel, skills, training
- computer software, simulations, uncertainty analysis

With outputs such as:

- raw measurement data
- Meteorological corrections
- Scale adjustments
- co-ordinate frame transforms
- quality control inspection reports
- best-fit analyses and transformation matrices
- aligned component / assemblies
- fiducially referenced components / assemblies
- survey uncertainty analyses
- signed off method statements, procedures, quality plans
- Survey Report

The measurement process needs to be fit for purpose; delivering the required outputs in an efficient manner and providing assurances that the process is under control. The IO shall be given the opportunity to review the process documentation prior to commencement and to witness inspections/surveys during manufacture, hold points shall be specified in the Manufacturing and inspection Plan (MIP) as required. In exceptional circumstances the IO reserves the right to carry out its own dimensional control measurements utilising its own personnel or a third party supplier.

The IO shall identify key interfaces which must be inspected during manufacture and monitored during assembly operations, such as welding, which may affect the fit, form or function of the assembly. The control of such operations shall be clearly defined in the process documentation with measurement data recorded in an appropriate format.

11.1 Large volume portable measurement systems

For large volume metrology it is often necessary to bring the measuring instrument to the job. Portable co-ordinate measurement systems such as Laser trackers, total stations, theodolites and photogrammetry, enable the surveyor/inspector to carry out the measurement task in the workplace however, with this flexibility comes added variables that must to be controlled.

The workshop environment is unlikely to be as rigorously controlled as a dedicated metrology lab. Changes in temperature, humidity and pressure all contribute to measurement variance and therefore need to be recorded and compensated for.

Measuring a large component or assembly will often require the use of multiple instrument stations. This may be due to line of sight constraints or as a means of reducing observation lengths within the survey to minimise measurement uncertainty. Whatever the reason, if the results are to be considered within a single coordinate system then a network solution to the fit will be required. Best practice is to carry out a bundle adjustment of the network; this iterative process will optimise the network by minimising the combined pointing errors of the measurements. With the instrument stations optimised the uncertainty of the measured points within the network can be calculated through a variance algorithm.

Minimising the potential for error will come from a good understanding of the technical specification, consideration and compensation for the working environment and by applying best practice processes.

11.2 Best-fit analysis and alignment transformations

Initial measurements taken during a survey will be valued within the measuring instrument's local co-ordinate system. Their relationship to each other will be clearly defined but they will require aligning to the part or assembly to which they relate.

The alignment can be defined by geometry measured within the measurement session i.e. points, lines and planes or by referencing measured points to features within the CAD model such as faces, surfaces etc.

Unlike the CAD model, the measured points will not fit perfectly to the design nominal therefore a series of weighted best-fits will need to be applied to optimise the alignment. The IO shall identify the key characteristics to be used for the alignment and prioritise their importance. This information shall either be provided within engineering drawings, annotated to the CAD model or as written instructions.

The supplier's measurement procedure shall identify best fit processes to be carried out including any data filtering that will be applied. In general, all raw data shall be maintained and stored for ease of recall and review by the IO.

11.3 Control of inspection measurement and test equipment

All measuring equipment must be fit for purpose to deliver to the tolerances specified. A documented calibration system must be in operation traceable to national standards and certificated through an accredited body. A calibration schedule must be in place with all calibrations logged within a register and all calibration certificates filed for ease of recall.

A Quality document shall clearly identify where and when measurement equipment has been used. Each piece of equipment shall be uniquely identified and must only be used when its calibration status is within date.

For critical measurements it may be necessary to calibrate a measuring instrument more frequently than the suppliers recommended interval. Where the IO deems this necessary it shall mark up the quality plan accordingly.

11.4 Coordinate systems and measurement units

In general, when conveying results of a survey/inspection the co-ordinate system used shall be coincident and of the same type as that used to specify the design. The measurement units shall be as defined in the drawing or model and the deviation from nominal of the as-built dimensions shall be reported in the same manner as they are toleranced.

Results from an inspection shall be expressed in quantative terms when a design characteristic is expressed in numerical units. Attribute data may be used (e.g. go/no-go) if no inspection technique resulting in a quantative measurement is feasible. Where this is the case the gauge used for the process shall be traceable to an appropriate national standard.

11.5 Metrology software and data formats

The ITER organisation has adopted Spatial Analyzer (SA), supplied by New River Kinematics (NRK), as its preferred metrology software. The software interfaces with the vast majority of measurement instruments; its architecture maintains full traceability of the measurement process storing all raw measurement data and environmental monitoring corrections.

The software has been specifically designed for large volume metrology applications; its optimisation algorithms for network configurations, computes measurement uncertainty by default and analyses instrument performance in the process. The system can be used offline for measurement simulations by utilising constructed geometry within the application or by directly importing Catia V5 models, complete with embedded GD&T if required.

The IO does not prescribe which software should be used however; it is critical that measurement data can be easily transferred between the parties to the ITER agreement. During manufacture this data may be required to qualify measurement processes, address non-conformance issues, consider concession requests and certainly to build up as-built models of the supply.

The following data formats can be read into SA:

ASCII, STEP, IGES,VDA, SAT, DMIS, AIMS-TDF, Polyworks (POL, PIF, PF, DPI), Direct Catia V4 V5 *.CGR process, Direct UG process, Direct ProE process, VSTARS .xyz file, VSTARS Cameras (outstar.txt), xyz ijk File (IJK), Digital network levels, IMETRIC, 1-D data (Datamyte).

In all cases measurement data must include uncertainty values, see following section.

11.6 Measurement uncertainty

Measurement uncertainty is the parameter, associated with the result of a measurement (e.g. a calibration or test) that defines the range of values that could reasonably be attributed to the measured quantity. When uncertainty is evaluated and reported in a specified way it indicates the level of confidence that the value actually lies within the range defined by the uncertainty interval.

No measurement is complete unless its uncertainty can be quantified. In a similar way that a tolerance relays the acceptance specification for a given dimension, the measurement uncertainty must be considered when determining whether a measured characteristic meets the design criteria.

For example: if the distance between 2 points is required to be 10m +/- 0.003m then a measurement returning a value of 10.0025m appears to be acceptable however; if the measurement uncertainty for each point is +/- 0.001m then the reality is that the measured dimension could be out of spec by up to 0.0015m.. Figure 1 demonstrates this pictorially

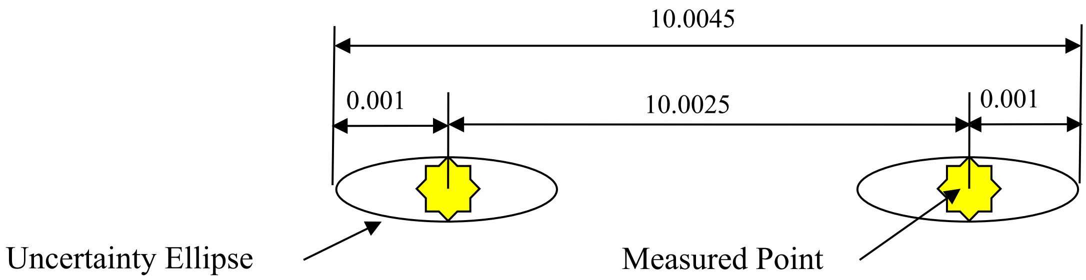


Figure 1: example of an uncertainty analysis for a linear dimension

11.7 Measurement scale

Components for the ITER machine are dimensioned nominally at 20˚C. For large objects the effects of temperature change on the physical size of the object can be considerable and as such must be taken into account during the measurement process.

Measurements, especially those carried out over a prolonged period, must be carried out in thermally stable conditions. The measuring instrument and component must be given time to acclimatise to the environment and the temperature must be monitored throughout the measurement task.

Where the measurements cannot be taken at 20˚C a scale factor will need to be applied to the measurement job. In consideration of the components orientation and fixturing, the scaling vector(s) shall be identified in the measurement plan for acceptance by the IO.

When using optical measuring systems such as laser trackers or total stations consideration needs to be given to distance measurements from these instrument's interferometers or absolute distance meters. Environmental factors such as changes in atmospheric pressure, temperature and humidity will affect the wavelength and as such need to be corrected. All environmental monitors used for this process must be calibrated in line with the manufactures recommendations and traceable to national standards.

Intersecting theodolite systems and photogrammetry rely on defined calibrated length measurements to scale the measurement job. Scale bars, interferometer measured distances or a controlled and traceable network of stable points can all be used to introduce scale. The important factor is that the scale system is controlled, fit for purpose and traceable.

11.8 Component orientation and fixturing for measurement

There are many large and heavy components which are assembled together to make the ITER machine. These components will distort to varying degrees depending on how they are supported during manufacture and assembly therefore it is essential that these parameters are considered and clearly defined within the measurement procedure.

Where a component is to be supported, machined and inspected in one orientation but put into service in another, the effects of the transformation need to be established.

By default, CAD models describe a components shape and size in a state of equilibrium, unaffected by external influences such as gravity. Computer added manufacturing and inspection systems often use the CAD model to drive the manufacturing and inspection processes therefore the CAD model either needs be morphed to reflect the geometric condition for inspection or offset values need to be supplied for the specific areas of interest.

11.9 Fiducialisation

Fiducialisation is the process used to define reference points (fiducials) on a component or assembly with respect to a reference coordinate frame. The position and orientation of the frame is constructed from as-built measurement data and reflects the optimum alignment achievable from the data set measured.

To define an object's 3D position and orientation, a minimum of 3 fiducials are required however, utilising more fiducials will add redundancy to the survey and provide a better representation of the measurement volume. The quantity and position of the fiducials will be driven by the design specification and qualified through tolerance assessment and uncertainty analysis.

Where fiducials are required to facilitate an alignment at the ITER site, their design, position and orientation will be defined by the IO. Fiducials used by the supplier shall either be permanently attached to the object or fitted temporarily during the measurement via a standard interface as descried in section 11.10.

11.10 Targets and tooling

Laser trackers and total stations measure to similar spherical targets called SMR retroreflectors or corner cubes. Photogrammetry also uses retroreflective targets but of a different type however, interchangeable targeting mounts are readily available.

A typical interface for these mounts could be an H7 hole of diameter 6, 8, or 10 mm reamed perpendicular into a reference face. The important thing to note is that whilst the mount will position the target coincident with the axis of the hole, the target will be offset from the reference face by a defined amount.

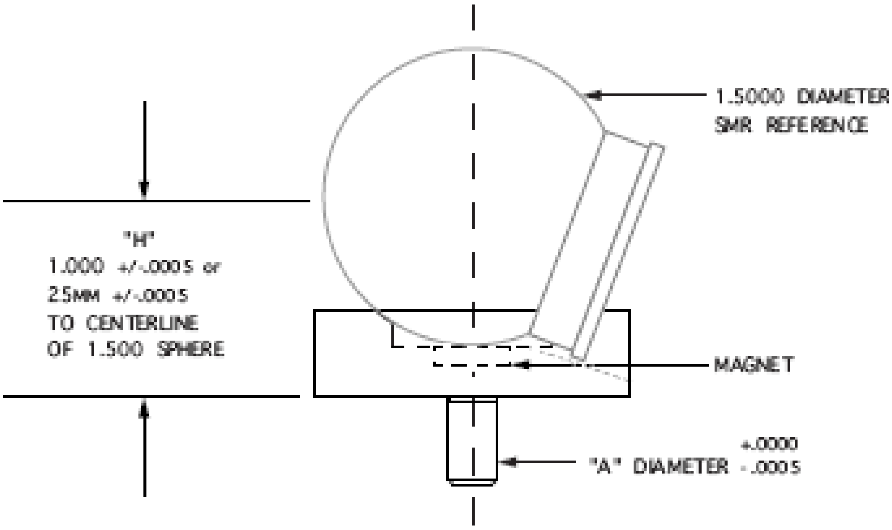


Fig. 1 Example of an SMR mounted in a pin nest

The example above shows a laser tracker SMR retroreflector mounted within a target mount. Dimension "H" identifies the offset applied and the manufacturing tolerance.

All targeting mounts or generically speaking tooling, that contributes to the measurement process shall be controlled within the supplier's calibration system and shall be uniquely identified. The measurement process shall specifically record when such tooling has been used defining the offset applied and its direction.

12 Coordination for metrology activities

Many of the components for the ITER machine have extremely demanding tolerances with respect to alignment and dimensional control. Their installation locations are often very constrained and their large size makes adjustment all the more difficult. These components may be standalone items or an embodiment of constituent parts combined to deliver a specific function. Whatever the requirement, if metrology is a contributor then it is an interface that needs to be resourced and managed.

The Metrology RO is available to give technical advice during the design phase of the project and is tasked to put in place and manage the requisite infrastructure to support the machine build and its associated systems. This will include the design and realisation of survey networks (section 8) development of alignment strategies, procurement of equipment and the day to day management of the metrology team.

The ITER metrology team shall be assembled to support the programmed metrology requirements of the ITER project therefore it is important that these needs are identified as early as possible to optimise the resourcing with respect to equipment and personnel.

12.1 Interface control

ROs for components, assemblies and systems requiring support from the ITER metrology team shall specify their requirements in an appropriate technical document i.e. SRD, ICD, dedicated IS.

Typical details required shall include:

- General description of the measurement task detailing processes and required outputs
- Reference datum systems to be used i.e. site primary datum system, pit datum system, locally defined system etc.
- Tolerance requirements for dimensional control and or alignment i.e. position angularity, elevation, level etc.
- Fiducialisation requirements (section 11.9)
- Location where the survey / inspection is to be carried out
- Scheduled date for the task and sub-tasks
- State of plant during the task(s); component orientation, supporting structures, scaffolding, adjacent work activities etc.
- Environmental controls envisaged during the survey

From the above information the Metrology RO will elaborate a measurement plan, detailing the work scope, equipment and tooling requirements, estimated task duration and manpower allocation. Any inputs required from the customer such as drawings, CAD models etc. will be identified and their required delivery dates included in the metrology schedule.

The ITER 'Assembly and Installation Management Manual' details the processes and procedures to be followed in preparation for and during implementation of assembly and installation activities. Reference 3 of the document details the 'System Assembly Compatibility Assessment Procedure' this procedure will be used by the Machine Assembly and Installation Section to assess compliance with assembly methodologies and standards and to determine readiness for development of assembly operating procedures. Appendix 1 to the document 'ITER System Assembly Compatibility Assessment Form' includes an input table specific to metrology activities; 'Table 6: Dimensional control and Alignment'. This table shall be completed by the Metrology RO in conjunction with the RO for the system applicable providing information, as applicable, relating to the following requirements:

- First article inspection
- Goods inwards inspection
- Datum references and setting out
- Pre-alignment (fiducial measurement)
- Final alignment

- Data processing
- As-built measurements
- Measurement simulation

12.2 Design reviews

Alignment and metrology requirements and processes will typically be reviewed at the design reviews for the system to which they apply. Design reviews will be carried out in accordance with ITER Design Review Procedure (2832CF) current at the time.

The conceptual design review shall demonstrate that the alignment requirements and tolerances for the system under review have been identified and included in the Design Compliance Matrix (DCM). Specific details shall be included in the interface sheet of the appropriate interface control document as they are developed and must be in place before the final design review.

At the preliminary design review the outline processes for alignment should be presented to provide an overview of the scope of the task including an indicative schedule. At this time it should be clear where responsibilities lie for the various stages of the installation be it with the IO the DA(s) or as a combined effort.

Alignment and Metrology activities could include:

- Goods inwards dimensional inspection of system components
- Fiducialisation of components for assembly (section 11.9)
- Provision of reference datums, network points, elevation lines (section 8.0)
- Setting out for enabling activities: marking out for location systems, stillages etc.
- As-built reconstruction for customisation of interfaces
- Alignment of components: position, orientation, elevation….

Following the preliminary design review the alignment and metrology processes will be elaborated by the responsible officer(s) concerned. The level of elaboration will be dependent on a number of contributors such as the uniqueness of the task, the complexity of the process, access restrictions, required accuracy etc. The preliminary design review will define the scope of this elaboration which will subsequently identify the metrology input for the final design review.

The final design review shall demonstrate that dimensional control and alignment processes have been sufficiently addressed to ensure that the system under review can be successfully manufactured and subsequently installed at the ITER site. The Metrology RO will use the metrology handbook as reference for the review process and the DCM to assess compliance with the design requirements, contributing to the overall acceptance process.

13 QA and documentation

All components, processes, documents and data within the scope of this handbook shall be subject to the ITER Quality Assurance Program (IDM Ref; ITER_D_22K4QX) and its related Management and Quality Programme (MQP) (IDM Ref; ITER_D_2NS3UH).

別紙－5　品質分類の等級に基づく要求事項の一覧

品質分類の等級に基づく要求事項の一覧

表 4.1 品質分類の等級に基づく要求事項

参考のため、本契約の仕様内での適用（ITER ダイバータでの適用範囲）をマーキングする。
なお、ここに記載の図書についての詳細は、別紙－2 の提出図書一覧に示す。

	品質クラス 1、2 (QC 1,2)	**品質クラス 3 (QC 3)**
設計	設計レビューと独立検証を含む設計管理	当事者間の他の合意が無い限り、設計レビュー及び独立検証は不要
ソフトウエア／モデル	ライフサイクル管理を含む設計、運転に使用するソフトウエア及びモデルの許容 使用するソフトウエアの同定とモデルの使用の評価	当事者間の他の合意が無い限り不要
調達／文書・記録	品質計画書(Quality Plan)	品質計画書(Quality Plan)
	検査・試験計画書（Inspection Plan）	当事者間の他の合意が無い限り不要
	適合基準のレビュー 特殊工程のクオリフィケーションのレビュー	
	製作関連図書（納入時）	
	規格基準に基づくコンプライアンス宣言、材料証明及び検査図書（納入時） 材料調達先の品質システム認証	規格基準に基づくコンプライアンス宣言、材料証明及び検査図書
	リリースノート(所有権移転時)	リリースノート(所有権移転時)
	完成図書(所有権移転時)	完成図書(所有権移転時)
製作	製作・検査計画書(MIP)	当事者間の他の合意が無い限り不要
	製作レビュー(MRR 又は PRR)	
品質管理	別表4―2及び表4－3による	附属書1による
建設、据付、アセンブリ	検査計画書	検査計画書
	建設レビュー	建設レビュー
品質監査	メーカーでの受注者監査	当事者間の他の合意により省略あるいは 文書レビューによる確認
製品の納入・輸送	リリースノート 輸送通知書	リリースノート 輸送通知書
	輸送計画書	当事者間の他の合意が無い限り不要
	サンプリング等による最低限の検査・検証	
	QST の要求又は製作者の手順書に基づく保管・保存	
	注記: (1) *クラス4のシステム及び機器は特段のQA要求事項はない。* (2) *‘独立’ とは、基の設計者に含まれない個人、グループ、部署、部門を意味する。‘独立’はまた第三者機関を指してもよい。*	

別紙－5　品質分類の等級に基づく要求事項の一覧

品質分類に基づく検査・確認内容

品質クラスに応じて表 4.2 で規定される品質管理レベル（契約業務で実施すべき検査・確認ポイントの程度を規定する管理基準）に基づき、表 4.3 で規定されるポイントで検査・確認を実施する。これらの検査・確認ポイントは表 4.1 の検査・試験計画書（製作検査計画書(MIP)を含む）に記載する。

品質管理レベルに基づく検査及び確認の頻度／程度は、立会検査や受注者監査等の結果が良好な場合は、QST 担当者との協議に基づき、条件を緩和することができるものとする。参考のため、本契約の仕様内での適用（ITER ダイバータでの適用範囲）をマーキングする。

表 4.2　品質クラスと品質管理レベルの関係

品質クラス	品質管理レベル
クラス1	レベル1
クラス2	レベル2
クラス3	レベル3

表 4.3　品質分類に基づく検査・確認ポイント

<table>
<tr><th rowspan="2">項　目</th><th colspan="3">品質管理レベル</th></tr>
<tr><th>レベル1</th><th>レベル 2</th><th>レベル 3</th></tr>
<tr><td>製作レビュー(MRR)</td><td>・MRR 実施時</td><td>・MRR 実施時</td><td>―</td></tr>
<tr><td>材料調達</td><td>・基準を満たさない場合に重大なリスクを及ぼす可能性がある場合</td><td>―</td><td>―</td></tr>
<tr><td>(新しい手法などの)重要とみなされる特殊作業手順(成形、切削、熱処理など)</td><td>・(曲げ加工等の)基準を満たさない場合に重大なリスクを及ぼす可能性がある場合(プロセスの認定用)
・初回検査
・定期的な検査</td><td>・初回検査
・基準を満たさない場合に重大なリスクを及ぼす可能性がある場合</td><td>・基準を満たさない場合に重大なリスクを及ぼす可能性がある場合</td></tr>
<tr><td rowspan="2">溶接方法</td><td>・溶接認証のモックアップ確認試験(スポットチェック)
・溶接認証(WPQR, WPQ など)</td><td>―</td><td>―</td></tr>
<tr><td>・溶接の重要作業(仮組、初回活動、溶接材料の保管状態、溶接記録確認など)</td><td colspan="2">・重要で前例のない初回の作業(仮組、初回活動、溶接材料の保管状態、溶接記録確認など)
・その後、ランダムに確認</td></tr>
<tr><td rowspan="2">非破壊検査(NDT)及び関連プロセス</td><td>・NDE の重要な作業(加工・成形後の VT/DT/PT/UT、溶接前・中・後の VT/DT/PT/UT/RT など)</td><td colspan="2">・重要で前例のない初回の作業(加工・成形後の VT/DT/PT/UT、溶接前・中・後の VT/DT/PT/UT/RT など)
・その後、ランダムに確認</td></tr>
<tr><td colspan="3">メーカーによる検査完了後の解析報告を含む変更履歴資料のレビューと承認</td></tr>
<tr><td>補修方法</td><td>補修の難易度による補修作業と検査への立会</td><td colspan="2">・基準を満たさない場合に重大なリスクを及ぼす可能性がある場合</td></tr>
<tr><td>最終目視検査・寸法チェック</td><td>重大なリスクがあると判断された場合</td><td>重大なリスクがあると判断された場合</td><td>―</td></tr>
<tr><td>特殊試験(リーク試験、モーター動作試験など)</td><td colspan="3">重大なリスクがあると判断された場合</td></tr>
<tr><td>圧力強度試験</td><td colspan="3">PE 及び NPE (*)が適用される場合で、重大なリスクがあると判断された場合</td></tr>
<tr><td>最終受入試験(FAT)</td><td colspan="3">重大なリスクがあると判断された場合</td></tr>
<tr><td>清掃、酸洗、表面安定化処理取扱・梱包、輸送、保管</td><td>・基準を満たさない場合に重大なリスクを及ぼす可能性がある場合</td><td>―</td><td>―</td></tr>
</table>

注記：(*) フランスの圧力容器規制(PE),原子力圧力容器規制(NPE)